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INFORMATION AND COMMUNICATION TECHNOLOGIES IN STEM EDUCATION

A B S T R A C T of PhD Thesis

ON THE DISSERTATION

for awarding the educational and scientific degree "Doctor"

PhD program: "Application of the Principles and Methods of Cybernetics in Various Fields of Science"

Professional area: 5.2 Electrical engineering, electronics and automatics

Scientific supervisor:
Prof. Dr. Nayden Shivarov

Sofia, 2025

The dissertation was discussed and admitted to defence at an extended meeting of the Department of Cyber-Physical Systems of IICT-BAS, held on 11 November 2025.

The dissertation contains 187 pages, including main content 146 pages, 107 figures, 7 tables, 3 applications, literature includes 126 titles and 6 websites.

The defense of the dissertation will take place on ....2025 from .... in hall 228 in bl. 2, IICT – BAS at an open meeting of a scientific jury consisting of:

1. Prof. Dr. Nikolai Stoimenov
2. Prof. Dr. Andon Topalov
3. Prof. Dr. Kosta Boshnakov
4. Assoc. Prof. Dr. Nikola Shakev
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The materials for the protection are available to those interested in room .... of IICTBAS, ul. "Acad. G. Bonchev", bl. 25A.

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Title: **INFORMATION AND COMMUNICATION TECHNOLOGIES IN STEM EDUCATION**

CONTENTS

INTRODUCTION

Relevance of the dissertation topic

Today, we stand on the threshold of Industry 5.0, which signifies the continuous evolution of information and communication technologies in society's daily life. For a society to be sustainable, economically efficient, and have a high quality of life, technologies must be woven into its very fabric. This preparation, beyond the family environment, also occurs within the educational system. However, the pace at which technology is advancing fails to synchronize with the educational system in Bulgaria.

The imbalance between technology and education has its roots in the 19th century, an age of numerous discoveries and unprecedented progress, driven by individuals' desire for advancement. Today, it is a known fact that the lifespan of a phone is two years, after which it is already considered outdated; however, the education system does not undergo renewal at the same pace.

In Bulgaria, the education system is in a state of crisis. Conversely, the labor market is technologically advancing, striving to sustain a robust society. Overcoming this functional collapse and catching up can be achieved through the application of ICT and STEM education. These are four global sciences unified into one, with the goal of their collaborative teaching within a single lesson. This teaching method has the potential to rebalance the educational system..

If the educational goal is for students to become adaptable and critically thinking young people, capable of solving the cases of tomorrow, then the following skills, which form the foundation of the STEM concept, must be fostered in them:

- Creative Thinking
- Critical Analysis (Analytical Thinking)
- Teamwork
- Initiative
- Mathematical Literacy
- Algorithmic Thinking
- Social-Emotional Skills (Empathy, Active Listening)

This dissertation is organized in the following manner:

CHAPTER 1 traces the historical development of the STEM educational method. It investigates its origins, its transformation, and its global dissemination. The chapter examines when this method reached Bulgarian shores, whether it has managed to integrate into our educational system, and if it has been adopted with continuity or has undergone modification. A review, analysis, and systematization of STEM education up to the present day, both in Bulgaria and worldwide, is provided.

CHAPTER 2 examines information technologies, communication technologies, and integrative technologies. It elucidates their essence, significance, and applicability in contemporary education. Artificial Intelligence (AI) is explored, incorporating a study conducted among students to assess their understanding of AI.

CHAPTER 3 introduces various educational robots, each analyzed in terms of hardware, software, and technological features. The study proposes STEM lesson solutions and develops algorithms for integrated lesson applications. The majority of these STEM approaches have been validated through trials with students and teachers, with corresponding tests or experimental results presented for each robot.

Purpose and tasks of the dissertation

The aim of this work is to demonstrate how information and communication technologies are applied in STEM education. More specifically, it shows how robots can facilitate technological education that encompasses information technology, mechanics, physics, engineering, mathematics, and other related fields.

To achieve this aim, the following objectives have been set::

- To conduct a critical analysis of the STEM teaching methodology.
- To analyze the interrelationships between the STEM methodology and technologies.
- To investigate technologies.
- To examine technologies within STEM education.
- To present original solutions for working with specific robots.

The objectives are formulated to support the hypothesis that ICT is a valuable tool for use in education and serves as a unifying element for different subjects within STEM learning.

Approbation of the results

Various parts of the results obtained have been reported at the following forums, conferences and workshops:

- 4th Interdisciplinary PhD Forum with International Participation", „Labyrinth with Codey Rocky;
- **„12th International Conference "TechSys 2023" – ENGINEERING, TECHNOLOGIES AND SYSTEMS"** –TU, Plovdiv – „Artie Max Robot as a STEM Education Tool Through Integration Technology, Math and English Language
- **„13th International Conference "TechSys 2024" – ENGINEERING, TECHNOLOGIES AND SYSTEMS"** TU, Plovdiv - "AI algorithms for object and gesture recognition with mobile robot XGO-mini 2 dog"
- **22nd TECIS 2024 IFAC Conference ot Technology, Culture and International Stability** – "Students understanding for AI in different educational levels
- **International Conference Automatics and Informatics 2024 (ICAI'24)** – „Distributed 3D camera distance measurement system for intelligent mobile robots"
- **„14th International Conference "TechSys 2025" – ENGINEERING, TECHNOLOGIES AND SYSTEMS" –** TU, Plovdiv - „Gaining Python Skills Through Interactive Education robot Ozobot EVO."
- **Seventh International Scientific Conference "Innovative STEM Education"**
  STEMedu-2025, представяне на презентация на тема: „Educational Mobile Robots as a tool for STEM education through the integration of technology, mathematics, and the Bulgarian language "

Publications on the dissertation topic

Scientific publications in referred journals and indexed in world-renowned databases (Web of Science, Scopus).

- Maya Staikova. “Gaining Python Skills Through Interactive Education robot Ozobot EVO”. "14th International Scientific Conference TechSys 2025—Engineering, Technology and Systems", 100, 1, MDPI , Engineering Proceedings, 2025, DOI:doi.org/10.3390/engproc2025100015, https://www.mdpi.com/2673-4591/100/1/15
- Nayden Chivarov, Radoslav Vasilev, Maya Staikova, Stefan Chivarov. “Development of an Educational Omnidirectional Mobile Ma-nipulator with Mecanum Wheels”. 14th International Scientific Conference TechSys 2025—Engineering, Technology and Systems, 100, 1, MDPI , Engineering Proceedings, 2025, DOI:doi.org/10.3390/engproc2025100016, https://www.mdpi.com/2673-4591/100/1/16
- Staikova, M., Vasilev,.R., Chivarov, N. “AI algorithms for object and gesture recognition with mobile robot XGO-mini 2 dog”. Proceeding, 13th International Conference “TechSys 2024” – ENGINEERING, TECHNOLOGIES AND SYSTEMS“, 3274, 1, AIP Publishing, 2025, DOI:doi.org/10.1063/5.0259622, https://pubs.aip.org/aip/acp/article/3274/1/040003/3338119/AI-algorithms-for-object-and-gesture-recognition
- Vasilev,.R., Chivarov, N., Staikova, M. “Distributed 3D camera distance measurement system for intelligent mobile robots”. Proceeding, International Conference Automatics and Informatics 2024 (ICAI'24), 2025, DOI:10.1109/ICAI63388.2024.10851561, 233-239, https://ieeexplore.ieee.org/document/10851561
- Ivanova, V., Chivarov, N., Staikova, M. “Combining Software Algorithms and Machine Learning in Business Data Processing”. 22nd IFAC Conference on Technology, Culture and International Stability, TECIS 2024, 58, 3, Conference Proceedings, 2024, ISSN:24058963, DOI:10.1016/j.ifacol.2024.07.150, 198-202. SJR (Scopus):0.4, https://www.sciencedirect.com/science/article/pii/S2405896324002337
- Staikova, M., Ivanova, V., Chivarov N. „ARTIEMAX robot AS A STEM education TOOL THROUGHT Integration technology, math and English language“. Proceedning, 12th International Conference “TechSys 2023” – ENGINEERING, TECHNOLOGIES AND SYSTEMS“, AIP Conference Proceedings, 2024, ISSN:0094243X, DOI:10.1063/5.0208311, SJR (Scopus):0.189, https://pubs.aip.org/aip/acp/article-abstract/3078/1/020007/3284708/Artie-max-robot-as-a-STEM-education-tool-through?redirectedFrom=fulltext
- Staikova, M., Ivanova, V., Chivarov, N. “Students understanding for AI in different educational levels”. 22nd IFAC Conference on Technology, Culture and International Stability, TECIS 2024, 58, 3, Conference Proceedings, 2024,

ISSN:24058963, DOI:10.1016/j.ifacol.2024.07.147, 182-186, https://www.sciencedirect.com/science/article/pii/S2405896324002301

- Yovkov S., Chivarov N., Chivarov, S., Staikova, M.. Educational Mobile Robot Equipped with Intelligent Camera Huskylens. Conference Proceedings, 9th International Conference on Control, Decision and Information Technologies, CoDIT 2023, IEEE, 2023, ISBN:979-835031140-2, DOI:10.1109/CoDIT58514.2023.10284418, 2269-2274, https://ieeexplore.ieee.org/document/10284418

Scientific publication in non-refereed journals with scientific review

- Staikova, M., Chivarov, N., Ivanova, V., Chivarov, S. ROBO STEAM - INCLUSIVE TECHNOLOGIES. The volume is dedicated to the International Science Conference "Educational Technologies - 2023", volume 38 (1), Union of scientists in Bulgaria - branch Sliven, 2023, ISSN:1311 2864, 33-40, https://streamitproject.eu/scientific-articles/scientific-article-robo-steam-inclusive-technologies/

Citations as of Sept 2025

- Shaohui Du, Zilong Liu, Wenqin Chen, Zhihan Tan, and Jian Chen. 2025. A Study of Remote Updating Techniques for Data from End-side Devices of the Hongmeng Operating System. In Proceedings of the 4th Asia-Pacific Artificial Intelligence and Big Data Forum (AIBDF '24). Association for Computing Machinery, New York, NY, USA, 112–119. https://doi.org/10.1145/3718491.3718512
- Radoslav Vasilev, Nayden Chivarov, Valentina Ivanova, "Integration of Object Recognition, Color Classification, and QR Decoding for the Purposes of an Intelligent Mobile Robot", *WSEAS TRANSACTIONS ON SIGNAL PROCESSING*, vol.21, pp.66, 2025. https://ieeexplore.ieee.org/document/10851561/citations?tabFilter=papers#citations

CHAPTER 1. STEM EDUCATION

Origin and Emergence of STEM

Definition

STEM is an acronym for science and technology education, or an educational approach that comprises four core disciplines: Science, Technology, Engineering, and Mathematics. A key nuance here is that the "Science" component encompasses all classified scientific branches such as Biology, Physics, Chemistry, etc.

There is no official definition for STEM, but today the acronym is used as a brand that describes the integration of science, technology, engineering, and mathematics into educational programs. In other words, students are tasked with solving real-world problems using all of these sciences together. This approach aims to foster innovation. [8, 9]

Concept

The concept provides an answer to how to overcome the "dull", unsatisfactory performance of pupils/students on standardized exams in mathematics and natural sciences. [8] The level we have reached today in Bulgaria as well.

STEM can be visualized through several variants using the following models shown in Fig. 1 [8] Models of the interdisciplinary relationships in STEM:

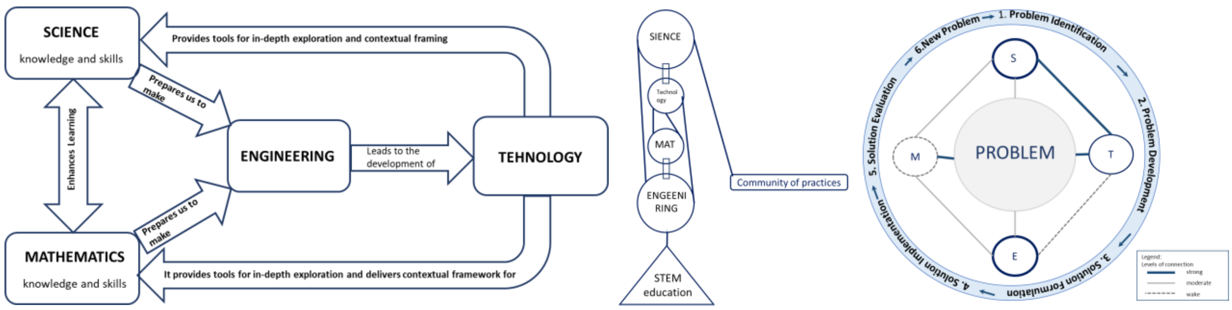


Fig. 1 Models of STEM Subject Relationships

STEM education proposes connecting scientific inquiry through formulating research questions in order to familiarize the student before they engage in the engineering design process for problem-solving. [16]

In STEM education, the student is at the center of the learning process. Creativity is encouraged, and the traditional dynamics of teaching and the relationship between teacher and student are transformed. Learning occurs through experience, experimentation, and problem-solving, with a focus on the practical application of developed skills and acquired knowledge. Furthermore, STEM builds upon traditional education by also focusing on creating interdisciplinary connections and teamwork, not only among students but also among educators.

The goal of STEM education is to encourage students to develop critical thinking, problem-solving, communication skills, and to be equipped with these soft skills for real life after reaching adulthood.

Despite the clarification of STEM up to this point, there is no internationally accepted definition for STEM. The most commonly used definitions are:

- Teaching and learning between two or more STEM subject areas or between STEM school subjects. [17, 18, 19]
- An effort to combine some or all of the four disciplines—science, technology, engineering, and mathematics—into a single class or lesson, which is based on connections between subjects and real-world problems. STEM curriculum models may include learning objectives focused on a single subject, but the contexts come from other subjects. [20, 21]
- The approach to teaching STEM content spans two or more areas, united by STEM practices in an authentic context with the goal of connecting these subjects to enhance student (adolescent) learning. The process must involve scientific inquiry, engineering practices, and mathematical, analytical thinking, and technological literacy. [22]

Founder of the STEM Concept

The name mentioned as the founder of STEM education is Georgette Yakman, who earned a master's degree from the Virginia Polytechnic Institute and State University and introduced the integrated Science-Technology-Engineering-Mathematics educational program into the university's curriculum in 2006. From an earlier period, the name Judith Ramaley is also encountered; she used the abbreviation SMET as far back as the 1990s..

The Evolution of STEM Education Over Time

Despite the common association of STEM with the 2006 reading, materials can be found from much earlier periods that bear witness to its principles, such as the Morrill Act of 1862. This act established land-grant universities to promote agricultural science. The act also later created engineering programs. Subsequently, more land-grant institutions emerged, and STEM education developed beyond academia, entering the workforce.

STEM Education on a Global Scale – A Retrospective

Countries that can be ranked at the forefront in terms of science and its development according to the OECD [23, 24] are:

- **South Korea**, with 32%, recorded the largest decline in the top ten, down from 39% in 2002, although the country retained its leading position in the OECD list.
- **Germany**, with 31%, ranks third in the average annual number of STEM graduates (about 10,000), placing it after the US and China.
- **Sweden** has 28% and ranks after Norway in the use of computers in the workplace, including for applications such as programming. More than three-quarters of the active population use computers at their workplace.
- **Finland** is the country with the highest proportion of STEM graduates - over 30% of university graduates have a STEM degree, not just STEM training.
- **France** can boast that its graduated STEM researchers are hired by industry, rather than by universities or the government.
- Although **Greece** ranks sixth, it spent only 0.08% of its GDP on scientific research in 2013, one of the lowest rates among developed countries. This fact explains why the percentage of those with STEM education fell from 28% in 2002 to 26% in 2012.
- **Estonia** holds the seventh position thanks to its female STEM graduates. They have the highest percentage - 41% in 2012.
- **Mexico** managed to increase STEM education by 1%, from 24% in 2002 to 25% in 2012, even though the government removed tax incentives for business investment in R&D.
- Despite its ninth place, **Austria** reaches 25% and ranks second in the highest number of doctoral graduates in STEM of working age, with 6.7 per 1000 women and 9.1 per 1000 men.
- **Portugal** can also boast that 25% of its students graduate with a degree in STEM. The country also has the highest percentage of PhD holders - 72% - working in the education sector among all European countries studied.

- **Canada** ranks 12th out of 16 countries in the percentage of graduates who studied in STEM programs, at 21.2%. This is a higher position than the US, but lower than France, Germany, and Austria.
- Another country outside the EU is **India**, with a total of 2.6 million STEM graduates in 2016. These specialists contribute exceptionally to the development of the Indian economy. The ascending development of the economy is largely due to the skills of STEM specialists.
- The country that provides many opportunities and materials, and where STEM education officially originated – the **United States** – had 9.0 million STEM workers in 2015. Approximately 6.1% of all workers were in STEM professions, compared to 5.5% in 2010.

Employment in STEM occupations grew much faster than in non-STEM occupations over the past decade (24.4% compared to 4.0%, respectively). From 2014 to 2024, this growth for STEM occupations is expected to be 8.9%, compared to 6.4% growth for non-STEM occupations.

STEM workers receive higher wages, earning 29% more than their non-STEM counterparts (2015 data).

Almost three-quarters of STEM workers have at least a college degree, compared to just over one-third of non-STEM workers.

Each year, the number of STEM jobs in the US doubles.

STEM promotes equality among genders, minorities, and other communities.

STEM Education in Bulgaria

In 2014, the document "Strategy for the Effective Implementation of Information and Communication Technologies in Education and Science of the Republic of Bulgaria (2014-2020)" was adopted. The main goal of the Strategy was to ensure equal and flexible access to education and scientific information at any time and from any location—via a desktop computer, laptop, tablet, or mobile phone. For the first time, a unified information environment serving school education, higher education, and science was created.

Discussions about STEM began in Bulgaria about a decade ago, starting as far back as 2014 when non-governmental organizations initiated the topic and gradually paved the way for its integration into the Bulgarian educational system. In 2018, Bulgaria joined as a full member of the European STEM Coalition. This is a network of national STEM platforms and organizations responsible for implementing national STEM strategies. Today, eight years later, there is a national strategy for STEM education, a National STEM Center at the Ministry of Education, one cycle of integrating STEM spaces in schools across the country has been completed, and a second cycle encompassing all state educational institutions—schools—is currently underway.

Despite the statistics and chronology, STEM was happening in Bulgaria even earlier, but it didn't have a name. As early as the last century, the so-called **Sendov System** laid the first steps towards modern STEM education. Education based on the Sendov system was implemented in Bulgaria between 1974 and 1996.

The foundation of the Sendov system is the philosophy that the driving forces of the educational process should be the child's curiosity and cognitive needs, not coercion and the threat of sanctions, and that the child should be an active participant and discoverer, not a passive listener. Learning by doing and the interdisciplinary approach, which blurs the boundaries between separate subjects (for example, instead of biology, physics, and chemistry, 'nature' was taught), are other distinctive characteristics of this model.

STEM education also emphasizes projects, experiments, learning through play, and so-called "interdisciplinary connections," which show students that what is learned in one subject can have applications everywhere in life and is connected to other subjects.

All education systems in the EU include the topic of sustainability in their curricula. Sustainability competencies are often incorporated in an interdisciplinary manner, through cross-curricular links or project-based learning. However, sustainability is included in curricula as a separate, often optional subject in only 6 EU countries (Cyprus, Hungary, Romania, Slovenia, Spain, and Sweden), according to a 2024 European Commission report.

Transformative pedagogical approaches are necessary to promote sustainability competencies. These pedagogies are action-oriented, characterized by elements such as self-directed learning, participation and collaboration, problem-oriented learning, inter- and transdisciplinary approaches, and linking formal, non-formal, and informal learning. Transformative approaches include asking students to explore different cultural perspectives (reported by 73.0% of teachers) or different social and economic perspectives (64.1%). More action-oriented examples are less common, such as working in small groups on various issues (46.5%), role-playing (20.0%), students proposing topics for subsequent lessons (18.4%), or projects involving gathering information outside of school, such as neighborhood interviews (13.1%). [26]

CHAPTER 2. TECHNOLOGIES IN STEM

The term Information and Communication Technologies (ICT) has a broad meaning, encompassing all known ways and means of exchanging information, such as radio, television, mobile phones, computer software and hardware, satellite systems, etc.

The concept of **Information Technology (IT)**, in its modern sense, was first used in 1958 in an article in the Harvard Business Review, where the authors Harold J. Leavitt and Thomas L. Whisler noted that "the new technology does not yet have a single established name. [27] We shall call it information technology (IT)."

Information and Communication Technologies act as an integrator in STEM education. They connect content from various disciplines.

2.1.Information Technology in STEM Education

Information Technology is a group of technologies designed for collecting, processing, storing, exchanging, creating, and disseminating textual-informational, graphical, audio, and online information, using for this purpose devices based on microelectronics, computers, printers, scanners, and mobile and telecommunication equipment. Information Technology encompasses the practical application of hardware and electronics, and computer science, as well as software technologies, and in this regard shares some common features with engineering disciplines. [28, 29]

The contemporary understanding of ICT used in education refers to technological tools and resources used for communicating, creating, disseminating, storing, and managing information.

Computer science originates from and is closely related to mathematics, linguistics, electronic engineering, and other sciences.

Technologies should not be associated only with digital media and new technologies. The definition of technology is any device or innovation created to meet a human need or desire.

Communication Technologies in STEM Education

ICT is a term used to denote all computer and communication technologies. That is, this term has a broad meaning, encompassing all known ways and means of exchanging information, such as radio, television, mobile phones, computer software and hardware, satellite systems, etc., as well as various types of related services and applications, such as video conferencing and distance learning.

As mentioned earlier, in 2014, with the adoption of the "Strategy for the Effective Implementation of ICT in Education and Science" in Bulgaria, the foundation for ICT in education was laid. The development of ICT in education progressed into e-learning, computer-based learning, and computer-mediated learning.

During the health epidemic, the types of communication became clearly distinguished, and previously created ICT programs for learning were put to the test. In this context, two types of communication can be distinguished – synchronous and asynchronous. They can be seen in Fig. 2.

Asynchronous	Synchronous
E-mail	Web conferences
Social Networks	Chat
Multimedia	VoIP
Web-based multimedia platform	Audio podcasts
Virtual libraries	Virtual worlds

Fig. 2 Asynchronous and Synchronous Communication

Integrative Technologies

2.1.1. Robotics

Robotics falls into many different fields and is therefore multidisciplinary, dealing with the design, construction, operation, and application of robots, as well as the computer systems necessary for their control. It encompasses engineering, electrical engineering, computer science, and other branches of science. Robotics finds application in various spheres, including industry, medicine, military technology, aerospace, and even in children's daily lives.

The word *robotics* originates from the word *robot*, which in turn was first used by the Czech writer Karel Čapek in his play *R.U.R. (Rossum's Universal Robots)*, which was staged in 1920. [32] The word *robot* comes from the Slavic word "*robota*" – work, labor. The play begins in a factory that makes artificial people called robots – creatures that could be mistaken for humans – very similar to the modern idea of androids. In fact, Karel did not invent the word. He wrote a short letter about the etymology of the word to the Oxford English Dictionary, in which he named his brother Josef Čapek as its actual creator. [32]

In 1948, Norbert Wiener formulated the principles of cybernetics, practically laying the foundation for robotics.

Fully autonomous robots only emerged in the second half of the 20th century. The first digitally controlled and programmable robot – The Unimate – was installed in 1961 to lift hot pieces of metal from a die-casting machine and stack them.

This is why, on the threshold of Industry 5.0, it is necessary for children from an early age to become acquainted with robotics not only as a toy but also as products they will coexist with, work with daily, and continue to develop. This is also the reason it is now being introduced into the educational system through STEM education.

Robots combine the advantages of computer systems with the excitement of human-robot interaction, which inspires the imagination of all students, thus exemplifying the advantages of STEM education.

Robots have great potential to be used as an educational tool; they add a brand new digital capacity to the educational system. They can be used as a powerful educational entertainment platform – combining traditional and innovative didactic methods and educational content in mathematics, physics, computers, electronics, mechanical engineering, drawing, music, and even artificial intelligence, with the experience of game-based learning.

2.1.2. Artificial Intelligence (AI) in STEM

Artificial Intelligence (AI) plays a significant role in our lives today. The term AI was created as part of a project and workshops at Dartmouth College in the mid-1950s. [36, 37]

Among the emerging challenges is also the attitude of students towards these changes. [39] To some extent, students as digital citizens are able to use artificial intelligence to improve their learning outcomes. [38]

In the period from 2010 to 2020, the focus of artificial intelligence split into three parts: knowledge representation, knowledge acquisition, and knowledge extraction. [41, 42] This was the beginning of the application of artificial intelligence in education.

Types of Artificial Intelligence

In the period 2010–2020, some trends in scientific research were identified: the Internet of Things (IoT), multiple intelligences, deep learning and neuroscience, as well as assessment of the impact of AI in education.

AI began its development in two segments: AI-based tools for classrooms and the use of AI to understand, measure, and improve learning.

The goals of developing a system integrating artificial intelligence in education can be grouped into four types: classification, matching, recommendations, and deep learning.

Over time, educators provide adaptive support for diverse learning environments with different types of learners.

At this point, artificial intelligence can be classified as "weak AI," "strong AI," and "super AI." "Weak AI," for example, includes digital assistants like Alexa and Siri.

"Strong AI" can solve any task as accurately as a human, like Bard and ChatGPT. "Super AI" is still not available.

Artificial Intelligence at Different Educational Levels

In Bulgaria, there are four educational stages: primary education, lower secondary education, upper secondary education (gymnasium), and university.

- **Primary School:** The artificial intelligence for children, from the "AI Singapore" project, is entirely aimed at primary school students, who need to learn the basic concepts of AI and use AI-based tools and applications in an ethical manner. ("AI Singapore" Project) [59]
- **Lower Secondary School:** In 2018, the Singapore government announced the "AI Singapore" project, aimed at developing students' skills in the field of artificial intelligence. Two programs for exploring AI were also launched.
- **Upper Secondary Level (Gymnasium):** I. Lee and B. Perret share their findings regarding teacher outcomes from conducting two one-week professional development seminars in the summer of 2021 and share the improvement suggestions made by the teachers. The participants in the professional development program were secondary school teachers from the southwestern and northeastern regions of the United States, representing various STEM disciplines: biology, chemistry, physics, engineering, and mathematics. [60]
- **University:** University students were among the first users of AI. They learned programming and then developed various applications or other variants of AI.

AI CLASSIFIED BY EDUCATIONAL LEVELS:

- **Use of AI in Preschool Age** is realized through activities without using a computer to introduce robots or intelligent agents, such as songs.
- **Use of AI in Primary School** is realized mainly through programming with Scratch and the Python language, environmental perception with an Arduino board, and introduction to various robots.
- **Use of AI in High School (Gymnasium)** is realized through understanding AI, introduction to AI applications, laying the foundations of AI, history of AI, Ethics of AI, Introduction to Neuro-Linguistic Programming (NLP), AI Language, Parts of Speech, Natural Language Processing, Word Vectors, Syntactic Analysis, Information Extraction, Knowledge Map, Problem Solving, Logical Inference, Expanding Logical Inference, Recognition Framework, Decision Tree Training, Search Engines.
- **University students** primarily engage in programming languages like C#, C++, Java, C to explore the possibilities of artificial intelligence and develop it further.

For comparison with already conducted research and the rising wave of AI in Bulgaria in 2024, I conducted a survey on what is understood by Artificial Intelligence among adolescents/students.

RESEARCH METHODOLOGY IN A PRIVATE SCHOOL

A study was conducted in a private school among students aged between 6 and 18 years. The total number of students participating in the study was 130.

Aim: To understand: "What do students understand by artificial intelligence?"

Research Hypotheses:

- Students correctly understand artificial intelligence and can use it.
- Students correctly understand artificial intelligence but cannot use it.

- Students do not understand what artificial intelligence is, but they use it.

Two methods were used: a task and a questionnaire.
Participants were divided into 4 age groups:

- **Pre-1st Grade – 6 years old;**
- **Grades 1-4 – 7 – 10 years old**
- **Grades 5-7 – 11-13 years old;**
- **Grades 8-12 – 14-18 years old**

Figure 3 shows the distribution of the number of students by age.

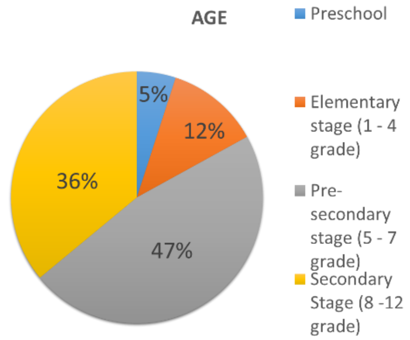


Fig. 3: Student Age Distribution by Educational Stage

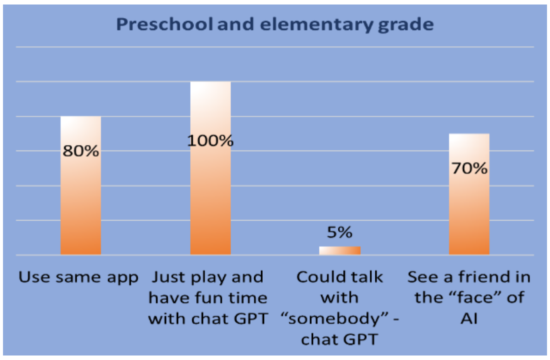


Fig. 4: Preschool and Primary School

Age Students who participated in the survey, in percentages:

- 5% preschool age (6 years old);
- 12% primary school - Grades 1-4 (7-10 years old)
- 47% lower secondary school - Grades 5-7 (11-13 years old);
- 36% upper secondary school (gymnasium) - Grades 8-12 (14-18 years old)

The preschool-aged children demonstrated that they can use technology only with the assistance of an older person. They do not have a proper understanding of the essence of the applications. They are still in the phase of developing their own perception of the world around them.

The primary school students also do not understand AI well. Among these students (aged 7-10), the understanding of AI is slightly more defined. Nevertheless, some students recognize certain applications that they have already used or have seen someone around them use. They play and have fun with ChatGPT – 100%. Interestingly, they are happy to use ChatGPT because they can talk to "someone" – 5%. The result shows that for them, ChatGPT is something fun, not something that "provides knowledge" in any way. They see a friend in the "persona" of the AI – 70%. (Fig. 4)

The experiment shows that if we provide them with correct information in a timely manner, students can understand and learn what ChatGPT is and how to use it correctly.

In Fig. 5, we can see that 100% of the lower secondary school students already use AI in the form of various applications in their daily lives or at school. Fig. 5 also shows that 10% of the students indicated ChatGPT as the platform their teachers use for assigning their homework, with an additional 10% noting other applications and platforms used by their teachers.

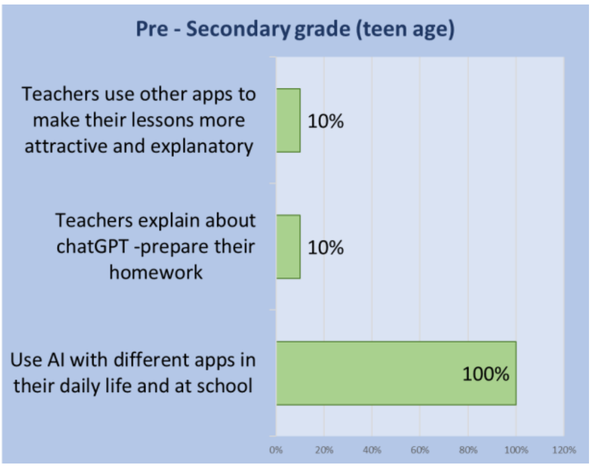


Fig. 5: Understanding of Artificial Intelligence in Secondary School

After using ChatGPT to prepare their homework assignments, the students were surprised to find that the artificial intelligence was not very good at working in Bulgarian and using the Cyrillic alphabet for questions and answers. They saw that the information was not entirely accurate. ChatGPT can find information, but this information is mixed, inaccurate, and in some cases misleading.

Most of the content was inaccurate when using the Bulgarian language. They had greater success when the content was in English.

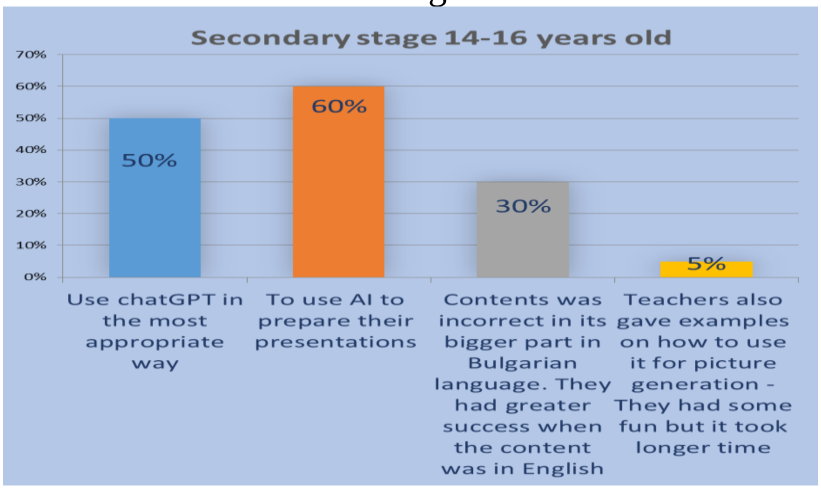


Fig. 6: Upper Secondary Education Stage (16-18 years)

Figure 6 shows that 50% of the 14-16-year-old subgroup used ChatGPT appropriately to prepare the required project. 60% used ChatGPT to create their presentation for Bulgarian Language and Literature. 30% of the students found that the content generated by ChatGPT was inaccurate. 5% of the students spent a lot of time providing more and more parameters to ChatGPT in order to get satisfactory generated images.

Figure 7 presents the situation with the same "homework" assignment when stricter criteria were applied. While the teacher provided the same parameters and the students were not allowed to make any changes, they all received the same result. The artificial intelligence provided 90% identical information/results to all students for the same task. When students applied critical thinking and did not fully trust ChatGPT, we observed a 50% similarity in the project presentations.

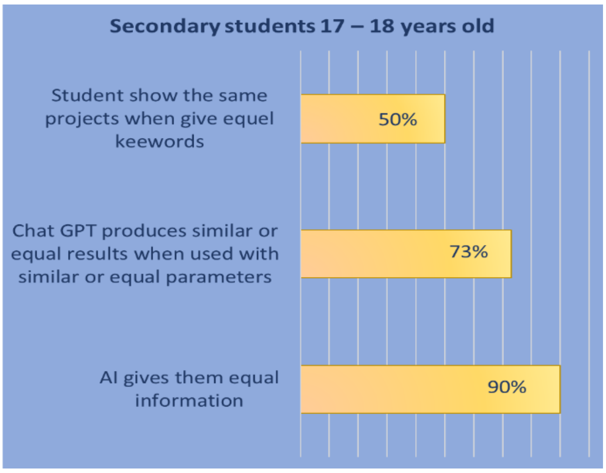


Fig. 7: Upper Secondary Education Stage (Ages 17-18)

The research investigating the understanding of students aged 6-18 about the use of Artificial Intelligence in education revealed that students across all age groups recognize ChatGPT's limitations as a perfect AI tool. While it can provide assistance and quick information, it cannot comprehensively complete tasks or projects. Although sometimes efficient and useful, it may also produce inaccurate results and require substantial configuration time, potentially outweighing its time-saving benefits.

2.1.3. Edge and Cloud Technologies

An "edge device" is a term from the field of computing and networking. It is a peripheral computing device for data processing.

An edge device is a hardware device that:

- Processes data locally (at the edge of the network)
- Reduces the need to transfer data to the cloud
- Improves performance and reduces latency
- Often includes artificial intelligence for local processing

Cloud technologies are technologies whose data processing is carried out through cloud computing.

The types of cloud technologies are:

- Public cloud
- Private cloud
- Hybrid cloud
- Cloud services

The two technologies have their differences, as well as their own benefits and drawbacks. Edge technology means on-site/local processing. Cloud technology involves processing data in a dedicated data center. It is suitable for complex analysis, storing large volumes of data, and large-scale services, but it involves latency. Table 1 presents a comparison between the two technologies, from which it is evident how to determine which technology to use for which type of task.

TABLE 1 Key Criteria for Edge and Cloud Technologies

Criterion	Edge Computing	Cloud Computing
Latency	Very Low (on-site, real-time processing)	High (delay due to transmission to a data center)
Offline Operation	Possible (autonomous operation without network)	Not Possible (dependent on internet connection)
Data Privacy/GDPR	High (data is processed locally)	Lower (data is transmitted and stored in a data center)
Computing Power	Limited (device resources)	Virtually Unlimited (scalable in the cloud)

ICT is of interest not only for manufacturing and solving practical case studies, but is also interesting for adolescents, who at the school-age stage can become familiar with the types of technologies, how they work, and their connection with sciences like mathematics and physics. This way, they will be able to start with scientific research and practical solutions much faster. This will be explored in the next chapter, where various practical tasks and solutions using ICT, implemented through the STEM method, are proposed. Such examples are:

- Primary level: Line following, executed using Edge technology by a robot;
- Lower secondary school: Controlling a robot with gestures, which is also an Edge technology;
- Upper secondary school (Gymnasium): Object and colour recognition and distance/depth measurement using Edge technology; the robot decides in real-time whether to stop/avoid/approach.
- Lower and Upper secondary school: Distance/depth measurement with Edge technology and Integration with Cloud – creating a classroom Dashboard with data history.

CHAPTER 3 DEVELOPMENT, RESEARCH AND INTEGRATION OF EDUCATIONAL ROBOTS IN STEM EDUCATION

3. Research and Development of Robotic STEM Solutions

3.1.1. Ozobot

Figure 10 shows an illustrative picture of the mini robot for the purposes of visualization and perception of its size.

Fig. 8: Mobile Robot Ozobot Evo

Fig. 9: Top View of the Ozobot EVO

„As can be seen from Fig. 8, the robot's dimensions are remarkably compact—only 2.5 cm × 2.5 cm, and it has a mass of just 17 grams. Despite its miniature size, Figures 9 and 10 provide the characteristics and capabilities of the Ozobot EVO."

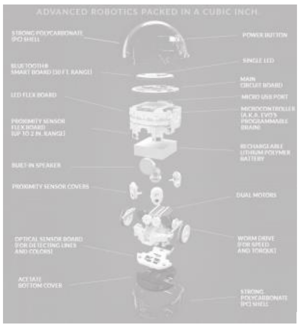


Fig. 10: Sensors and Ports of the Ozobot EVO

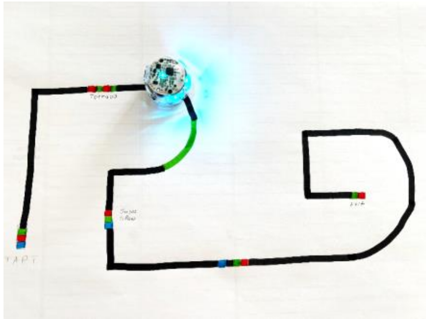


Fig. 11: Color-Based Programming with Ozobot

In the absence of a digital interface, the robot utilizes color recognition technology to interpret color information from drawn paths, which represent simple programs printed with a color code understandable by Ozobot. Examples of such color codes are shown in Fig. 11.

At a later stage, when students are able to use computer-like devices, Ozobot allows them to work via a tablet, phone, or computer. While the youngest students are learning to read, they can transition to block-based programming. They will arrange pre-built commands but will be able to read them and understand which commands they are using. Fig. 12and 12 show the Ozobot block programming interface.

Fig. 12: Block-Based Programming for Beginners

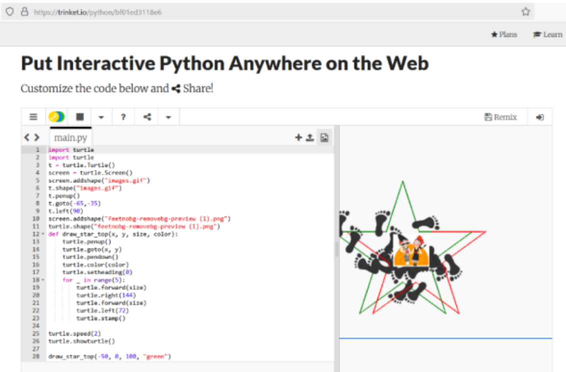
Fig. 13: Advanced Block-Based Programming

The program is developed across five levels, ranging from a beginner level to a master level of difficulty.

When students observe the actual execution of the program in the form of the robot moving or singing, they gain a deeper understanding of what they are creating.

When they are 12 to 13 years old, students can transition to the real programming language Python. At that point, they are introduced to libraries, concepts such as arrays, and other important topics which they will gradually master.

This exemplar lesson from the Computer Modeling and Information Technology curriculum demonstrates the integration of the Ozobot EVO robot. The lesson incorporates specific Python code fragments compatible with the Ozobot platform to facilitate the execution of programming tasks. A core component of this lesson involves the development of a movement algorithm designed to replicate the choreographic pattern of a Thracian folk dance (specifically, the Buchinsko Horo). The programming code required for this task is algorithmically structured to generate a star-shaped pattern, which emerges from the dance's sequence of steps. The corresponding instructional code is presented in Figure 14, while a proposed optimized version of the algorithm, leveraging the Ozobot's motion capabilities, is illustrated in Figure 15.



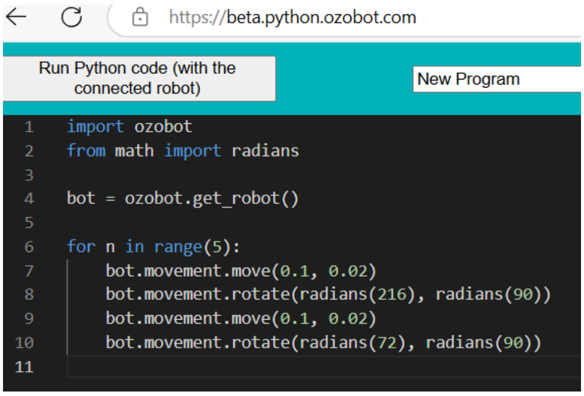
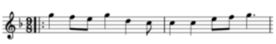


Fig. 14: Thracian Horo Code in Trinket PythonФиг. Fig. 15: Thracian Horo Code in Ozobot Python

In this context, beyond physical movement, the student's exploration of computer science concepts can be further enriched by integrating music programming and implementing algorithms to generate a Thracian horo – Svornato horo (9/8).

Сворнато хоро (9/8)



Ноти:	До	Ре	Ми	Фа	Сол	Ла	Си	Сол	Фа	Ми	Сол	Ре	До	До	До	Ми	Фа	Сол
Ноти Ozobot:	C	D	E	F	G	A	B	G	F	E	G	D	C	C	C	E	F	G
Такт /ритъм/:	1/4	1/8	1/8	1/4	1/4	1/8	1/8	1/4	1/8	1/8	1/4	1/4	1/8	1/4	1/4	1/8	1/8	3/8

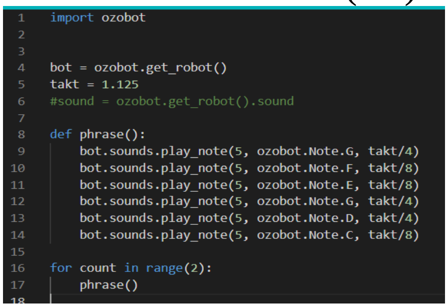


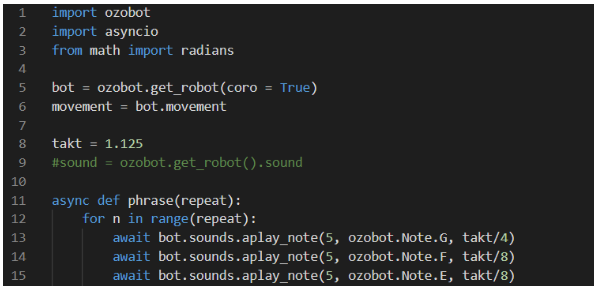
Fig. 16: Musical Notation of Svarnato Horo

Fig. 17: Svarnato Horo Music algorithm (9/8) of Ozobot Python

For this task, it is important to identify the musical notes corresponding to the horo and then systematically encode their phonetic representation. As shown in Figure 16, a part of this task constitutes a separate project, as illustrated in Figure 17 (which is part of the music lesson).

The subsequent project phase entails a synthesis of two previously discrete project components: the development of an Ozobot EVO algorithm designed to simulate a dancing robot's behavior. This integrated system executes a star-shaped trajectory while simultaneously generating an audio output emulating a Thracian horo melody. The implementation specifically involves programming the robotic platform to navigate a precise star-patterned path concurrent with real-time audio synthesis. Corresponding algorithm fragments demonstrating this integrated functionality are documented in Figures 18 and 19.

Furthermore, it is crucial to utilize asynchronous programming paradigms for this project. The initially proposed implementations used synchronous coding techniques; however, the current version requires the use of asynchronous libraries to facilitate the desired concurrent operations.



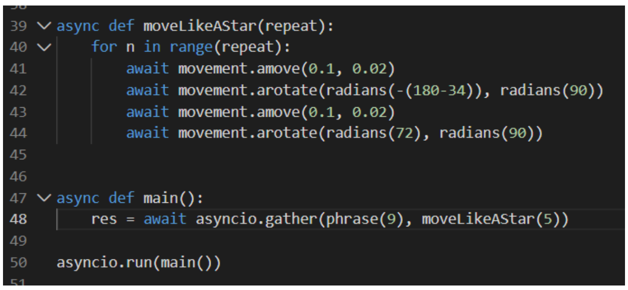


Fig. 18: Audio Algorithm for Svarnato Horo of Ozobot Python

Fig. 19: Audio Code for Svarnato Horo (9/8) of Ozobot Python with asynchronous

To illustrate the star shape, a colored marker was attached to the robot, allowing the robot's movement to be visualized according to the programmed code. Fig. 20.

Fig. 20: Visualization of Thracian Horo Dance Steps Using Ozobot EVO

This graphical presentation can be precomputed through an algorithmic process, thereby enabling the subsequent formulation of the control algorithm.

3.1.2. BlueBot

Another mobile robot suitable for the educational system is the BlueBot, shown in Fig. 21. It is slightly larger, measuring 13 cm x 10 cm x 7 cm, and weighs only 340 grams. Like the Ozobot, it is made of polycarbonate, giving it the advantage of being durable over time. It has a rechargeable battery, and the charging port is USB type B. The battery lasts for 6 hours of operation, which fits within a standard work or school day for using the robot, and it takes 4 hours to charge. It moves on two wheels and balances on an aluminum ball located centrally beneath its "eyes." The infrared sensors can communicate with other robots of the same type, and it has a microphone and a speaker, allowing for recording and playback of audio.

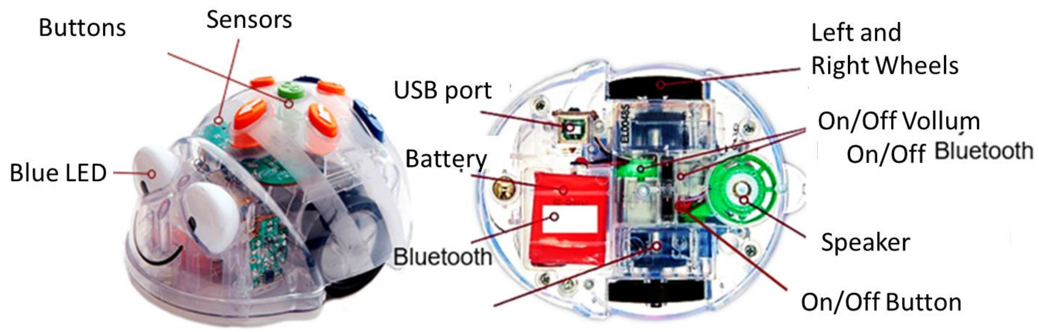


Fig. 21: BlueBot Configuration

LED lights - these are the eyes that blink or glow steadily in blue. It uses the Bluetooth system to communicate with other devices such as phones (Fig. 22), tablets (Fig. 23), computers (Fig. 24), or a reader (TacTile Reader) Fig. 25. It offers compatibility with Android, Windows 7+, and iOS. The mobile robot can be programmed via buttons - manually, or through phone, tablet, or computer applications using step-by-step or block-based programming (Fig. 22).

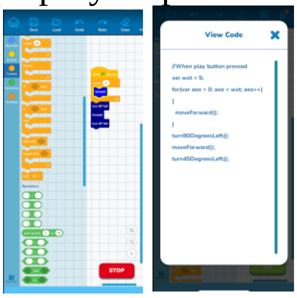


Fig. 22: BlueBot Mobile Application (On smartphone)

Fig. 23: BlueBot Tablet Application Interface on tablet

Fig. 24: BlueBot Desktop Application Interface

Fig. 25: Operation with TacTile Reader

The robot also has various attachments that allow for the specification of tasks. One of these attachments includes an option to hold a marker. This enables the integration of a STEM lesson with the Bulgarian language (Fig. 26). The lessons can be conducted using button control, through the reader, or via a computer. Of course, this involves not only language knowledge but also mathematics—calculating distances, letter sizes, type of script (e.g., print), paper dimensions, letter size, and so on (Fig. 27 and Fig. 28)

Fig. 26: Writing "3 MARCH Using Buttons

Fig.27: Writing "3 MARCH" Using a Reader

Fig. 28: Writing "8 MARCH"

The Blue-Bot moves in 15 cm steps, can rotate 90 degrees, and remembers up to 200 commands. When programming via an application or using the TacTile reader with additional command tiles, the robot can be programmed to rotate only 45 degrees or simply repeat the assigned algorithms. In this context, working on a grid is very convenient (Fig. 29). This is why various exercises can be practiced using worksheets with filling in arrows for a given direction or by arranging ready-made cardboard command cards. Custom grids can be created, or ready-made ones (mats) can be used for the robot to move on. In Fig. 30, it is moving on a transparent mat/board. In Fig. 24, the board is shown in the form of a map, which is also uploaded into the program.

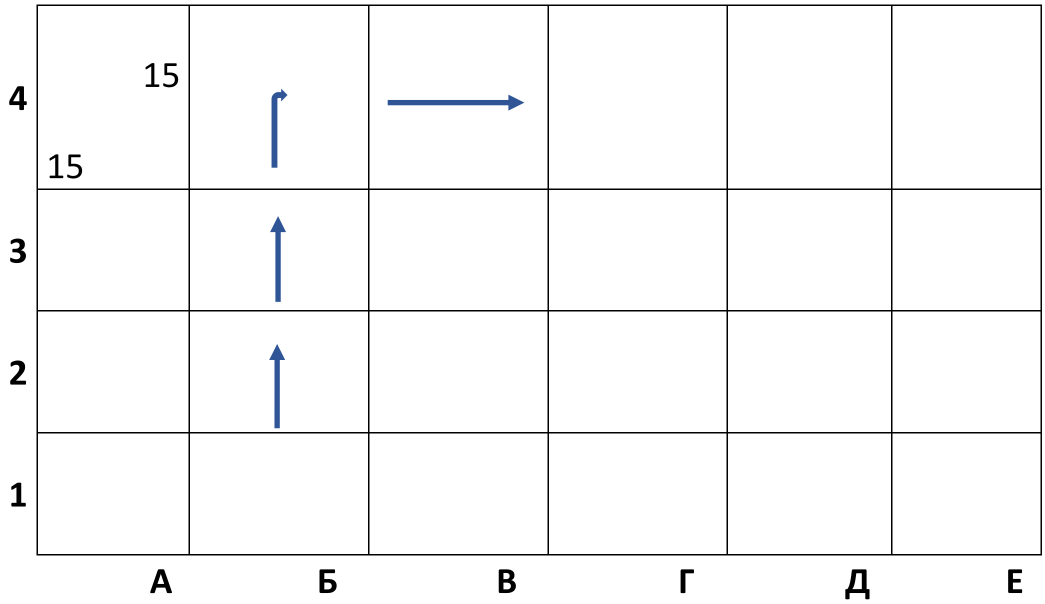


Fig. 29: Worksheet – Grid Template for BlueBot

Fig. 30: BlueBot Navigating Obstacles

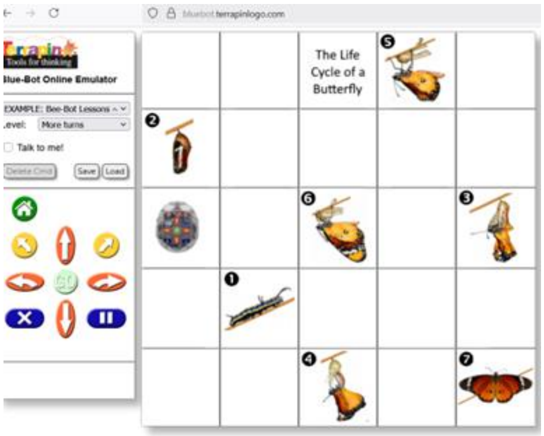


Fig. 31: BlueBot Online Simulation – The Butterfly's Path

In addition to the previously mentioned methods for working with BlueBot, the application available at https://bluebot.terrapinlogo.com/ can also be used. This website is an online simulation where the robot's movements are visible; it is placed on a map, which can be used to conduct a lesson, in this case, about the life cycle of a butterfly. Fig. 31.

3.1.3. ArtieMax

Another robot used in experiments and testing with students and teachers for schoolwork is the educational robot Artie Max and its integration into the learning process. The robot displays the code in a simulation environment. It presents hardware challenges when it does not draw the same code on paper as in the simulation. A very important aspect is assigning tasks and having students seek solutions for their mental development and logical thinking from primary school onward. This goal, as I mentioned earlier, is achieved using the STEM educational approach.

The hardware specifications of the educational robot Artie Max were determined through reverse engineering, as the manufacturer did not provide such information.

The robot measures 17.5 x 17 cm. The ESP32 (Fig. 32) is a highly efficient and cost-effective system-on-chip microcontroller with a dual-core system featuring two Xtensa LX6 processors with Harvard architecture. All embedded memory, external memory, and peripheral devices are located on the data bus and/or instruction bus of these processors. [77]

With a few minor exceptions, the address mapping of the two processors is symmetrical, meaning they use the same addresses to access the same memory. Multiple peripheral devices in the system can access the embedded memory via DMA (Direct Memory Access).

The two central processors are named "PRO_CPU" and "APP_CPU" (for "protocol" and "application"), but for most purposes, the two central processors are interchangeable. [78, 79]


Fig. 32: ESP32 Microcontroller

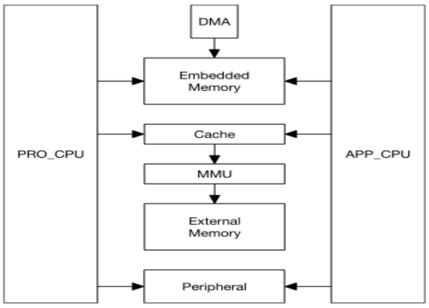


Fig. 33: System Architecture [77]

Figure 33 shows the block diagram illustrating the system's structure.
The ESP32 can function as a completely standalone system or as a subordinate device to a host MCU (Micro Controller Unit - a small computer chip found in electronic devices), reducing the communication stack load on the main application processor. The ESP32 can interface with other systems to provide WiFi and Bluetooth functionality through its SPI/SDIO or I2C/UART interfaces.

The system starts with two stepper motors. (Fig. 34)


Fig. 34: Two Stepper Motors

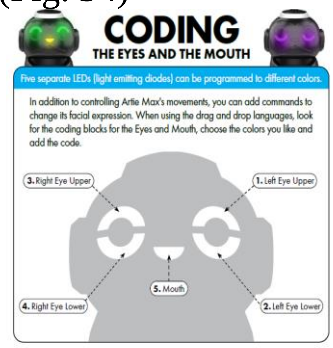


Fig. 35: Four LED "Eyes"

The robot is equipped with:

- LED eyes (Fig. 35)
- A speaker
- A lithium-ion battery
- A power charging block with a USB port
- A board / ESP32 is a dual-core system/
- Sensors

The Power Supply/Battery can be seen in Fig. 36:

- Warranty: 1 year (12 months)
- Brand Name: AUK
- Model Number: 18650 3.7v 2600mAh lithium-ion battery
- Type: Rechargeable Li-Ion Battery
- Voltage: 3.7 V
- Cycle Life: 500 times

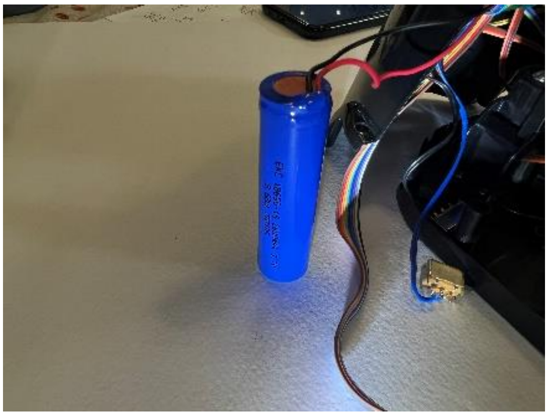


Fig. 36: Lithium-Ion Battery

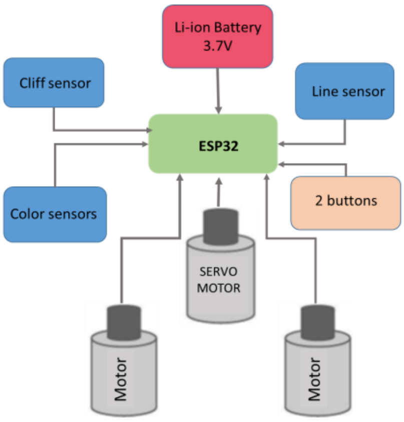


Fig. 37: Control System Schematic

The control system schematic is illustrated in Fig. 37, which shows the controllers, drivers, and sensors of the ArtieMax mobile robotic platform.

ArtieMax Software

ArtieMax™ comes supplied with 3 washable ink markers (Fig. 38) - blue, green, and pink. The product is compatible with all markers having a diameter between 8 - 10.5 mm. [78]

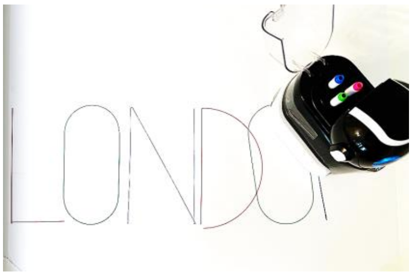


Fig. 38: ArtieMax with Three Markers

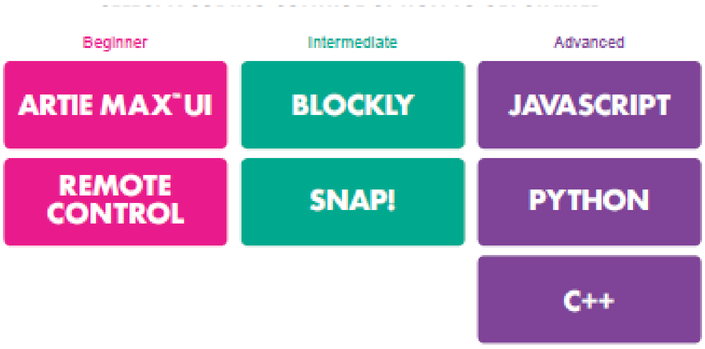


Fig. 39: Programming Environments - Remote Control

Figure 39 shows the programming environments for the robot. After remote control, students move on to block-based programming – Blockly, where they become familiar with ready-made commands, learning how to arrange them to create a shape. Fig. 40 (a cube) [80][81].

Students begin their educational journey by learning a language through its written symbols and phonetic meanings. In addition to handwriting the symbols, a STEM lesson can be conducted by writing the letters of the English alphabet using the educational robot. This approach combines knowledge reinforcement and builds interdisciplinary connections - language, information technology, and mathematics.

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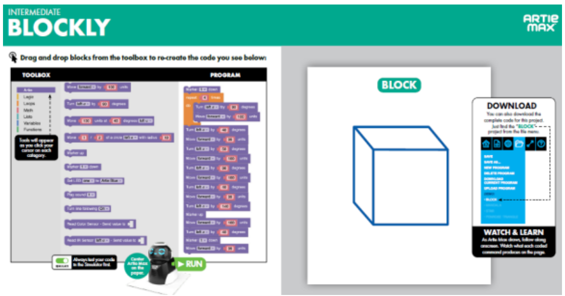

Fig. 40: Command Cube (Sequencing commands to form patterns)

In the exemplary lesson, a function for writing the word LONDON will be utilized. This implementation requires students to program individual letters, research the geographical location, prepare a presentation about the city, and calculate letter positioning and dimensions—constituting an integrated STEM lesson.

The algorithm (Fig. 41) follows a structured approach: initially creating individual letters, subsequently connecting them into the complete word through teacher-guided mathematical functions. The word appears in the simulation as demonstrated in Fig. 42, with predefined dimensional parameters ensuring proper letter spacing and fit within specified page margins (Fig. 43).

From a STEM perspective, this activity incorporates mathematical concepts including measurement, units of length, distance calculation, and spatial reasoning. Concurrently, it demonstrates algorithmic writing as a technological literacy component, while simultaneously reinforcing English language learning objectives.

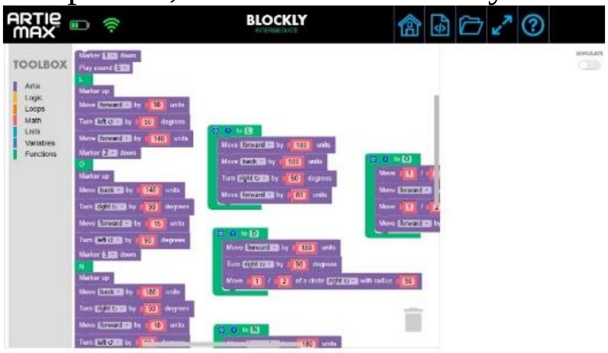

Fig. 41: Block Diagram Algorithm

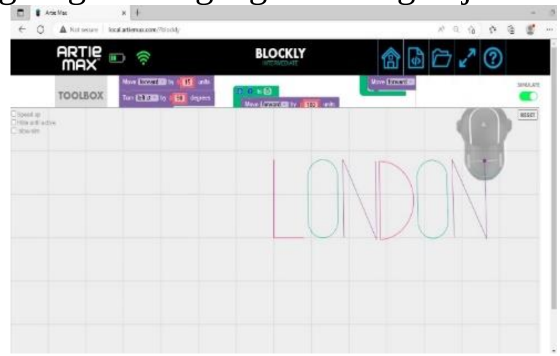

Fig. 42: Simulation

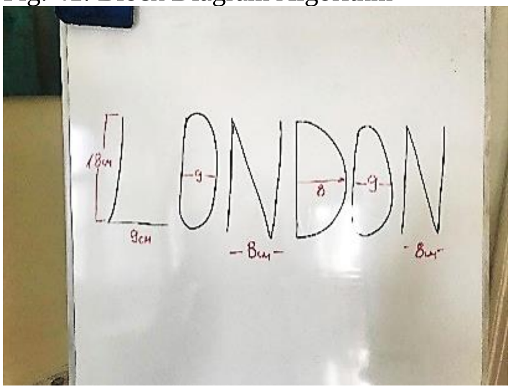
Fig. 43: Inter-Character Spacing

Fig. 44: Test Results

The word LONDON as written on paper by the educational robot appears as follows: Figure 44 - test results.

Fig. 44 shows a deviation in alignment and distortion of the letters after the letter D. During the testing process, two causes were identified.

One is the slope of the surface, in this case, an unevenness of the table. It turned out that the robot is very sensitive, and even the slightest slope affects it, but this was determined through several tests. The deviations were very clearly visible with the letter O as well. (Fig. 45, Fig. 48, Fig. 50)

Tests Conducted

As already observed, the distortion occurs for two reasons. When one is eliminated or minimized - the slope of the drawing surface - the software solution comes into play. In this specific case, a discrepancy is visible between the letter D and the following O. The corrective solution is to increase the robot's rotation angle or to increase the distance between them, or both.

The experiments showed that by correcting and increasing the distance by +10 mm (1 cm) and increasing the rotation (+5°), the letter O separates very clearly from the letter D and is positioned correctly. Fig. 45 and the simulation in Fig. 46, where the letter O is clearly tilted to the right in the simulation, but on paper the letter is upright.

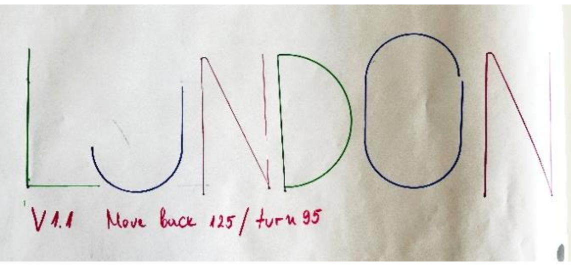

Fig. 45: The letter O is clearly distinguished from the letter D and is correctly positioned

Fig. 46: Simulation demonstrating clear rightward inclination of the letter O

In the experiment, increasing the distance by +5 mm (0.5 cm) and increasing the rotation by (+5°) shows a tilt towards the right side of the letter O, and accordingly, the aligned letter N is also rotated towards the right side. Fig. 47 - simulation and Fig. 48 - result. In this case, in both places - in the simulation and on paper - a leaning towards the right side is visible.

Fig. 47: Simulation

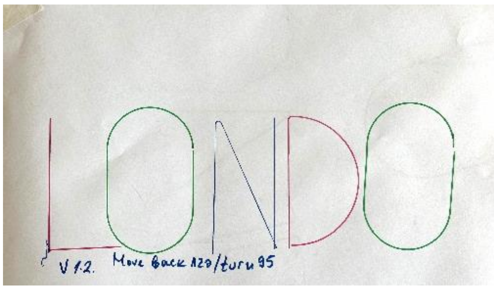

Fig. 48: Result

In the experiment with an increased distance of +5 mm (0.5 cm) and maintaining the initial rotation of 90°, the text appears aligned in the simulation (Fig. 49), but on paper, the letter O is positioned much closer to the letter D (Fig. 50).

Fig. 49: Experiment with Distance Increase of +5 mm (0.5 cm) While Maintaining Initial 90° Rotation

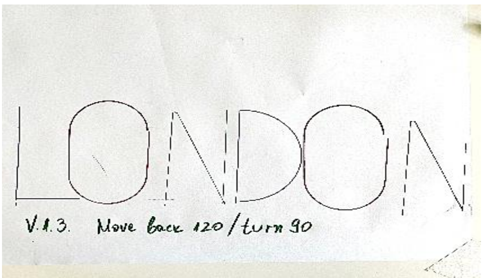

Fig. 50: The letter O positioned significantly closer to the letter D

The error exhibited by the robot led to the derivation of mathematical models for the motion of the robot's wheels. ArtieMax is a robot with one driving wheel and two passive wheels. (Fig.51) To facilitate the visualization of the movement trajectory, I will use a geometric model of the robot's wheels (Fig.52), utilizing only one of the passive wheels..

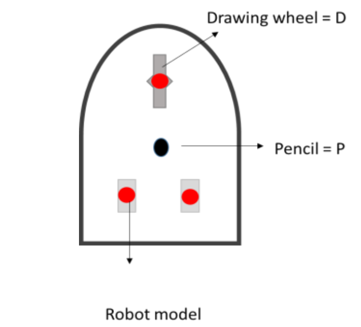

Fig. 51: ArtieMax Robot Model

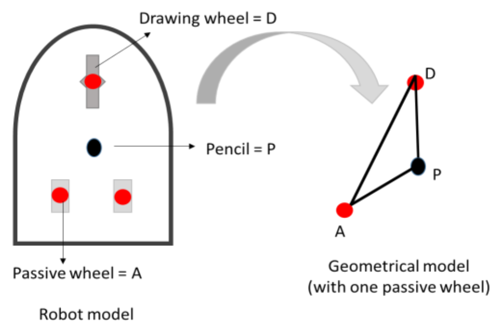

Fig. 52: Geometric Model with a Single Passive Caster Wheel

The other passive wheel will move along with it. (Fig. 53)

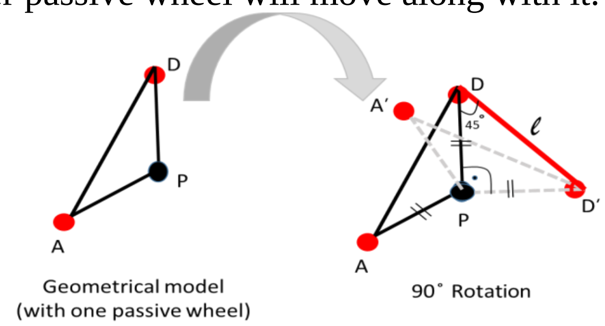

Fig. 53: 90° Rotation Model

`l = DD'` is the travel length of the driving wheel when a 90° rotation is required. Since the speed of the driving wheel is constant, the travel length `l` is a function of the movement time, i.e., `l = f(t)`. Therefore, if the rotation angle is less than 90°, it means the length `l` is less than required. In this case, the travel length of the driving wheel must be increased, and since the length is a function of time, the movement time must be increased. (Fig. 53)

Despite the robot's limitations, the implemented lesson featuring an algorithm for STEM integration—encompassing English language, mathematics, computer modelling and information technology, art, geography, and history related to London (United Kingdom)—successfully enhanced student knowledge and engagement, thereby supporting STEM education objectives. The methodology included a word-writing algorithm utilizing mathematical functions alongside an error-correction algorithm.

3.1.4. Artie 3000

The predecessor of the ArtieMax is the Artie 3000. Its dimensions are smaller: 14 x 14 x 15.5 cm, requiring less working area, and it weighs 449.06 grams. It stands more stably due to having two wheels. It does not have LED lights. It operates on 4 AA batteries. It also has a USB port for connecting to a computer if reinstallation, updates, etc., are necessary. Its marker is positioned through the head and body, between the two wheels (legs) of the robot (Fig. 54).

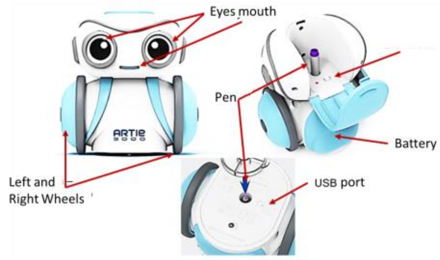

Fig. 54: Artie 3000 Device Configuration

Fig. 55: Artie 3000 Programming Environments

The robot can be programmed at three levels, each with two modules. Beginners start with control methods like using a remote control or by clicking and dragging (Point & Click) the mouse on the computer's simulation grid; the robot will follow the movement and draw the picture. JavaScript and Python are programming languages for older students, around grades 6-7. For students between 7 and 12 years old, block-based programming with Blockly or Snap! is most suitable. (Fig. 55)

Artie 3000 also exhibits slight deviations when drawing the assigned code, again depending on the drawing surface and the material being drawn on. Figure 56 presents the algorithm for rendering a graphical model from an integrated and validated STEM lesson (Appendix 1), combining mathematics, computer science, and Bulgarian language. Figure 57 displays the resultant output, which demonstrates zero deviation

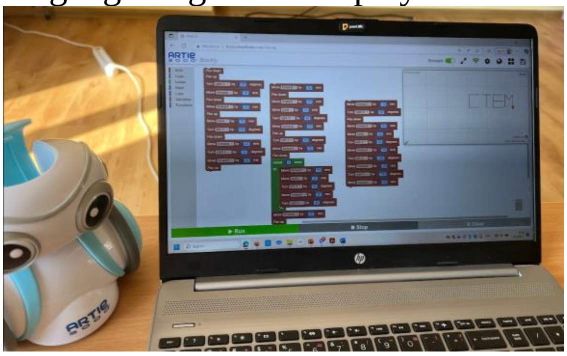

Fig. 56: Algorithm for Writing the Word "STEM" Execution

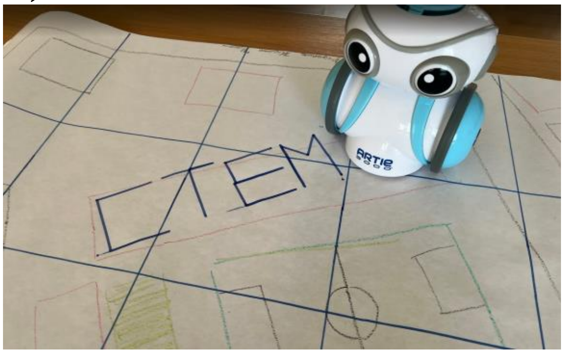

Fig. 57: Output Result from Artie 3000 Writing

3.1.5. Cody Rocky

Codey Rocky is an educational mobile robot that works with block-based programming. It also has sensors that can be integrated into the programming, helping to understand many of the inventions around us, such as lighting that turns on upon detecting motion. This is achieved using sensors programmed to detect movement and then execute specific actions. Other applications include chip-based door unlocking, alarm systems, or various remote controls. Color or line following is also prevalent in the automotive industry. Although new developments constantly emerge, there is still a demand for improvements or novel solutions for vehicle movement, home security, and facilitating the mobility of people or animals. Figure 58 shows the design of the mobile educational Codey Rocky. It consists of two separable parts – Codey and Rocky.

Codey is the "head," used for communication with the computer and for receiving the code to execute. The head is equipped with a power on/off button, a speed selection button, three buttons that can be assigned different commands, an infrared receiver and transmitter, a color indicator, a light and sound sensor, a 6-axis gyroscope, and a speaker.

Rocky is the lower part, featuring tracked wheels on the left and right sides. At the front, between the wheels, there is a panel with infrared proximity sensors that can rotate towards the ground and forward. This means it can detect obstacles on the ground, such as drops like stairs or holes, or obstacles in front of the robot like walls.

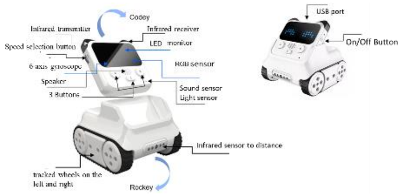

Fig.58: Codey Rocky Component Architecture

Fig.59: Codey Rockey with Lego Spike

Fig.60: Codey Rockey with Lego WeDo 2.0.

The mobile robot uses an ESP32 microcontroller, a DC gear motor, and a dual-core Tensilica LX6 processor. It has a rechargeable 3.7V LiPo battery. Its dimensions are 102 × 95.4 × 103 mm (L × W × H), and it weighs 295 grams.

Communication can be established via a USB port (Micro Type B), Bluetooth, or Wi-Fi.

The robot works with the mBlock software, which can be used online in a browser or downloaded to a computer for offline use. The software supports block-based programming similar to Scratch and can also be programmed with Python.

Codey Rocky is compatible with LEGO education bricks – Lego Spike/Lego WeDo 2.0. (Fig. 59, Fig. 60).

To verify whether the Codey Rocky mobile robot is compatible with the educational process and where it can be integrated as part of STEM lessons, a lesson titled "Maze with Codey Rocky" was conducted.

The aim of the research was to determine if the Codey Rocky robot can be used in class to integrate technology as an aid for the teacher. To achieve this, a mathematics lesson was created, integrated with robotics, technology, and entrepreneurship. A maze was constructed for the robot to navigate through using a pre-defined program that utilized the available programming blocks and sensors.

The first task given to the students was to create a rectangular maze from boxes or cardboard. The dimensions of the rectangle were to be at least 140 cm x 60 cm. Subsequently, they were to test whether the robot would collide with the walls or if it could avoid the obstacles (the walls of the rectangle) before proceeding to create a more complex maze. (Fig. 61)

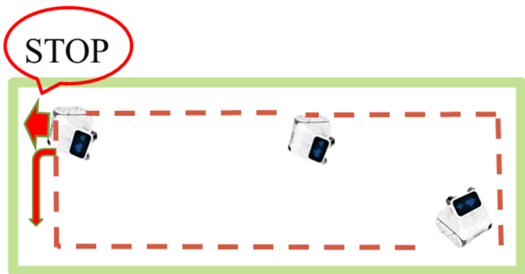

Fig. 61: Rectangular Maze Configuration

The initial practical component of the lesson involved constructing a rectangular labyrinth and programming the robot to navigate through it without colliding with the walls (obstacles). Practical observations revealed that students utilized time-based and power-based commands to control the robot's movement. However, in both instances, the algorithms (Fig. 62 and Fig. 63) proved unsuccessful. The robot collided with walls, stopped at incorrect locations, and demonstrated inappropriate speed regulation.

Analysis of the algorithm diagram in Fig. 64 indicates that while the structure incorporates a stopping function, it lacks the necessary procedural logic to reinitiate motion.

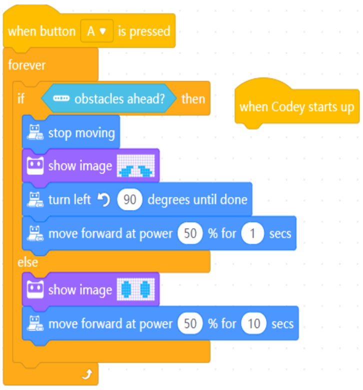

Fig. 62: Obstacle Avoidance Code - Version 1

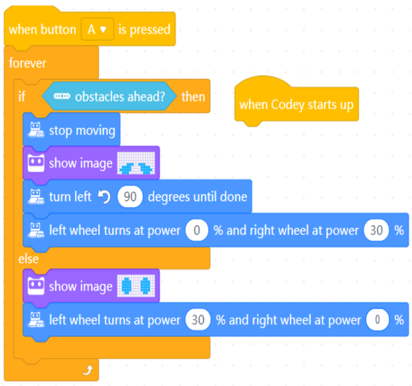

Fig. 63: Obstacle Avoidance Code - Version 2

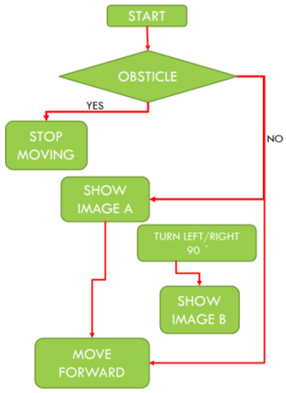

Fig. 64: Algorithm Flowchart

This situation presents a valuable opportunity to motivate students to explore alternative variables and seek different solutions in order to arrive at the correct implementation. Through this process, adolescents learn to think critically and persist in solution-seeking, developing resilience toward unsuccessful attempts.

Figures 65 and 66 illustrate an obstacle-avoidance motion algorithm that successfully initiates, navigates the maze, and avoids wall contact. Specifically, when encountering an obstacle, the robot executes a command to stop and change direction. The corresponding code algorithm is visible in
Fig. 67.

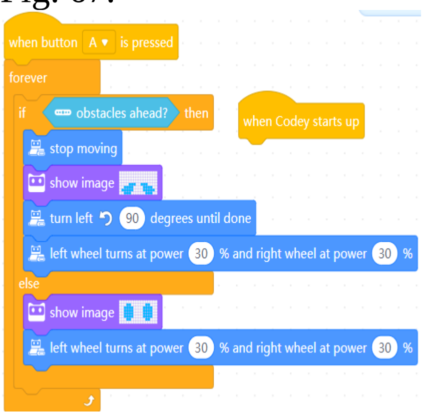

Fig. 65: Obstacle Avoidance Code - Version 3

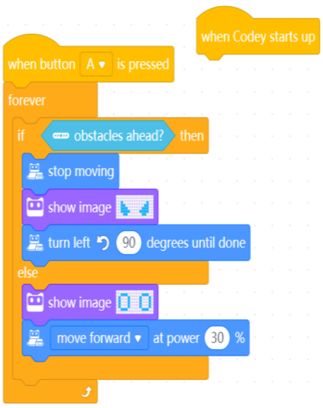

Fig. 66: Obstacle Avoidance Code - Version 4

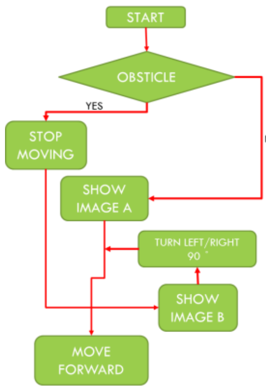

Fig. 67: Algorithm Flowchart 1

Once they had a correct code for the robot's movement, the maze was made more complex by adding additional walls, as shown in Fig. 68. In Fig. 69, more walls were added to the previous ones, creating corner obstacles for the Codey Rocky. The experiment showed that it moves correctly, does not crash into walls, and rotates until it finds a path to move forward.

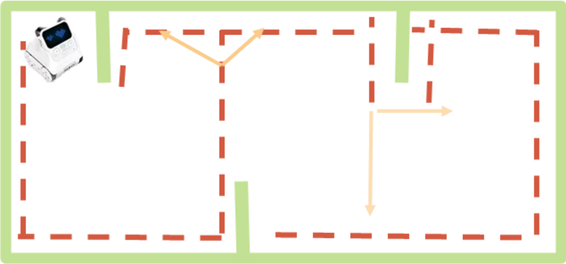

Fig. 68: Labyrinth with 3 Additional Partitions

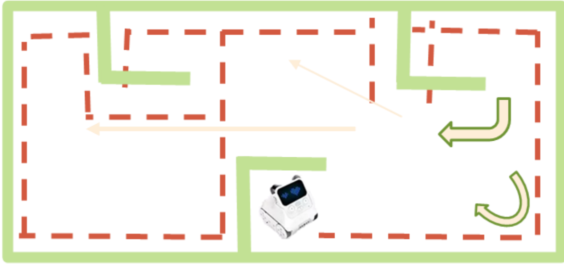

Fig. 69: Labyrinth with 6 Additional Partitions

In a single lesson, we can combine different roles for the students themselves: as learners, as creators, and as presenters to demonstrate or explain the maze.

From the conducted lesson integrating mathematics, technology and entrepreneurship, Bulgarian language and literature, and physics, the following conclusions can be drawn:

- If the task is unsuccessful, i.e., the maze is not navigated successfully, the students will use mathematics and physical laws to help them modify the initially set code and complete the task successfully.
- Students can work in teams of at least two, with a maximum of five children.
- The maze can be created in various configurations.
- With the available possibilities alone, it is not sufficient to complete the maze. A change in the code is necessary—its improvement through measurements, calculations, and the logical sequencing of the code blocks to successfully navigate the maze.

3.1.6. XGO-mini 2 Dog

XGO-mini 2 Dog is a robot that can be the next step after block-based programming with Scratch or similar programs, serving as a tangible reality: programming (software) or a product – a robot (hardware).

The XGO-mini 2 Dog robot is very flexible and features an aluminum alloy body. It can be programmed using three development environments: Blockly, Python, and ROS. The XGO-mini 2 Dog offers creative possibilities through software challenges and hardware upgrades. Here, I will suggest some artificial intelligence (AI) exercises.

It is important to be familiar with the hardware of the mobile XGO-mini 2 Dog robot. As the name suggests, it is a dog robot. Its size is compact, like that of a small dog. Its dimensions are 270 x 150 x 180 mm, and 270 x 145 x 170 mm in a standing position. Its weight is 915 g. The XGO-mini 2 Dog robot has four legs equipped with smart 6V servo mechanisms, as shown in Fig. 70. This type of servo provides high torque and can maintain a stable position under heavy loads.

The mobile robot features omnidirectional movement, six-dimensional position control, and multiple motion modes that can flexibly adapt to various scenarios and tasks. Equipped with an IMU, joint position sensors, and current sensors, it provides real-time feedback on its own orientation, joint angle, and torque, supporting internal algorithms and enabling further development. [90]

The battery is a standard 18650 with a capacity of 3500mAh and a 3C current. The POWERPAQ product line is based on cylindrical cells in the 18650 or 21700 format.

The XGO-mini 2 Dog is equipped with a robotic arm and a gripper (a gripping part/claw), as well as a built-in Raspberry Pi CM4 module for AI applications (Fig. 70).

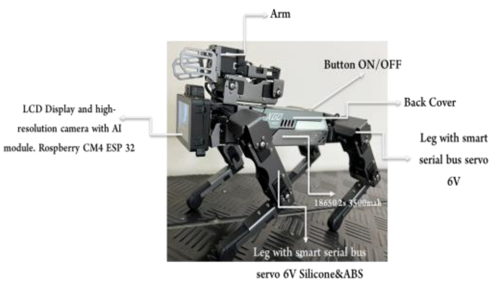

Fig.70: XGO-mini 2 Dog

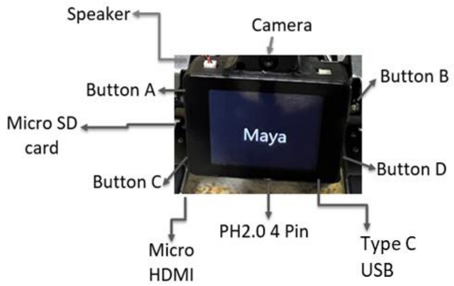

Fig.71: XGO-mini 2 Dog – the robot's head

The XGO-mini 2 Dog has a memory capacity of 4 GB, enabling it to process and store large volumes of data. It also features 4 programmable buttons for more interaction and control possibilities. The Micro HDMI video input interface and the USB Type-C port allow the XGO-mini 2 Dog to connect to external devices and transfer data. [92] (Fig. 71)

The robot's head unit is a monitor (Fig. 71) which contains the XGO-CM4 module. This module incorporates a Raspberry Pi CM4 with 2 GB RAM and an ESP32 microcontroller, which provides servo control for the body, an audio DAC (Digital-to-Analog Converter) and a speaker, an SD (Secure Digital) card slot, four buttons, and a camera. [91] The ESP32 microcontroller is a dual-core system with two Harvard Architecture Xtensa LX6 processors [92]. All embedded memory, external memory, and peripherals are located on the data bus and/or instruction bus of these processors.

When the XGO is powered on, it has three options: Programs, RC, and Try Demo. Two of the options range from basic speech transcription and keyword recognition for commands in the "Speech" section, to shape and color recognition, as well as computer vision demonstrations involving face and gesture recognition. The "Programs" serve more as template code for developers working with the system. [92]

The robot uses the following modes: "AgeSex", "Emotion", "Recog", "Pose", "Training", "QR code".

The mobile educational dog recognizes objects based on Yolo. However, in the case of the dog robot, this is not very useful, as it gets distracted by any person holding an object and produces inaccurate results in scenes with multiple objects.

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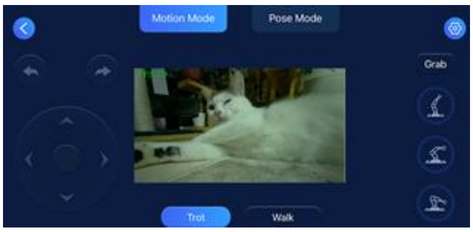

Fig. 72: XGO Remote Control via Smartphone

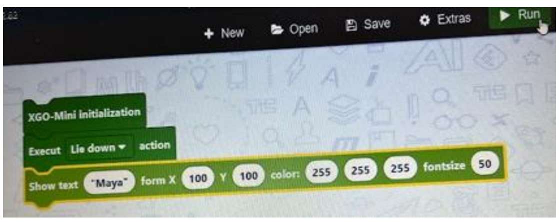

Fig. 73: XGO Block Code in the Integrated Development Environment

The XGO-mini 2 Dog can be controlled independently using the "XGOBOT" application. While controlling the robot remotely, you also get a live view from the robot's perspective via its camera (Fig. 72).

For basic programming, there is an integrated development environment. When you open the interface in a browser, it allows you to create and send code directly to the robot, which then executes it immediately. The environment is loaded via the "XGO-Blockly" link from the manufacturer's website (Fig. 73). Once the IDE environment loads, you can use it directly from your web browser.

"XGO-Blockly" is a version of Google's Blockly, which is a block-based programming environment. It generates Python code, which you can view and edit manually at any time. This is an easy way to teach students and to create more examples that can be used.

Tests Conducted with the XGO-Mini 2 Robot

Some of the ready-to-use AI functions are shown in Figure 74.

Fig. 74: AI Examples

Before proceeding with the use of the AI Vision module, the robot must be initialized. This is done in the web environment at xgorobot /working/ [96]. The robot initialization block is shown in Figure 75.

Fig. 75: Initialization Block

The XGO-Mini 2 Robot has a range of artificial intelligence recognition capabilities accessible through the AI Vision module: gestures, YOLO, QR code, face, emotions, and more (Fig. 76)

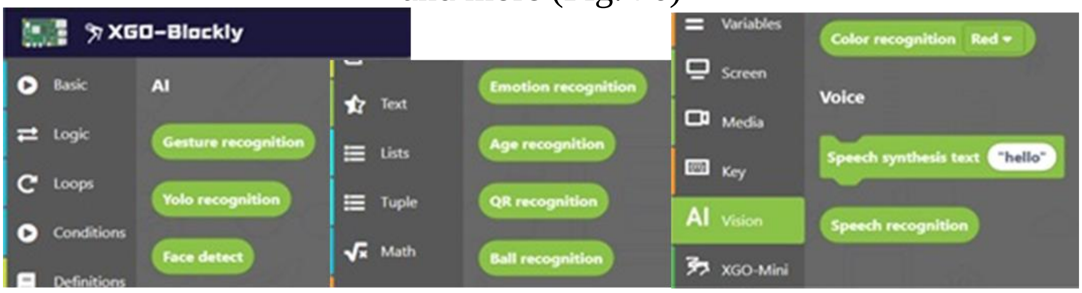

Fig. 76: AI-Powered Visual Recognition Module

YOLO is an algorithm for object recognition in images and videos.

Test 1 (Fig. 77) shows a quick code example using YOLO.

```
from xgolib import XGO
from xgoedu import XGOEDU
XGO_mini = XGO("xgomini")
XGO_edu = XGOEDU()

def yolo():
   print("YOLO Recognition")
   while True:
      yolo_recognition = XGO_edu.yoloFast()
      if yolo_recognition is not None:
         print(yolo_recognition)
         # Geting the information
         yolo_object = yolo_recognition[0]
         coordinate_point = yolo_recognition[1]
```

```
# Geting the coordinate values
         x_coordinate = coordinate_point[0]
         y_coordinate = coordinate_point[1]

         # Display information
         print("Object:", yolo_object)
         print("Coordination:", coordinate_point)
         print("X:", x_coordinate)
         print("Y:", y_coordinate)
         print()

      if XGO_edu.xgoButton("c"):
         break
yolo()
```

Fig. 77: Recognition with YOLO Module

The XGO-mini 2 dog robot can recognize specific objects, including: dog, cat, cow, and others.

Gesture recognition is a technique for interpreting gestures made with hands or other body parts, with the aim of communicating with a computer system. This technology is used in various fields such as computer vision, interactive systems, virtual reality, gaming, and others. One of the primary applications of gesture recognition is in controlling contactless interfaces, which offer a natural way to interact with devices.

Some key stages in gesture recognition include:

- **Data Preprocessing**
- **Feature Extraction**
- **Model Training**
- **Gesture Recognition**
- **nterpretation and Response**

This technology continues to evolve and find new and innovative applications across various fields.

The XGO-mini 2 Dog can recognize the following gestures (Fig. 78):
["1", "2", "3", "4", "5", "Good", "Ok", "Rock", "Stone"]

Fig. 78: Gestures Recognized by the Robotic Dog

Here are some possible interpretations of these gestures:

- **"1" to "5"**: Corresponds to showing one to five fingers. This can be used to indicate a number or to execute a specific command.
- **"Good" (Thumbs Up)**: This gesture can be associated with positive confirmation or approval. For example, when a user makes the "Good" gesture, the system might interpret it as a signal to confirm or approve an action.
- **"OK"**: This gesture is typically used to confirm understanding or acceptance of something.
- **"Rock"**: This gesture might be used to initiate a specific action or to signal a particular state.
- **"Stone" (Fist)**: This gesture could be used to indicate a specific position or a state that requires stability or immobility..

Fig. 79: Finger Recognition

We can observe that the artificial intelligence recognizes the number of fingers and displays the number on the left side of the monitor (Fig. 79). Despite the presence of multiple background objects, this test was fast and accurate.

I propose three QR code-based algorithms for controlling the mobility of a canine-inspired mobile robot. When presented with specific QR codes, the robot executes predefined movements — completing rectangular, square, or circular trajectories around a designated object.

Test 3 involves the source code for reading the created QR codes 1, 2, and 3.

```
from xgolib import XGO
from xgoedu import XGOEDU
XGO_mini = XGO("xgomini")
XGO_edu = XGOEDU()

def qr_decode():
    while True:
        # Check if there is a QR code
        qr_recognition = XGO_edu.QRRecognition()
        if qr_recognition:
            # Extract the value from the QR code
            qr_value = qr_recognition[0]
            print("Extracted value from the QR code:", qr_value)

            # Split the value into parts based on the space
            qr_parts = qr_value.split()
            num_parts = len(qr_parts)
            # Check the number of parts and print information accordingly
            if num_parts == 1:
                print("QR part 1:", qr_parts[0])
            elif num_parts == 2:
                part1, part2 = qr_parts
                print("QR part 1:", part1)
                print("QR part 2:", part2)
            elif num_parts == 3:
                part1, part2, part3 = qr_parts
                print("QR part 1:", part1)
                print("QR part 2:", part2)
                print("QR part 3:", part3)
            else:
                print("The QR code has more than 3 parts and cannot be processed.")

            print()

    qr_decode()
```

The program output when the "Circle 450" QR code was provided.

Figure 80 presents the three QR codes used in Test 4, which involved reading, decoding, and executing the code.

Кръг 450 | Правоъгълник 300 400 | Квадрат 500

Fig. 80: QR Codes – Circle, Rectangle, Square

The example can be modified according to the needs of the overall program and can include different interpretations of the QR codes.

Motion Algorithm Based on QR Encoding. The movement functions of the XGO-mini 2 robotic dog: locomotion, turning, and speed, are presented in the following tables. (Table 2, Table 3, and Table 4):

TABLE 2. Movement (Direction, Step)

Parameter Name	Type	Value	Description
direction	char	'x', 'X', 'y', 'Y'	'x' or 'X' for forward/backward movement, 'y' or 'Y' for left/right movement
step	int	x:[-25,25], y:[-18,18]	Step is the amount of movement. A positive value means forward or left movement, a negative value means backward or right movement.

TABLE 3. Rotation (Step)

Parameter Name	Type	Value	Description
step	int	[-150, 150]	Step is the increment. A positive value signifies forward or left, while a negative value signifies backward or right. The step represents the rotational speed in degrees per second, with positive being clockwise and negative being counter-clockwise.

TABLE 4. Pace Mode (Speed)

Parameter Name	Type	Value	Description
mode	char	['normal', 'slow', 'high']	This parameter represents the stepping frequency, where "normal" is the standard stepping speed, "low" is the slow speed, and "high" is the fast speed.

An interesting task for exploring the movements of the mobile dog robot is: The robot is shown a QR code that encodes information about the type of shape, for example, a square of a specific size in millimetres. After recognizing the figure, the dog robot must perform movements corresponding to the decoded shape and its dimensions. Test 4 involves executing this task based on the following source codes for the three different movements: circle, rectangle, and square..

```
from xgolib import XGO
from xgoedu import XGOEDU
XGO_mini = XGO("xgomini")
XGO_edu = XGOEDU()
import math

mode = 'slow' # ['normal','slow','high']
# For a floor where there is no slippage with the robot dog's feet, the value of the coefficient is 1.0
friction_coefficient = 1.0

# *** Movement of the robot dog of rectangle ***
r_step_x = 25 # x:[-25,25] robot dog step back and forth.
r_step_y = 18 # y:[-18,18] robot dog step left and right.

# Limit the values of step
r_step_x = max(-35, min(35, r_step_x)) # Interval restriction [-35, +35] for 'x'
r_step_y = max(-18, min(18, r_step_y)) # Interval restriction [-18, +18] for 'y'

# The values are determined according to the selected step. Increasing the values decreases the robot dog's movement time.
r_decreasing_steps_x = r_step_x * 3.1
r_decreasing_steps_y = r_step_y * 2.7

r_decreasing_steps_x = max(1.0, r_decreasing_steps_x) # Interval restriction [1.0, decreasing_steps_x]
r_decreasing_steps_y = max(1.0, r_decreasing_steps_y) # Interval restriction [1.0, decreasing_steps_y]

# *** Movement of the robot dog of circle ***
c_step_x = 18
c_step_y = 18
# How many parts to divide the circle into
c_number_parts = 40
# Increasing the values decreases the robot dog's movement time.
c_decreasing_time = 300

# Checking the number of parts, displaying the information and calling a function
if num_parts == 1:
print("QR part 1:", qr_parts[0])
elif num_parts == 2:
part1, part2 = qr_parts
print("QR part 1:", part1)
print("QR part 2:", part2)
if part1 == 'Circle':
# Call the function xgo_move_circle
xgo_move_circle(part2)
else:
print("There is no set functionality for this QR code.")
print()
print("#####################################")
print("Battery level: ", XGO_mini.read_battery())
print("#####################################")
print("\n<<< Show the camera a QR code >>>")
qr_decode()
```

The provided examples can be used in the educational sphere, as they incorporate elements of science, technology, engineering, and mathematics, demonstrating the applicability of the STEM education methodology. In this context, the XGO-mini 2 Dog mobile robot serves as an excellent tool for STEM classes.

Regarding object recognition using AI, the experiment proved to be very challenging. The cow had to be positioned very close to the camera, at the level of the dog's head, and achieving focus was particularly difficult (Fig. 81 and Fig. 82). The artificial intelligence only recognized cows with a body, head, and white with black spots. The AI could not recognize the cow's face or cows of other colors. This test was conducted using the YOLO module. The camera has a very limited field of view.

Fig. 81: Cow Recognition Test – 2 Successful out of 3 Attempts

Fig. 82: Cow Recognition – Three out of Three Tests

During the programming experiments in the online environment, several challenges were noted, such as significant foot slippage on the floor surface during movement functions—as mentioned in the "Methods Related to Mobility" section [97]. There is a lack of precise step number adjustment, which complicates some experiments and research.

Beyond sensors and hardware, the dog robot also offers various technologies, including AI. However, currently, aside from the device control aspect intended for an age group up to 10 years old, it has not been tested with students in higher grades, where it would be a good tool integrating knowledge from various fields to improve the currently identified weaknesses and to consider new challenges for its use. The STEM lesson could combine physics, mechanics, mathematics, natural sciences (studying habitats), music, physical education (for movement), and more.

3.1.7. Intelligent Mobile Robots

One of the primary challenges still facing intelligent mobile robots is object recognition, measuring distances to objects, determining their physical dimensions, and optimizing the computational resources required to perform these tasks [115, 116, 117, 118].

The presented distributed system is designed for real-time scene analysis, focusing on two-dimensional objects in a three-dimensional environment. Consequently, all recognized objects are defined with dimensions in two-dimensional space (diameter, width, height). Some three-dimensional objects are simplified to their two-dimensional analogues.

The hardware components include: a microcomputer module based on Raspberry Pi 5; an Orbbec Petrel A depth camera; a router; and a computer station (desktop or laptop) [124, 125]. The software components encompass specific programs that ensure coordinated interaction between the various stages of real-time information processing.

The depth camera is connected to the Raspberry Pi. The frames captured by the camera are transmitted via cable or wirelessly through the router to the computer station. Frame analysis is performed on the computer station. Additional functionality has been incorporated into the programmable model, which calculates the distance to recognized objects and their physical dimensions, enabling better analysis of objects in the three-dimensional space.

In the context of a mobile robot, the system allows the analysis of a 3D scene to be performed on a remote computer, which has the capacity to process large volumes of data and generate results in real time. A block diagram of the distributed system is shown in Figure 83.

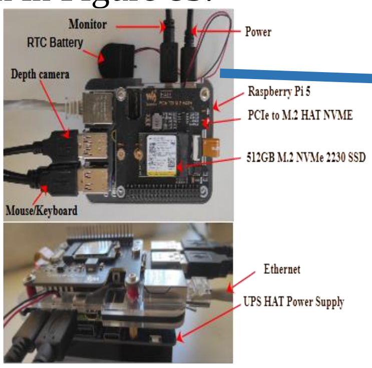

Fig.84: Microcomputer module, based on Raspberry Pi 5

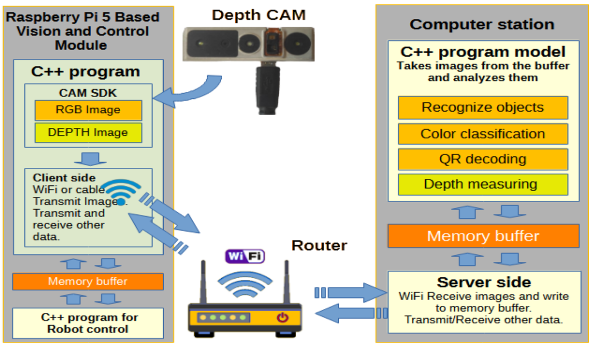

Fig.83: Block diagram of the distributed analysis and control system

Hardware Setup

A microcomputer module based on the Raspberry Pi 5 is used. Fig.84 The module is connected to a mouse, keyboard, Ethernet cable, and an RTC battery.

The tasks of the microcomputer module are as follows:

- To read frames from the camera, process them into a suitable format, and send them to the computer station for subsequent processing and analysis.
- To provide communication with the computer station by sending and receiving information. This communication is carried out via a router.
- To transmit and receive information to and from the program responsible for controlling the mobile robot, labeled in Figure 83 as the "C++ Robot Control Program".

The depth camera measures the distance to points in space. The Orbbec Petrel A camera [119] was used in the present research and experiments (Figure 85).

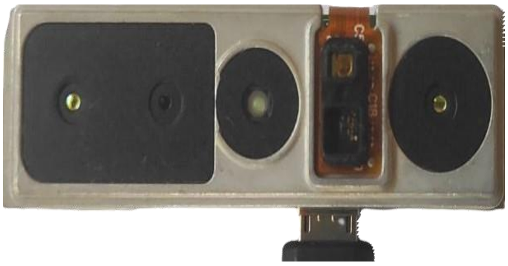

Fig.85: Camera Petrel A, Orbbec.

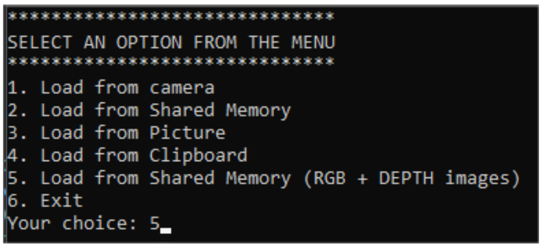

Fig. 86: Added Functionality for RGB and and Depth Image Processing Options

The camera captures both RGB and depth images. The images obtained from the camera are received by a program running on the Raspberry Pi 5 and are then sent to a remote computer station.

A specialized program, which runs on the computer station and is labeled as the "C++ Program Model" in Figure 83, integrates the following capabilities:

- Recognition of various types of objects (shapes).
- Color classification of the recognized objects.
- Decoding of QR codes on objects, if they contain such marked codes.

Within the context of current development, new features have been added to this program model:

- Measuring the distance to a recognized object.
- Measuring the physical dimensions of the recognized objec

These new functionalities are implemented by adding Option 5 to the program menu, as shown in Figure 4.

Option 5 utilizes a programmatic approach for memory sharing [122]. This approach extracts two images from the shared memory: the first is the RGB image, and the second is the depth (DEPTH) image. For this purpose, a server program was developed that runs on the computer station side. This program receives RGB and DEPTH images from the client (the microcomputer module based on Raspberry Pi 5) and writes them into the shared memory area, from which the program model can extract them for processing and analysis. The code added to the model program calculates the physical dimensions of the recognized objects and the distance from the camera to them, based on the acquired depth image. Figure 87 illustrates a block diagram of the main loop.

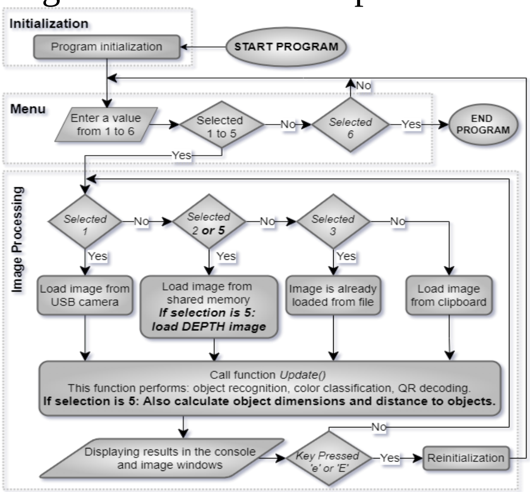

Fig.87: Block diagram of the image analysis ***program model***

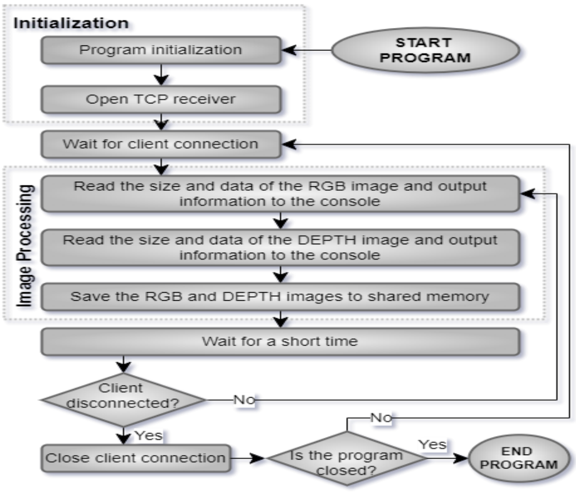

Fig.88: Block diagram of the server program

The server program is loaded from the computer station and uses the Boost.Asio library for asynchronous network communication and OpenCV for image processing. It is configured as a server that waits for incoming connections from a client. The program uses an acceptor that listens for incoming connections on a specific port. When it receives an incoming TCP connection, the program accepts RGB and depth images from the client, decodes them, and then either displays them or writes them to shared memory. Figures 83 and 88 illustrate the functionality of the client program.

The client program runs on the microcomputer module based on the Raspberry Pi 5. A block diagram of the program is shown in Figure 89.

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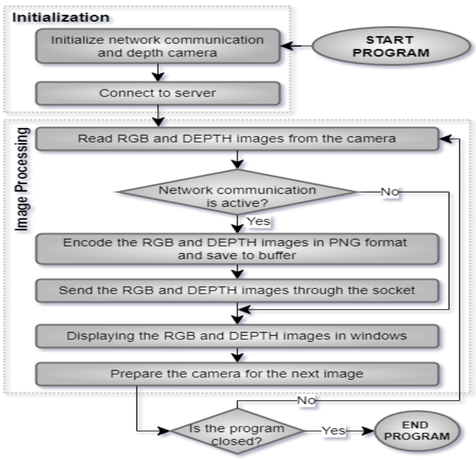


FIg.89: Block diagram of the ***client*** program

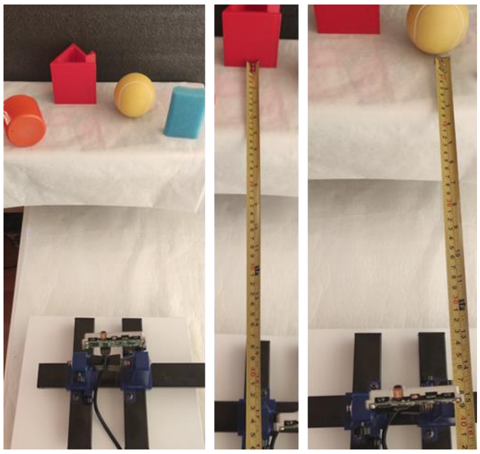


Fig.90: The experimental model – objects and camera

The RGB and depth images are aligned using "Software Depth-to-Color Alignment" before being sent to the computer station.

Experiment 1

The experimental setup presented in Figure 90 includes several objects. The distance to the objects is approximately 40 cm. The primary goal of the conducted experiments is to verify the system's capabilities for object recognition.

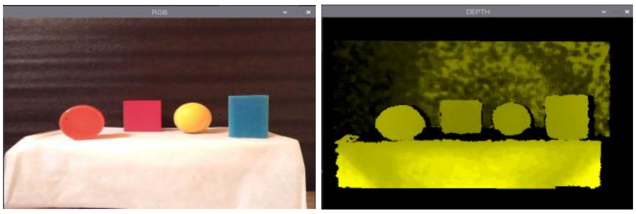
Table 5 describes the actual colors and dimensions of the objects.

Table 5. Actual Colors and Dimensions of the Objects in the Model.

Object	Color	Object Size	Distance from Camera
Circle	Orange	Diameter: 63 mm	33.0 cm
Square	Red	Side: 75 mm / 75 mm	43.0 cm
Circle	Yellow	Diameter: 70 mm	38.0 cm
Rectangle	Blue	Side: 57 mm / 80 mm	34.0 cm

Experiment 2 - Client Side – Microcomputer Module based on Raspberry Pi 5

When the program starts, it captures images from the camera. Figure 91 illustrates RGB and DEPTH images of the experimental setup.



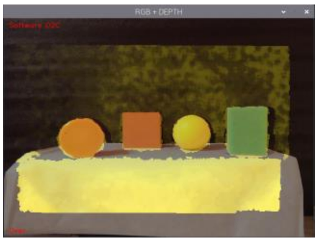
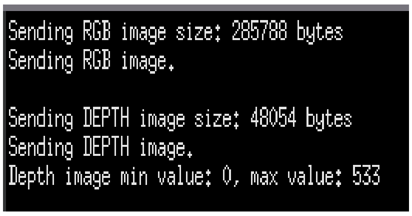


Fig.91: RGB and DEPTH images of the experimental model

Fig.92: RGB and DEPTH superimposed, and aligned images

Figure 92 shows a composite image, which is a blend of the RGB and depth images.

The client side sends both the RGB and depth images to the server. Figure 93 illustrates the size of the encoded images in .png format, as well as the minimum and maximum values of the measured distances for points in space (pixels). The maximum value is 533 mm (53.3 cm), which corresponds to the actual dimensions of the experimental setup.



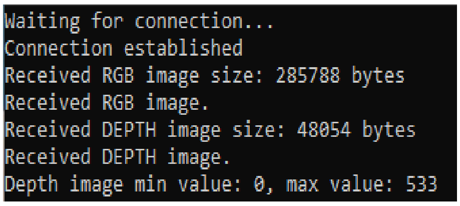


Fig.93: Information about the client-sent RGB and DEPTH images..

Fig.94: Information about the server-received and DEPTH images

Experiment 3 - Server Side – Computer Station

The RGB and DEPTH images received by the server correspond to those shown in Figure 91. The server receives these images and outputs information about them to the console. Figure 94 illustrates that the images sent from the client have been successfully received by the server, and their size matches that of the sent images (Figure 93).

Figure 95 presents a depth image received by the server.

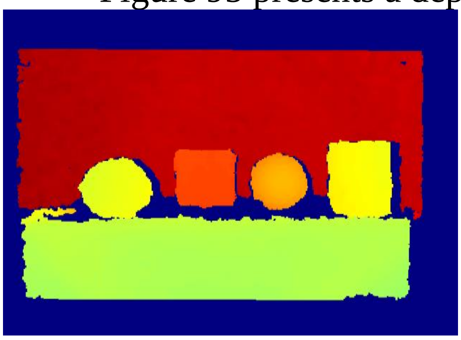


Fig.95: Normalized DEPTH image in color format

Fig.96: Average time to receive both images from the client

The translated text is already in English. Here it is again, slightly refined for clarity and flow:

The presence of dynamic objects in the observed environment means that communication delays can result in the loss of critical information about object positions and movements. At a resolution of 640x480 pixels, the average time to receive both RGB and DEPTH images from the client is approximately 60 ms (Figure 96).

For tracking moving objects, image processing speed is critical. Any delay in the processing cycle can cause a lag in the robot's response, reducing its effectiveness in tracking moving targets. At 640x480 resolution, the scene analysis program completes a processing cycle in about 20 milliseconds. This cycle includes object recognition, color identification, distance measurement to the object, and calculating its two-dimensional dimensions.

Based on this robot and the hardware enhancements implemented, a novel distance measurement model has been developed. This model demonstrates the integration of all core components of Information Technology (IT), Communication Technologies (CT), Cyber-Physical Systems (CPS), Artificial Intelligence (AI), and Cloud Computing. It is applicable for STEM education, combining language, technology, computer science, mathematics, and physics, while also fostering the essential soft skills required to enhance the technological capability and stability of society.

The next step for the presented robot involves conducting trials and evaluations with both students and teachers.

3.1.8. Other Mobile Educational Robots

A team of researchers developed an autonomous mobile robot called Tele-ROBCO and the necessary software to enable virtual on-site visits to museums.
This is a low-budget autonomous mobile robot, consisting of a differential-type mobile robot platform, a computer and controllers, a drive system including two 12V LiFePo batteries and a charging station, and a sensor system. The sensor system includes: infrared, ultrasonic, a laser scanner, a 3D "Real Sense" sensor, and an integrated accelerometer, gyroscope, and inertial sensor (Fig. 97).

One of the robot's functionalities is a telepresence mode for a school classroom (Fig. 98). A "Tele-visit" guided tour of the museum – The robot will collaborate with the museum tour expert – the guide – and will serve as an avatar for the visiting class (students), following the thematic presentation of the museum expert. At each exhibit, the expert guide conducts a discussion, prepared and didactically aligned with the subject's curriculum

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Fig.97: TELE-ROBKO

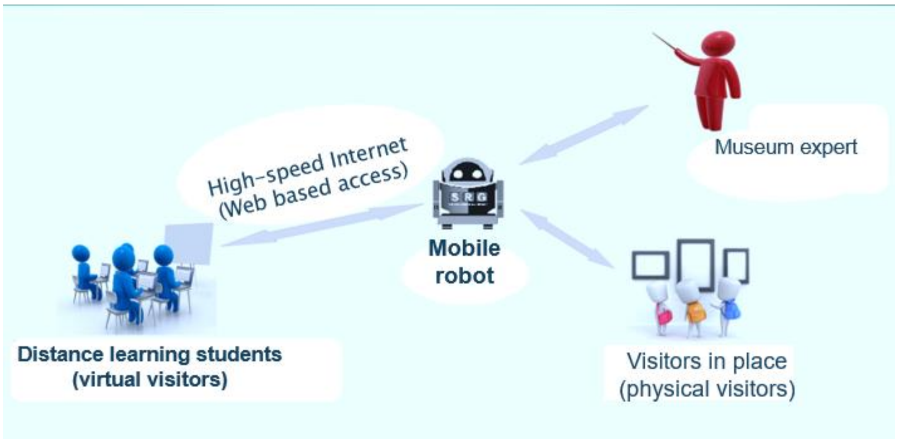

Fig. 98: Telepresence in a School Classroom

The trialed lesson demonstrated interdisciplinary connections and the development of ICT skills integrated with history, geography, and Bulgarian language, while the technical aspects encompassed mathematics, mechanics, and more, confirming the principles of STEM education.

Another robot, still in development, is an educational manipulator. An educational mobile manipulator robot is being developed for the educational system. This mobile manipulator robot uses a Raspberry Pi Pico W and is programmed in Python. It is being created to enrich STEM education by providing an interactive environment for studying robotics from both hardware and software perspectives, i.e., learning about sensor integration and programming. The robot is built on a standard chassis, equipped with mecanum wheels and a robotic arm (gripper), which is controlled by servo motors. This robot can be programmed in a Python environment and offers control of both the chassis and the gripper via a web interface, accessible through the robot's Wi-Fi hotspot (Fig. 99).

This robot is aimed at the high school level and is being tested in specific lessons that integrate language, mathematics, physics, mechanics, IT, CT, AI, and more, with the goal of training specialists in engineering sciences.

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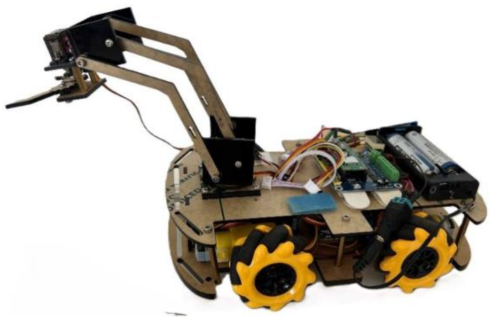

Fig.99: Educational manipulator

OUTCOMES

Use of ICT in Primary School: Basic programming with Scratch and Python, environmental sensing with Arduino, and introduction to various robots.

Use of ICT in Secondary School: Introduction to AI, concepts of AI, use of multiple sensors, problem-solving through data and algorithms. AI laboratory (e.g., robot, face and voice recognition). Python (basic programming and application).

Collaboration and Pedagogy: Bulgarian educators need to collaborate with AI engineers to bridge the gap between technology and pedagogy. Students understand that ChatGPT can perform some tasks without human intervention. There is a need for instructional methods on how to create appropriate tasks and problems so that this knowledge can be used appropriately in task execution. The primary goal of artificial intelligence is to transform the teacher from a source of information into a mentor who guides students towards knowledge in a specific field.

Collaborative Learning: Children had the opportunity to explore and discuss activities in pairs or small groups. This emphasizes teamwork.

Research and Future Studies: The conducted research on understanding artificial intelligence in Bulgaria lays the groundwork for many future studies with a broader group – including students from more and different schools – private and state.

This study will be used as a basis for future research on how and when education in STEM and artificial intelligence can be integrated into the students' curriculum.

Teacher Reception and Specific Robots: Trials with teachers also show continuity and openness to the method, albeit more cautiously. However, it would be more enjoyable education and a useful teaching method.

- **Ozobot EVO:** Using RGB technology to read colors, block-based programming, and Python 3 programming, it performs tasks with set parameters measurable for distance, time, etc., achieves set goals, and integrates with various subjects. In the trialed example in seventh grade, students utilized Bulgarian language, history, sports, music, information technology, mathematics, technologies, and entrepreneurship to achieve the final result: presenting the robot in the role of a boy/girl in national costume, who performs folk dances and sings a folk song.
- **Blue-Bot:** The robot is extremely durable, compact, and cost-effective for use in STEM lessons at the primary level or in kindergartens. Blue-Bot features Bluetooth technology, an interface, and Edge. Multiple lessons have been trialed with students aged 6-10 and with teachers who understand the technologies, see the connections across various subjects: language (Bulgarian and foreign), mathematics, drawing, computer modeling, homeland studies, the world around us, technologies and entrepreneurship, music.
- **ArtiMax Educational Robot:** Has potential for working with students. Even its imperfections make it more suitable for use, creating new challenges for students. They must find new solutions, which will generate interest and curiosity in the students.
- **XGO-mini 2 Dog:** The dog robot provides good opportunities for educational purposes in the fields of software, hardware, and artificial intelligence. Since education also seeks motivational and fun elements, the dog meets both criteria

CONCLUSIONS

This dissertation presents newly developed STEM methodologies and custom algorithms for various educational robotics platforms. The research includes comprehensive analysis of hardware and software capabilities for each robot implementation.

The selected testing protocols were designed to systematically evaluate robotic functionalities and characterize operational performance. These assessments were further utilized to validate age-appropriateness and determine suitable student age groups.

Based on technical capabilities of the robotic systems, complete STEM lesson plans have been developed and empirically validated through classroom implementation with students aged 6-18 and their educators.

Information and Communication Technologies (ICT) can be seamlessly integrated into educational frameworks to deliver comprehensive STEM training, thereby contributing to the development of a stable society capable of achieving elevated standards and sustainable economic growth.

AUTHOR REFERENCE

Contributions: Scientific; Scientific-Applied; and Applied

- Development of a novel algorithm for the Ozobot EVO platform that enables the robot to navigate a complex star-shaped trajectory without line intersection, demonstrating advanced path-planning capabilities. Implementation of a complementary algorithm for the execution of rhythmic patterns from Bulgarian folklore, showcasing the integration of cultural heritage with educational robotics.
- Developed an algorithm for the XGO-mini 2 mobile robotic dog enabling trajectory execution along circular, rectangular, and square paths around a designated object with predefined parameters
- Hardware Re-engineering of the ArtieMax Mobile Robot.
- Developed an algorithm for the ArtieMax robot to facilitate an integrated STEM lesson combining technology, mathematics, and English language instruction.
- Development of a Mathematical Writing Algorithm and Error-Correction Protocol for the ArtieMax Robot.
- A novel model for object distance measurement utilizing a 3D camera has been developed. Through the integration of new hardware and software components, the system introduces enhanced functionality to the proposed platform, specifically enabling comprehensive three-dimensional spatial analysis. The architecture employs a distributed computing approach, allocating complex computational tasks and resource requirements across specialized subsystems, thereby establishing a foundation for optimized real-time autonomous control of the mobile robot.
- A mixed-methods investigation was conducted to assess both qualitative and quantitative dimensions of AI comprehension in educational contexts among students aged 6 to 18 years.
- Developed an obstacle avoidance algorithm for the Codey Rocky tracked robot, designed for integration into mathematics-focused STEM lessons.
- An innovative history lesson was developed utilizing the Streaming method with the educational robot "Robco" (https://www.youtube.com/watch?v=bJJLvZO6tAg)

Acknowledgements

I extend my sincere gratitude to my scientific supervisor, Prof. Dr. Nayden Shivarov. Thank you for being my mentor, and for your support, guidance, and constructive criticism, which made this dissertation possible. Thank you for our collaborative creative work, a period during which we were dedicated to science and shared common interests.

My thanks also go to all my colleagues from IICT (Institute of Information and Communication Technologies) in the "CFS" section and the "Distributed Information and Control Systems" section with whom I have collaborated.

REFERENCES

[1] Bell, Bradford S., and Steve WJ Kozlowski. "Advances in technology-based training." Managing human resources in North America. Routledge, 2012. 27-43.

[2] de Freitas, S., Liarokapis, F. (2011). Serious Games: A New Paradigm for Education?. In: Ma, M., Oikonomou, A., Jain, L. (eds) Serious Games and Edutainment Applications. Springer, London. https://doi.org/10.1007/978-1-4471-2161-9_2

[3] Ma Minhua, Oikonomou Andreas, "Serious Games and Edutainment Applications", book, Springer Cham, doi.org/10.1007/978-3-319-51645-5, ISBN978-3-319-51643-1, https://doi.org/10.1007/978-3-319-51645-5

[4] Chen, NS., Hwang, GJ. Transforming the classrooms: innovative digital game-based learning designs and applications. *Education Tech Research Dev* **62**, 125–128 (2014). https://doi.org/10.1007/s11423-014-9332-y

[5] Elder CD. Serious Games. By Clark C. Abt. (New York: The Viking Press, Inc., 1970. Pp. 176. $5.95, cloth; $1.95, paper.) - A Primer on Simulation and Gaming. By Richard F. Barton. (Englewood Cliffs: Prentice-Hall, Inc., 1970. Pp. 239. $8.95 cloth, $4.95 paper.). *American Political Science Review*. 1971;65(4):1158-1159. doi:10.2307/1953510

[6] Friedman, S. and Schultz, D., "Generational Politics in the United States: From the Silents to Gen Z and Beyond", book, ISBN:9780472904440, 2024, University of Michigan Press, https://books.google.bg/books?id=RnEDEQAAQBAJ

[7] Chute, E. (2009). STEM education is branching out: Focus shifts from making science, math accessible to more than just brightest. Pittsburg Post-Gazette, 947944–947298.

[8] Christopoulos A, Pažeraite A., Chytas C., Tenberge C., Timotijevic D., Lale Eric D., Vaivadiene E., and team, "A PRACTICAL HANDBOOK ON EFFECTIVE DEVELOPMENT AND IMPLEMENTATION OF STEAM TEACHING AT SCHOOL", book, Pressbooks, Funded by Erasmus+ Programme of the European Union

[9] Mohr-Schroeder M., Cavalcanti M., Blyman K., "Stem Education: Understanding the Changing Landscape", 2015, pp.3 – 14, DOI:10.1007/978-94-6300-019-2_1, https://www.researchgate.net/publication/294287197_Stem_Education_Understanding_the_Changing_Landscape

[10] Dugger, William E,.Jr, "Standards for technological literacy: Content for the study of technology. Reston", ITEA, 2000, стр. 7, (2000/2/2007), ITEA, 2000, https://www.researchgate.net/publication/234677078_Standards_for_Technological_Literacy

[11] Technical Foundation of America, "Standards for Technological and Engineering Literacy", https://www.iteea.org/stel

[12] National Research Council 1996. National Science Education Standards, Washington, DC: The National Academies Press. https://doi.org/10.17226/4962, http://nap.edu/4962
[13] Betzner, J. and Marek, E. (2014) Teacher and Student Perceptions of Earth Science and Its Educational Value in Secondary Schools. Creative Education, 5, 1019-1031. doi: 10.4236/ce.2014.511116, https://www.scirp.org/journal/paperinformation?paperid=47209
[14] Homkes R. and Strikwerda. R. A., 2009, Meeting the ABET program outcome for issues and responsibilities: an evaluation of CS, IS, and IT programs. In Proceedings of the 10th ACM conference on SIG-information technology education (SIGITE '09). Association for Computing Machinery, New York, NY, USA, 133–137. https://doi.org/10.1145/1631728.1631764
[15] Stefanidou, C. and Skordoulis, C. (2014) Subjectivity and Objectivity in Science: An Educational Approach. Advances in Historical Studies, 3, 183-193. doi: 10.4236/ahs.2014.34016. https://www.scirp.org/journal/paperinformation?paperid=50254
[16] Kennedy T., Odell M., 2023, STEM Education as a Meta-discipline, Contemporary Issues in Science and Technology Education (pp.37-51), DOI:10.1007/978-3-031-24259-5_4, https://www.researchgate.net/publication/368796346_STEM_Education_as_a_Meta-discipline
[17] Sanders, M. (2009). Integrative STEM education: Primer. Technology Teacher, 68(4), 20–26
[18] Shernoff, D.J., Sinha, S., Bressler, D.M. et al. Assessing teacher education and professional development needs for the implementation of integrated approaches to STEM education. IJ STEM Ed **4**, 13 (2017). https://doi.org/10.1186/s40594-017-0068-1, https://link.springer.com/article/10.1186/s40594-017-0068-1#citeas
[19] Bennett, J.M.P., An investigation of elementary teachers' self-efficacy for teaching integrated science, technology, engineering, and mathematics (STEM) education, Dissertation, Regent University, ProQuest Number: 10137835, 2016, https://www.proquest.com/openview/48f43dce3b88d5bcec7c49544e38475e/1?pq-origsite=gscholar&cbl=18750
[20] Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices (pp. 35-60). Purdue University Press. https://experts.umn.edu/en/publications/implementation-and-integration-of-engineering-in-k-12-stem-educat
[21] Purzer, S., Strobel, J., Cardella, M.E 2014 book Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices, Purdue University Press, ISBN: 9781612493589, https://books.google.bg/books?id=bl7yDwAAQBAJ
[22] Kelley, T.R., Knowles, J.G. A conceptual framework for integrated STEM education. IJ STEM Ed 3, 11 (2016). https://doi.org/10.1186/s40594-016-0046-z
[23] OECD (2015), OECD Science, Technology and Industry Scoreboard 2015: Innovation for growth and society, OECD Publishing, Paris,

https://doi.org/10.1787/sti_scoreboard-2015-en. https://www.oecd.org/en/publications/oecd-science-technology-and-industry-scoreboard-2015_sti_scoreboard-2015-en.html

[24] Harrington R., 2015, These are the 10 smartest countries in the world when it comes to science, Business insider, https://www.businessinsider.com/most-technological-countries-lag-behind-in-science-2015-12#6-greece-spent-only-008-of-its-gdp-on-research-in-2013-which-was-one-of-the-lowest-reported-among-developed-countries-it-might-explain-why-its-stem-degree-rate-dropped-from-28-in-2002-to-26-in-2012-5

[25] Georgieva S., 2014, Добре забравено старо: Сендовската система вече се нарича STEM, https://www.segabg.com/hot/category-education/dobre-zabraveno-staro-sendovskata-sistema-veche-se-naricha-stem?fbclid=IwY2xjawHu-SZleHRuA2FlbQIxMQABHXc-HSr9GOArCdJhWQG5ZymfQ2FEGYWw2-QIa6q883VSXVkfP9uRPT_7kA_aem_tJxgGhfvz-Uf8V14kudVwg

[26] European Commission's, 2024, Education and Training Monitor 2024, Comparative report, Luxembourg: Publications Office of the European Union, ec.europa.eu/education/monitor, op.europa.eu/etm

[27] Leavitt, Harold J et al. Management in the 1980's, *Harvard Business Review*. 11 1958

[28] nhttps://bg.wikipedia.org/wiki/%D0%98%D0%BD%D1%84%D0%BE%D1%80%D0%BC%D0%B0%D1%86%D0%B8%D0%BE%D0%BD%D0%BD%D0%B8_%D0%B8_%D0%BA%D0%BE%D0%BC%D1%83%D0%BD%D0%B8%D0%BA%D0%B0%D1%86%D0%B8%D0%BE%D0%BD%D0%BD%D0%B8_%D1%82%D0%B5%D1%85%D0%BD%D0%BE%D0%BB%D0%BE%D0%B3%D0%B8%D0%B8

[29] Longley, Dennis et al. Dictionary of Information Technology, 2. Macmillan Press, 1985. ISBN 0-333-37260-3. p. 164

[30] Glushkov, V.M. and other. Encyclopedia of Cybernetics. Kyiv, 1975.

[31] Information: A Very Short Introduction. Luciano Floridi // Oxford University Press, 2010. Посетен на 16 септември 2010.

[32] Zunt, Dominik. Who did actually invent the word „robot“ and what does it mean? // The Karel Čapek website. 2007.

[33] https://bg.wikipedia.org/wiki/%D0%A0%D0%BE%D0%B1%D0%BE%D1%82%D0%B8%D0%BA%D0%B0

[34] Q. Wu, "Networking College's Smart Education System Based on Omnidirectional Interaction Model," *2021 2nd International Conference on Information Science and Education (ICISE-IE)*, Chongqing, China, 2021, pp. 141-144, doi: 10.1109/ICISE-IE53922.2021.00039.https://ieeexplore.ieee.org/abstract/document/9742435/citations#citations

[35] Angeline, R., Adhityaa, C., Ranganathan, V.P., Kailash, K.E. (2024). Intelligent Educational Chatbot for Student Interaction Based on DaVinci Model. In: Senjyu, T., So–In, C., Joshi, A. (eds) Smart Trends in Computing and

Communications. SmartCom 2024 2024. Lecture Notes in Networks and Systems, vol 947. Springer, Singapore. https://doi.org/10.1007/978-981-97-1326-4_19, https://link.springer.com/chapter/10.1007/978-981-97-1326-4_19
[36] B. Williamson, J. Pykett, and S. Nemorin, “Biosocial spaces and neurocomputational governance: brain-based and brain-targeted technologies in education,” Discourse: Studies in the Cultural Politics of Education, vol. 39, no. 2, pp. 258–275, 2018.
[37] B. Willizmson, R.Eynon, (2020) “Historical threads, missing links, and future directions in AI in education”, Learning, Media and Technology, 45:3, 223-235, DOI:10.1080/17439884.2020.1798995.
[38] X. Zhai, X. Chu, C. Sing Chai, Morris Siu Yung Jong, Andreja Istenic, Michael Spector, Jia-Bao Liu, J. Yuan, Yan Li, "A Review of Artificial Intelligence (AI) in Education from 2010 to 2020", Complexity, vol. 2021, Article ID 8812542, 18 pages, 2021. https://doi.org/10.1155/2021/8812542
[39] A. Flogie and B. Aberšek, “Transdisciplinary approach of science, technology, engineering and mathematics education,” Journal of Baltic Science Education, vol. 14, no. 6, pp. 779–790. Ijaz, A. Bogdanovych, and T. Trescak, “Virtual worlds vs books and, 2015.
[40] K videos in history education,” Interactive Learning Environments, vol. 25, no. 7, pp. 904–929, 2017.
[41] T. Horakova, M. Houska, and L. Domeova, “Classification of the educational texts styles with the methods of artificial intelligence,” Journal of Baltic Science Education, vol. 16, no. 3, pp. 324–336, 2017.
[42] T. Horakova, M. Houska, and L. Domeova, “Classification of the educational texts styles with the methods of artificial intelligence,” Journal of Baltic Science Education, vol. 16, no. 3, pp. 324–336, 2017.
[43] S. Vattam, A. K. Goel, S. Rugaber et al., “Understanding complex natural systems by articulating structure-behavior-function models,” Educational Technology & Society, vol. 14, no. 1, pp. 66–81, 2011.
[44] A. Casamayor, A. Amandi, and M. Campo, “Intelligent assistance for teachers in collaborative E-learning environments,” Computers & Education, vol. 53, no. 4, pp. 1147–1154, 2009
[45] A. Gogoulou, E. Gouli, and M. Grigoriadou, “Adapting and personalizing the communication in a synchronous communication tool,” Journal of Computer Assisted Learning, vol. 24, no. 3, pp. 203–216, 2008.
[46] A. Tüfekçi and U. Köse, “Development of an artificial intelligence based software system on teaching computer programming and evaluation of the system,” Hacettepe Üniversitesi Eğitim Fakültesi Dergisi, vol. 28, no. 2, pp. 469–481, 2013.
[47] V. V. Nabiyev, Ü. Çakiroğlu, H. Karal, A. K. Erümit, and A. Çebi, “Application of graph theory in an intelligent tutoring system for solving mathematical word problems,” Eurasia Journal of Mathematics, Science & Technology Education, vol. 12, no. 4, pp. 687–701, 2016.
[48] A. Mukherjee, U. Garain, and A. Biswas, “Experimenting with automatic text-to-diagram conversion: a novel teaching aid for the blind people,” Journal of Educational Technology & Society, vol. 17, no. 3, pp. 40–53, 2014

[49] M. Liu, V. Rus, and L. Liu, "Automatic Chinese factual question generation," IEEE Transactions on Learning Technologies, vol. 10, no. 2, pp. 194–204, 2017.

[50] K. R. Malik and T. Ahmad, "E-assessment data compatibility resolution methodology with bidirectional data transformation," EURASIA Journal of Mathematics, Science & Technology Education, vol. 13, no. 7, pp. 3969–3991, 2017.

[51] J. Petit, S. Roura, J. Carmona et al., "Jutge.org: characteristics and experiences," IEEE Transactions on Learning Technologies, vol. 11, no. 3, pp. 321–333, 2018.

[52] I. Zipitria, A. Arruarte, and J. Elorriaga, "Discourse measures for Basque summary grading," Interactive Learning Environments, vol. 21, no. 6, pp. 528–547, 2013.

[53] G. P. Jain, V. P. Gurupur, J. L. Schroeder, and E. D. Faulkenberry, "Artificial intelligence-based student learning evaluation: a concept map-based approach for analyzing a student's understanding of a topic," IEEE Transactions on Learning Technologies, vol. 7, no. 3, pp. 267–279, 2014.

[54] C. Rapanta and D. Walton, "The use of argument maps as an assessment tool in higher education," International Journal of Educational Research, vol. 79, pp. 211–221, 2016.

[55] A. Jones, "Philosophical and socio-cognitive foundations for teaching in higher education through collaborative approaches to student learning," Educational Philosophy and Theory, vol. 43, no. 9, pp. 997–1011, 2011.

[56] G. Kessler, "Technology and the future of language teaching," Foreign Language Annals, vol. 51, no. 1, pp. 205–218, 2018.

[57] D. H. Jonassen, "Ask systems: interrogative access to multiple ways of thinking," Educational Technology Research and Development, vol. 59, no. 1, pp. 159–175, 2011.

[58] Davy Tsz Kit Ng, Jiahong Su, Jac Ka Lok Leung & Samuel Kai Wah Chu (2023), "Artificial intelligence (AI) literacy education in secondary schools: a review, Interactive Learning Environments", DOI: 10.1080/10494820.2023.2255228

[59] Jiahong Su, Yuchun Zhong, Davy Tsz Kit Ng, "A meta-review of literature on educational approaches for teaching AI at the K-12 levels in the Asia-Pacific regions Computers and Education: Artificial Intelligence", Volume 3, 2022, 100065, ISSN 2666-920X

[60] I. Lee, B. Perret, "Preparing High School Teachers to Integrate AI Methods into STEM Classrooms,"The Thirty-Sixth AAAI Conference on Artificial Intelligence (AAAI-22), 2022

[61] F. R. Melo, E. L. Flôres, S. D. Carvalho, R. A. G. Teixeira, L. F. B. Loja, and R. de Sousa Gomide, "Computational organization of didactic contents for personalized virtual learning environments," Computers & Education, vol. 79, pp. 126–137, 2014.

[62] Irene Lee, Beatriz Perret "Preparing High School Teachers to Integrate AI Methods into STEM Classrooms", The Thirty-Sixth AAAI, Conference on Artificial Intelligence (AAAI-22), 1997
[63] J. Andriessen, J. Sandberg, "Where is Education Heading and How About AI?", International Journal of Artificial Intelligence in Education (1999), 10, 130-150.
[64] Huang, S.; Wang, B.; Li, X.; Zheng, P.; Mourtzis, D.; Wang, L. Industry 5.0 and Society 5.0—Comparison, complementation and co-evolution. J. Manuf. Syst. 2022, 64, 424–428.
[65] Staikova, M.; Ivanova, V.; Chivarov, N. Artie max robot as a STEM education tool through integration technology, math and English language. AIP Conf. Proc. 2024, 3078, 020007. https://doi.org/10.1063/5.0208311.
[66] Khine, M.S.; Ohmer. Robotics in STEM Education; Springer: Berlin, Germany, 2017; pp. 262, ISBN: 978-3-319-57785-2.
[67] Breiner, J.M.; Harkness, S.S.; Johnson, C.C.; Koehler, C.M. What Is STEM? A Discussion About Conceptions of STEM in Education and Partnerships. Sch. Sci. Math. 2012, 112, 3–11. https://doi.org/10.1111/j.1949-8594.2011.00109.x.
[68] Vega, J.; Canas, J.M. Open vision system for low-cost robotics education. Electronics 2019, 8, 1295. https://doi.org/10.3390/electronics8111295.
[69] Weinberg, J.B.; Yu, X. Robotics in education: Low-cost platforms for teaching integrated systems. IEEE Robot. Autom. Mag. 2003, 10, 4–6. https://doi.org/10.1109/MRA.2003.1213610.
[70] Staikova, M.; Ivanova, V.; Chivarov, N. Students understanding for AI in different educational levels. IFAC-PapersOnLine 2024, 58, 182–186. https://doi.org/10.1016/j.ifacol.2024.07.147.
[71] Ozobot Educator's Guide. Available online: https://ozobot.com.
[72] Khine, M.S., Khine, M.S. and Ohmer, 2017. Robotics in STEM Education. Springer.
[73] Jonathan M. Breiner, Shelly Sheats Harkness, Carla C. Johnson, Catherine M. Koehler, What Is STEM? A Discussion About Conceptions of STEM in Education and Partnerships, School Science and mathematics, 2012
[74] Vega, J. and Canas, J.M., 2019. Open vision system for low-cost robotics education. Electronics, 8(11), p.1295.
[75] Weinberg, J.B. and Yu, X., 2003. Robotics in education: Low-cost platforms for teaching integrated systems. IEEE Robotics & automation magazine, 10(2), pp.4-6.
[76] Chivarov, N., Yovkov,S., Chivarov, S., Tosheva, I., Pleva, M., Hladek, D. NITRO Educational Mobile Robot Platform for Maze Solving and Obstacle Avoidance, 2022. IEEE Xplore. Restrictions apply.
[77] ESP32 - Technical Reference Manual, Copyright © 2022 Espressif Systems, version 4.8
[78] Maier A., Sharp A. and Vagapov Y., "Comparative analysis and practical implementation of the ESP32 microcontroller module for the internet of things," 2017 Internet Technologies and Applications (ITA), Wrexham, UK, 2017, pp. 143-148, doi: 10.1109/ITECHA.2017.8101926.
[79] Rai P. and Rehman M., "ESP32 Based Smart Surveillance System," 2019 2nd International Conference on Computing, Mathematics and Engineering

Technologies (iCoMET), Sukkur, Pakistan, 2019, pp. 1-3, doi: 10.1109/ICOMET.2019.8673463.

[80] Educational Insights, ArtieMax Guide

[81] Sutherland C. J., "Blockly in a Box: How Children Explore Block-Based Robot Programming," 2022 19th International Conference on Ubiquitous Robots (UR), Jeju, Korea, Republic of, 2022, pp. 263-267, doi: 10.1109/UR55393.2022.9826278.

[82] Minard P., Pintos F., Louzir A., Chambelin P., Naour Y. Le and Bras L. Le, "On-board integration of compact printed WiFi antennas with existing DECT antenna system," 2008 IEEE Antennas and Propagation Society International Symposium, San Diego, CA, USA, 2008, pp. 1-4, doi: 10.1109/APS.2008.4618944.

[83] Villacís D., Acosta F. R. and Lara Cueva R. A., "Performance analysis of VoIP services over WiFi-based systems," 2013 IEEE Colombian Conference on Communications and Computing (COLCOM), Medellin , Colombia, 2013, pp. 1-6, doi: 10.1109/ColComCon.2013.6564813.

[84] Web page of LUMA Centre at Aalto University http://luma.aalto.fi, 12.5.2016

[85] http://koodiaapinen.fi/en/

[86] https://macsources.com/artie-max-code-and-draw-review/

[87] https://www.techadvisor.com/article/723603/best-coding-and-stem-toys-for-kids-2022.html

[88] Xun Xu, Yuqian Lu, Birgit Vogel-Heuser, Lihui Wang, "Industry 4.0 and Industry 5.0—Inception, conception and perception, Journal of Manufacturing Systems", Volume 61,2021,Pages 530-535, ISSN 0278-6125

[89] Humayun M., "Industrial Revolution 5.0 and the Role of Cutting Edge Technologies", International Journal of Advanced Computer Science and Applications; West Yorkshire Vol. 12, Iss. 12, (2021), pp. 605 – 614.

[90] Nosta J. „The 5th Industrial Revolution: the dawn of cognitive age", (6.10.2023), https://www.psychologytoday.com/us/blog/the-digital-self/202310/the-5th-industrial-revolution-the-dawn-of-the-cognitive-age

[91] Orphanides K.G., "Review: Luwu Dynamics XGO-Mini2", (17.06.2023), https://www.wired.com/review/review-luwu-dynamics-xgo-mini2/

[92] Mouser Electronics Team, "Newest products: Raspberry Pi Compute Modules 4 (CM4), (24.07.2023), "https://www.mouser.bg/new/raspberry-pi/raspberry-pi-cm4-compute-modules/

[93] Maurya A. and Sharma V., "Facial Emotion Recognition Using Keras and CNN," 2022 2nd International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE), Greater Noida, India, 2022, pp. 2539-2543, doi: 10.1109/ICACITE53722.2022.9823480.

[94] Khopkar A. and Saxena A. A., "Facial Expression Recognition Using CNN with Keras", Biosc. Biotech. Res. Comm. special Issue Vol 14 No 05 (2021) Pp-47-50

[95] Elecfreaks Team, "ELECFREAKS CM4 XGO-Mini Robot Dog Kit For Raspberry Pi ", (2023), https://www.elecfreaks.com/

[96] The xgorobot web /working/ environment : http://block.xgorobot.com/
[97] Elecfreaks Team, „CM4 XGO Robot Kit V2", (2023), https://wiki.elecfreaks.com/en/pico/cm4-xgo-robot-kit/
[98] Nosta J., "The New Cognitive Age: In the 5th Industrial Revolution, technology and humanity will evolve together", (8.11.2023), https://futurist.bg/the-5th-industrial-and-cognitive-revolution/
[99] Montiglio, D. (2009), "Guide To Understand The Bulgarian Educational System", Journal of Foreiner,
[100] Gokuladas, V. K., Sam, S.K., (2022), "Student Satisfaction In Secondary Education: An Empirical Study of Indian Expatriate Students", Journal of Research in International Education, 75 – 83.
[101] Bosworth K, Ford L and Hernandaz D (2011) School climate factors contributing to student and faculty perceptions of safety in select Arizona schools. Journal of School Health. 81(4): 194–201.
[102] Halachev, P. (2009), "Educational Challenges for e-Learning in Higher Education in Bulgaria", The International Journal of Learning Annual Review 16(6):737-746.
[103] Kostova, D., (2008), "The Bulgarian educational system and evaluation of the ISCED-97 implementation", 163 – 173p.
[104] Bieri, F., Imdorf., Ch., Stoilova, R., Boyadjieva, P., „The Bulgarian educational system and gender segregation in the labour market", Pages 158-179 | Received 08 Apr 2014, Accepted 21 Dec 2015, Published online: 19 Feb 2016
[105] Boyadjieva, P. (2012) 'Higher education and rating systems of higher schools in Bulgaria: Situation, problems, and outlook (published in Bulgarian)', Bulgarian Journal of Science and Education Policy 6: 5–84.
[106] Anthony, M., „Cognitive Development in 11-13 Year Olds. Children become increasingly competent at adult-style thinking during the "tween" years." <https://www.scholastic.com/parents/family-life/creativity-and-critical-thinking/development-milestones/cognitive-development-11-13-year-olds.html>, 2015 (accessed 15.05.15)
[107] Methodology for studying of students' satisfaction with the quality of education, Dimitar A. Tsenov Academy of Economics, https://wwwold.uni-svishtov.bg/app/quality/CKO_DOCUMENTS/Metodologia_IAOKU.pdf (15.06.2019).
[108] Zsheliaskova-Koynova, Zsh., Mileva, (2019), E., "STUDENTS' SATISFACTION WITH PEDAGOGY TEACHING", Trakia Journal of Sciences, Vol. 17, Suppl. 1,
[109] Fischer, K. W. (1980). A theory of cognitive development: The control and construction of hierarchies of skills. Psychological Review, 87(6), 477–531. https://doi.org/10.1037/0033-295X.87.6.477
[110] Anderson, M. (1992). Intelligence and development: A cognitive theory. Blackwell Publishing.
[111] Huitt, W., Hummel, J. (2003), "Piaget's theory of cognitive development. Educational Psychology Interactive. Valdosta, GA: Valdosta State University. Retrieved [date] from <http://chiron.valdosta.edu/whuitt/col/cogsys/piaget.html>

[112] Collins,.A., (1984), "Divelpment During Middle Childhood", National Academy press, Washington, D.C. 1984

[113] Rubio F., Valero F., L lopis-Albert C., "A review of mobile robots: Concepts, methods, theoretical framework, and applications". International Journal of Advanced Robotic Systems. 2019;16(2). doi:10.1177/1729881419839596

[114] Siegwart R., Reza Nourbakhsh I., Scaramuzza D., "Introduction to Autonomous Mobile Robots", book of Massachusetts Institute of Technology, 2011

[115] Bilbro G. and Snyder W., "A System To Recognize Objects In 3-D Images", Proc. SPIE 0635, Applications of Artificial Intelligence III, (26 March 1986); https://doi.org/10.1117/12.964125

[116] Farhadi A., Endres I., Hoiem D. and Forsyth D., "Describing objects by their attributes", 2009 IEEE Conference on Computer Vision and Pattern Recognition, Miami, FL, USA, 2009, pp. 1778-1785, doi: 10.1109/CVPR.2009.5206772

[117] Frome A., Huber D., Kolluri R., Bülow T., Malik J., "Recognizing Objects in Range Data Using Regional Point Descriptors.", In: Pajdla, T., Matas, J. (eds) Computer Vision - ECCV 2004. ECCV 2004. Lecture Notes in Computer Science, vol 3023. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-24672-5_18

[118] Johnson A. and Hebert M., "Recognizing objects by matching oriented points," Proceedings of IEEE Computer Society Conference on Computer Vision and Pattern Recognition, San Juan, PR, USA, 1997, pp. 684-689, doi: 10.1109/CVPR.1997.609400

[119] Team of Obi Zhongguang Technology Group Co., Ltd., "ORBBEC Depth Camera", Product specification, Co Copyright © 2013–2022, Orbbec Incorporated, https://www.orbbec.com/wp-content/uploads/2023/07/Petrel-A-En.pdf

[120] Team of Obi Zhongguang Technology Group Co., Ltd., https://www.orbbec.com/developers/openni-sdk/

[121] Smolskiy M., "Open Source Computer Vision Library", https://github.com/opencv/opencv

[122] Microsoft Team, "Learn", https://learn.microsoft.com/en-us/windows/win32/memory/using-file-mapping

[123] Gochev G., "Computer Vision and Neural Networks", Technical University Publishing House, 1998. (translated from Bulgarian)

[124] Shade J., S. Gortler, Li-wei He, Richard Szeliski, "Layered depth images", 24 July 1998, SIGGRAPH98: The 25th International Conference on Computer Graphics and Interactive Techniques

[125] Tom van Dijk, Guido de Croon;" How Do Neural Networks See Depth in Single Images?", Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV), 2019, pp. 2183-2191

[126] Coradeschi, S., & Saffiotti, A. (2003). Perceptual Anchoring of Symbols for Action. Proceedings of the 17th International Joint Conference on Artificial Intelligence (IJCAI), 407-412.