

Article

Innovative Approach on Teaching and Learning with Technical Aids for STEM Education at the Primary Level

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Abstract: Education is a constantly evolving field that encompasses various approaches to teaching and learning. In our paper, we focused on qualitative research conducted with future primary level teachers using a STEAM (Science, Technology, Engineering, Arts and Mathematics) approach. The research involved classroom observation, analysis of the student work, and obtaining interpretations from the students via report protocols and focused interviews. We examined the students' learning and problem-solving strategies within STEAM-based activities as well as their perspectives on its use in primary education. Students participated in the research activity in two stages. In the first stage, further referred to as Activity 1, they followed a predetermined algorithm, instructions to construct an electronic device. The instructions for this device were developed to serve as a resource for primary education and to prepare the students for the second stage. In the second stage, further known as Activity 2, the students were tasked with creating a new electronic device together with providing the instructions. The new device was required to have a practical application. Following the completion of these activities, we collected and analyzed the procedural reflections and didactic interpretations from students. Within these interpretations, we also sought their opinions on how STEAM projects like these could help develop various aspects of STEAM competencies in children such as technical skills and knowledge, algorithmic thinking, and device architecture as well as mathematical and scientific thinking.

Keywords: technical education; technical aid; STE(A)M education; primary level; students' opinions



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1. Introduction

According to Redecker [1], the widespread use of digital technologies has greatly transformed various aspects of society including communication, work practices, leisure activities, and the acquisition of knowledge and information. Children and young adults are growing up in a world where digital technologies are omnipresent. Consequently, STEM education plays a crucial role in the educational systems of all countries. In Slovakia, the implementation of STEM education can be found in the document by Pupala and Fridrichová [2]. This document emphasizes the significant role of mathematics education in STEM education, as it helps students develop mathematical skills that are essential for effective communication, reasoning, critical thinking, and overall confidence in utilizing mathematical concepts beyond the realm of mathematics itself. Well-organized mathematics education is expected to increase the students' interest in pursuing STEM subjects, as they will perceive mathematics as an intriguing field for exploration and as a valuable tool for problem-solving in various domains. Additionally, students will comprehend the broader significance of mathematics.

According to Houghton, Oldknow, Diego-Mantecón, Fenyvesi, Crilly and Lavicza [3], the advantage of STEM education is, in fact, that this kind of education offers educational

situations where the individual and social skills of pupils or students are required in creative problem-solving challenges featuring a mixture of science, technology, engineering, and mathematics. Conde, Sedano, Fernández-Llamas, Gonçalves, Lima and García-Peñalvo [4] argue that there is a need for experts who are prepared to solve the problems that arise in it, which requires them to have a deep knowledge of the methodologies, tools, and devices to be used in digital society. The students or pupils (as future workers) need to develop several skills that later support their employability such as critical thinking, teamwork, problem-solving, creativity, and to acquire competences connected with computational thinking. STEM education is a possible answer to this necessity, but this kind of education requires new learning methodologies and tools.

2. Theoretical Background

2.1. Integrated STEM Education

National education policymakers for the 21st century and educational institutions around the world are increasingly emphasizing the provision of sufficient training for students that reflects the current needs and demands of the labor market [5]. However, many learning environments today do not sufficiently engage students in learning as effectively as they should because they are based on educational models established more than half a century ago [6]. The majority of education in primary and secondary schools (ISCED1–ISCED3) continues to focus on theory rather than application and experiential learning and teaches in a way that does not strengthen the links between different educational disciplines [7]. Given the increasing demand for a STEM-savvy workforce, national education policy efforts to promote STEM education in primary and secondary schools around the world are also intensifying [8,9].

In the professional literature, the STEM approach to education has been described in different ways [10–15]. For example, Vasquez, Comer and Gutierrez [16] state in their book that STEM education is an interdisciplinary approach to teaching and learning that breaks down the traditional barriers between the four disciplines of science, technology, engineering, and mathematics and integrates them into relevant units of learning applicable to students in real life. According to Dugger [17], STEM is an educational approach that aims to provide students with the ability to communicate in an interdisciplinary manner, carry out teamwork, think creatively, engage in engaged inquiry, and produce and solve problems, with a focus on integrating the knowledge and skills of science, technology, mathematics, and engineering into engineering design-based instruction. In Kelly and Knowles (2016) [18], the STEM approach in education referred to the teaching, learning, and integration of the disciplines of science, technology, mathematics, and engineering into science topics, with an emphasis on solving modeled real-world situations and practical tasks. In this approach, students acquire core competencies and complex cognitive skills. These skills are needed to make meaningful connections in processing knowledge, resulting in interdisciplinary meaningful understanding. In Spelt et al. (2009) [19], the authors defined interdisciplinarity as the ability to integrate knowledge from two or more disciplines in order to achieve cognitive progress in a way that would be impossible or improbable to achieve using the resources of a single discipline.

The STEM approach is a radical step forward in relation to traditional teaching and learning, which is still dominated by a non-STEM approach delivered through frontline teaching. The benefits of the STEM approach in relation to the quality of learning and making connections between knowledge, quality cognitive skills, and needs applicable in real life are numerous [20,21]. In real life, students encounter a variety of problem situations and often tend to solve them from only one aspect, without considering the possibility of combining knowledge acquired in other educational areas and disciplines. In light of this, an interdisciplinary approach to teaching and learning is beneficial for students as it enables them to adopt a holistic view of the issues of everyday life. This is why the STEM approach is receiving increasing attention from science education practitioners and researchers [22]. In a meta-analysis of twenty-eight selected studies, Becker and Park (2011) [23] concluded

that the effect of an integrated approach in STEM subjects through interdisciplinarity in the classroom was positive in relation to student achievement and learning outcomes. In terms of individual levels of learning, integrative approaches between STEM subjects showed the largest effect size at the primary school level (ISCED1–ISCED2) and the smallest effect size at the higher education institution level (ISCED5–ISCED6). According to the Lamb et al. (2015) [24], there is much evidence that the integration of STEM learning in lower primary school (ISCED1) is becoming particularly important for pupils. STEM activities also contribute to the higher cognitive and affective development of students compared to their non-STEM peers. Another research study [25] revealed similar findings, as the application of the STEM approach contributed to a statistically significant increase in the students' understanding of the presented science processes, science concepts, and science content knowledge compared to a group of students for whom the STEM approach was not applied.

2.2. Innovative Tools for STEM Education

The integration of technology into teaching and learning is vital for improving educational curricula and student learning outcomes, especially when used alongside a variety of conventional teaching methods. Technology can not only facilitate creative, flexible, and purposeful thinking and knowledge building by students, but also extend the 'reach' of learning opportunities for students. With the rapid pace of innovation in technology and its application in all areas of our lives including educational processes, educators and researchers are increasingly emphasizing the potential benefits of applying it with the intent of optimizing STEM learning outcomes [26]. In the relevant literature, we found a number of well-established ways in which the integration of innovative tools and technology solutions impacts student learning and engagement in STEM subjects [27].

When we talk about technology solutions for STEM education, we are referring to the teaching and learning of subject matter in science and engineering classrooms through selected software applications or robotics and coding kits. As Kennedy and Odell point out [28], the main purpose of integrating them into the school science and engineering teaching process, which teachers are hereby pursuing, is to try to stimulate the learning engagement and motivation of youngsters for different aspects of the teaching and learning process in the above-mentioned areas of their educational curriculum. In particular, if they are operated directly by students during the lesson, they can help them to sort out and clarify theoretical knowledge and science or scientific phenomena that are demanding on the imagination. It is a well-known fact that today's youth are difficult to keep engaged when learning about science. Often, they become easily disinterested when teachers use traditional teaching methods. We know that today's young generation has a largely positive attitude toward digital technology and are used to a high level of interactivity when using them, for example, through (video) games or other common software applications.

Primary and secondary school teachers (ISCED1–ISCED3) currently have a wide range of STEM learning tools at their disposal to creatively engage their students in these subjects and really bring STEM learning to life in their classrooms. Because their acquisition cost is (mostly) not exactly low, many educational institutions are not able to provide their students with adequate access to real laboratory equipment suitable for science learning. As a consequence, students do not have enough opportunities in school to learn mathematics and science from a practical point of view and thus to understand issues applicable to everyday private and working life. However, on the other hand, it should be noted that European projects in particular have had a major role in equipping schools with these STEM learning tools (with software available in national language software localizations).

The most commonly used digital tools to support an engaging and interesting way for students to interact with science while increasing their access to hands-on science education are interactive virtual laboratories with gamification elements, simulation tools, and virtual and augmented reality applications. With advances in the availability and sophistication of technology, interactive computer simulations are becoming a unique tool to support STEM

subject learning by providing opportunities to manipulate both virtual and real-world environments. Interactive interfaces with iterative manipulation features help students observe experimental simulations multiple times, helping them develop an understanding of a particular science/science phenomenon and thus develop knowledge essential to the STEM field. The simulation is usually built on a basic model representing a real-world situation by using different forms of expressing the dependencies between the components of the model. The idea is to expose students to a significant abstraction of some physical phenomena or ecosystem process that is based on some real-world behavior [29]. Digital simulation tools can give students access to knowledge that is normally unobservable such as the natural process of seed germination and its transformation into a healthy plant. Simulation tools can be used to bring to life various physical phenomena such as the change in the length of a person's shadow according to the position of the Sun in the sky, or some meteorological phenomena such as the movement of storm currents at different locations on Earth.

Gamified virtual laboratories are effective pedagogical tools that enable educators to create participatory learning activities for students, thereby ensuring that all students are actively engaged in the learning continuum [30]. Prevailing analytical findings suggest that gamified virtual laboratories can potentially be a suitable pedagogical tool for promoting the critical thinking of students [31]. For example, through educational gamified virtual laboratories, we can expose students to learning content that cannot be demonstrated to them in real school settings such as how atoms and molecules are formed. Similarly, we can demonstrate learning content that may be dangerous for students such as chemical and nuclear reactions [32].

The future of STEM education and training is linked to augmented and virtual reality, which allow students to explore complex concepts in immersive ways. Augmented reality is software that is used on a smart digital device such as a tablet, smart glasses, or smartphone to bring digital objects into the real world, creating interactive learning experiences for students. Virtual reality takes this process even further. Instead of projecting onto the real environment, virtual reality creates an entirely new digital environment that can be viewed in a 360-degree format [33]. Whether the learning takes place in a school classroom or in the students' home environments, using virtual reality, students can, for example, tap into the different systems of the human body or virtually visit remote historical sites around the world. By using augmented and virtual reality in the classroom, students can grasp challenging ideas in a more tangible way, fostering deeper understanding and increasing engagement in STEM subjects.

Among pupils as early as the first year of primary school (ISCED1), robotics and coding kits are popular to support STEM learning, which provide students with an excellent introduction to engineering and computer science. These robotics kits often come with pre-assembled robots that students can program and control using coding. By engaging in hands-on activities with robotics, students will witness the practical application of STEM skills. For example, they can build and program a robot to navigate a maze or perform specific tasks, fostering problem-solving skills and reinforcing the importance of coding and engineering in today's society. Robotics has been proven in many studies to be a successful teaching method for primary school students (ISCED1–ISCED2), building on Papert's pioneering work in constructivism and constructionism [34]. A number of studies have highlighted the practicality and usefulness of robotics in many educational settings in the context of achieving better learning outcomes for primary and secondary school students (ISCED1–ISCED3). For example, Kim, Kim, Yuan, Hill, Doshi and Thai [35] pointed out the positive impact of teaching with robotics in improving critical thinking and problem-solving skills. Other studies [36–39] applying educational robotics have also emphasized the improvement in reasoning and skills related to physics and mathematics, higher levels of student engagement in the learning process, and the improved teamwork and interpersonal skills of students. For example, a study by González-García, Rodríguez-Arce, Loreto-Gómez and Montaña-Serrano [40] suggested that robotics can provide a

successful environment for knowledge application (i.e., knowledge reinforcement) and improved social interactions [41].

By integrating these innovative STEM learning tools into the classroom, whether by teachers or by the students themselves, we can make sure that STEM education delivered in primary and secondary schools is more engaging, interactive, and fun for students. These tools complement traditional teaching methods and allow students to better understand complex concepts while developing the basic skills they need to fully participate in modern society.

2.3. Implementation of STEM Education Projects in Slovak Primary Schools

As an example of the successful implementation of non-formal education aimed at promoting STEM in Slovak primary and secondary schools, the Greenpower Slovakia project can be mentioned. The Greenpower project was established in 1999 in the UK as a response to the decline in young people's interest in STEM and the resulting negative implications for the sustainability of industrial development. The aim of this project is to introduce the world of technology to pupils already in primary schools and to awaken their interest in studying based on their own positive experience. In the project, a team of pupils/students is challenged to design and build their own electric formula and race it on well-known racing circuits. Greenpower has three competition categories, divided according to the age of the participants and the technical difficulty: Formula Goblin (primary and secondary school pupils aged 9 to 11), Formula F 24 (primary and secondary school pupils aged 12 to 16), and Formula F 24+ (secondary school and university students aged 17 to 25). In the current school year 2023/2024, the third year of the Greenpower Slovakia project is taking place, and the experience so far has shown that it can be very beneficial for our schools and their teachers in their transformation into schools that prepare young people for the 21st century. The added value of the project is the fact that it also has the potential to involve the faculties of education involved in the undergraduate training of future teachers of regional education in this transformation [42].

The Ministry of Education, Science, Research and Sport of the Slovak Republic (hereinafter referred to as the Ministry of Education) has been supporting the implementation of the STEM approach to teaching and learning at the primary and secondary school level for a long time through various national projects and competitions. As an example, a national project has been implemented in cooperation with Siemens called STE(A)M. The project promotes innovative and interdisciplinary approaches to teaching Slovak pupils through a curriculum focused on science, technology, engineering, art, and mathematics. Such teaching is unique, according to the Slovak Ministry of Education, in that it seeks to foster the creativity, exploration, and curiosity of pupils, and digital skills as well as to reduce regional disparities and to encourage the interest of Slovak pupils in technical fields. The STE(A)M project currently has 50 primary, secondary, and vocational schools enrolled in the first year (2024) of its implementation, and the number should reach at least 200 by the next year. The number of certified teaching staff will be the same, so each school will have at least one certified staff member.

Another successful step of the Ministry of Education of the Slovak Republic, in cooperation with the National Institute of Certified Measurement Education and the FLL Slovakia civic association, is the effort to successfully introduce the innovative FIRST LEGO League programs to schools across Slovakia with the vision of increasing interest in technical STEM subjects. FIRST LEGO League introduces science, technology, engineering, and mathematics (STEM) to children and young people aged 4–16 through fun and exciting hands-on learning. Through experiential learning, it challenges all participating pupils/students to think like scientists and engineers. Pupils/students learn to build and program their own robot and then carry out various missions with it in a robot competition. Participants in this international, robotics-oriented program that helps today's youth and teachers build a better future will gain real-world problem-solving experience. Through hands-on learning

in STEM and robotics, FIRST LEGO League's three different age categories inspire youth to experiment and develop their critical thinking, programming, and design skills.

3. Mechatronics Kit in Education of Future Primary Education Teachers

The implementation of robotics and various mechanical kits such as the mechatronics kit in education is a rapidly growing area and is prioritized within the STEM and STEAM movements [43]. Several studies have indicated that working with robots and mechanical kits enhances the students' motivation, engagement, and attitude toward learning as well as their skills in design, construction, and programming. The use of robots and the mechatronics kit can foster creative thinking and improve problem-solving skills [44]. Scaradozzi, Sorbi, Pedale, Valzano and Vergine [45] argue that working with robotic and mechatronic kits is enjoyable for primary school children, making them an excellent tool for introducing ICT at this level. The "4D Frame Mechatronics Kit" was developed, according to Fenyvesi, Park, Choi, Song and Ahn [46], up to now more than 15 years in South Korea by Ho-Gul Park, a Korean engineer and model maker and it is also an educational tool for inquiry-based, playful learning and to experience-oriented pedagogical approaches or to phenomenon-based learning, which is suitable for education at the primary level.

In primary school, students have the opportunity to engage in practical activities and develop specific competencies such as curiosity, imagination, clear communication of experiences, participation in conversations through questions and narratives, observation, and critical thinking. Research studies including Valzano, Vergine, Cesaretti, Screpanti and Scaradozzi (2021) [47] have demonstrated that robots and mechatronic-oriented kits can help students develop problem-solving abilities and learn computer programming, mathematics, and science.

The educational approach outlined in this paper is centered around nurturing logic and creativity in today's generation of primary education students, who are at the outset of their educational journey. Learning to program, develop, and build robots and mechatronic kits offers primary school pupils an opportunity to cultivate linguistic and logical skills, with an emphasis on pedagogical rather than technological concerns.

According to Leoste, Lavicza, Fenyvesi, Tuul and Öun [48], the mechatronics kit can be regarded as a digital educational toy, STEAM kit, and device supporting STEAM teaching and learning approaches. Participants in the conducted research were briefed and introduced to the type of kit during the "Technical Education in Primary Education" course, a didactics program that focuses on suitable methodological approaches for teaching "Technical Education" in primary school.

The use of the "4D Frame Mechatronics Kit" guides students step by step through inquiry-based education, enabling them to explore the functionalities of the kit's parts using a discovery method. This approach is pivotal for the practical training of future primary education teachers, as they will similarly introduce their students to the set during teaching lessons.

Engaging with the "4D Frame Mechatronics Kit" supports the development of various competencies among future primary education teachers. On the one hand, it enhances psycho-motor skills including manipulation, coordination, and automatization [49]. On the other hand, it fosters digital competencies as students use electronic motors in their constructions, controlled via computer. The preparation of constructions using this kit also involves calculative activities, contributing to the development of mathematical competence.

Critical thinking is nurtured during the design and construction of a product, where students participate in discussions and arguments about why and how they should proceed with the design and use of individual parts of the kit. In mathematics, they apply their knowledge of geometry in the context of polygons and solids. They also draw on scientific knowledge regarding mechanical and electrical phenomena in nature at an elementary level.

4. Conducted Research

In the following section of this paper, we explain the research carried out with pre-service primary education teachers at the Faculty of Education, Comenius University, Bratislava. The conducted research followed the principles of the qualitative methodology of a phenomenological research nature due to our aspiration to understand subjective acts and meanings addressed to specific phenomena by the subjects of research. Qualitative research, according to Severini and Kostrub [50], involves investigating actions and issues within their natural environment to gain a comprehensive picture of selected phenomena based on the data and the specific relationships between the researcher and the research participants. By applying the principles of the phenomenological type of qualitative research, we aimed to identify specific phenomena within the observed acts and obtain testimonies about specific phenomena so the studied reality could be interpreted.

4.1. Problematization and Goal of Research

We consider it important for students of teaching (future primary education teachers) to learn about teaching and learning, educational activities, and didactics via practical experience. Moreover, it is important to gain the perspective of learners and teachers respectfully, in order to understand relations between both roles. Specifically, in the context of the research described, through reflecting on experience, subjects of research should be able to gain insight into the needs of the learners and the process of designing and implementing teaching scenarios in their future teaching practices.

The presented research focused on identifying the learning and problem-solving strategies of students of teaching within STEAM (Science, Technology, Engineering, Arts, and Mathematics) activities, specifically designed for primary educational settings and getting to know their interpretations on the didactic aspects of the activities.

4.2. Research Questions (RQ)

RQ1. *What learning strategies do future teachers of primary education apply when addressing STEAM problems, and how do they reflect on their approaches?*

RQ2. *What is their didactic aspect on the activities based on their experience?*

4.3. Organization of Research and Applied Methods

The data were collected during the academic year 2022/2023 and included the participation of 31 full-time and 44 part-time students, making up a research sample of 75 students, who are future primary education teachers associated with the mentioned faculty. Part-time students underwent the present form of teaching some Friday afternoons and some Saturdays. The system of work with full-time and part-time students was similar. The qualitative phenomenological research was conducted in the context of the compulsory course “Technical Education in Primary Education” of the study program “Teacher Training for Primary Education” at the mentioned faculty, a curriculum segment guiding students in the principles of the didactics of Technical Education. Participants collaborated in 11 groups, consisting of four to seven members. Initially, they were directed to assemble a structure or device using the 4D Frame Mechatronics Kit based on the provided instructions. Within this first stage in the frame of activity 1, students were asked to analyze the provided instructions and construct the device using the instructions within a team. Students were also asked to report their analysis and reflections in written protocols, focusing on a reflection of the given instructions, (teamwork) process and their opinion on the activity itself from a didactic aspect. These assembled structures or devices were to be dynamic, operational, energized via a motor powered by a laptop, and regulated through a smartphone or laptop interface.

Subsequently, in the second phase, participants were assigned to a challenge of conceptualizing, strategizing, and crafting a functional apparatus—a prototype of a machine. This means that in the second stage in the frame of activity 2, students were to create a

new electronic device with accompanying documentation—instructions. This task also required naming the invention, detailing its utility, and creating a comprehensive guide for its assembly, employing photographic, textual, or video-based instructions. These projects were subsequently showcased to the entire class, encompassing student reflection of the (teamwork) process and their didactic aspect.

To address these inquiries, further methods of research were used:

Indirect, intentional observation was realized via a camera recording of activities 1 and 2 with the aim to fully observe the ways of how students handled the task and identify their learning, problem-solving strategies, and reflection. Indirect observation served as means for repeated analysis of the observed reality.

Open coding was used as a method of analyzing observed phenomena within the activities and within the report protocols. It served for initial analysis, involving the exploration of the text (transcript) of the research subjects' actions, statements, and the creation of codes and categories [51]. The process of the open coding of data was carried out in line with an inductive (conceptual) approach, involving the analytical study of the transcript. This approach applied repeated, nonlinear ("zig-zag") movement within the research material, meaning from case to case (and back) up to the conceptual understanding of the phenomenon/phenomena. Through this process (systematic comparison) in the coding phase, the principle of theoretical (pre)reflection on the obtained data was pursued.

The strategy of applying the constant comparative method (CCM) was employed for the purpose of systematizing the research data, categories, and monitoring the category saturation (Table 1) with the aim of generating a theory about the studied phenomena [52,53]. CCM was applied across the research in the data analysis process, influencing the acquisition of new, more precise data during repeated returns to the field (e.g., within focused interviews). This involved continuous interactions among the researchers, subjects, and data, utilizing repetitive processes, for example:

Refinement of future interactions between the researcher, research subjects, and data as well as theory generation;

The process of open coding (utilizing a "zig-zag" movement in research material) from one statement to another within individual protocols;

Exploration of common relationships between groups of subjects and protocols (identifying strong codes based on the context of their occurrence and repeatability);

Distribution of codes into categories based on following a common generalizing theme within cases;

Monitoring the saturation of categories (analyzing them into smaller units, codes);

Repeated returns to the field (focused interviews), refining, and supplementing categories and emerging concepts;

Generation of research theory.

Focused interviews as a method of enriching the emerging theory were employed to affirm the understanding of the research subjects' interpretations and to create concepts based on the researchers' identification of a specific set of subjective experiences, hypothetically significant elements [54]. The focused interview (Table 2) followed a pre-prepared basic framework of questions derived from the previous analyses of observations and report protocols. This allowed for a more precise formulation of the basic categories and concepts during the emergence phase, approaching the perspectives of subjects, revealing meaningful contexts, and reformulating or formulating new concepts. The selected subjects who participated in the focused interviews were those whose statements from the observed actions and report protocols were identified as research-relevant and related to the subject and research questions.

Table 1. Overview of the saturation of categories related to research questions no. 1: What learning strategies do future teachers of primary education apply when addressing STEAM problems, and how do they reflect on their approaches? and no. 2: What is their didactic aspect on the activities based on their experience? (preview).

Main Categories Related to Research Question No. 1	Concepts	Saturation of Category
Student strategies Creativity and effective teamwork Equipment design skills Team problem solving skills Constructive discussions	Research of activities (material and its parts, instructions, inspirations on the Internet); Use of previous experience with a similar task (instructions first, then own solution to the problem, knowledge of material properties); Division of tasks and mutual cooperation based on communication: production of proposals, procedures, reflection and revision, appreciation and constructive criticism of ideas, proposals); Finding solutions (how to deal with problems—instructions, material).	75
Didactic interpretations—conditions that the teacher should ensure	Clear instructions; Hardy material; Group work; Sufficient time; Enable or relate to previous experience; Adequate challenge and related tasks (real product—usable in life, own creation of instructions—structure).	75
Potentials for optimizing learning conditions and processes via applying such activities	Entertainment; Active learning; Integration of subjects and learning areas; Development of psychomotorics; Manipulation of objects; Motivation (real product, collaboration, exploration, problem solving, appreciation, sense of accomplishment, authorship); Awareness of learning strategies and procedures (creating own instructions, reflection protocols).	75

Table 2. Monitoring the understanding of interpretations and meanings and contexts in a focused interview (sample).

Selected Research Significant Statements of Subjects or Their Sequences	Selected Questions of the Moderator in the Focused Interview Routing the Convergence of the Subject’s Point of View and Meaningful Contexts
<p>“...We cannot fully imagine how students in the first grade of elementary school would manage to build such a structure. . . ; ...In the second lesson, we managed to complete activity 1. It was much easier than in the first lesson, as we already knew part of the procedure and we were also better played as a team. . .”</p> <p>“...The advantage was that the form of group work was chosen in this activity, while we helped and complemented each other. . .”</p> <p>“... each of us got involved, tried to contribute our ideas and help others in the group to make this carousel.</p>	<p>“...Could it be understood that you see a connection between the task in question and the teaching/learning conditions. . .?”</p> <p>“...What does that mean to you?..”</p>

4.4. Phases of Research Implementation over Time

The subjects’ task solving within activities 1 and 2 and statements about their experience (intentional observation, open coding, focused interviews, CCM—and data pre-analysis) for 2022/2023 were examined.

We also constructed a theoretical framework containing the results (essence) of the investigation (conceptualization and theorization of the problem—techniques of generating significance) for 2023/2024.

4.5. Procedure of Activities

Furthermore, we presented a sample of the record of the qualitative research. Education with the 4D Frame Mechatronics Kit is possible to realize at different levels of education. In Guerrero-Osuna, Nava-Pintor, Olvera-Olvera, Ibarra-Pérez, Carrasco-Navarro and Luque-Vega (2023) [55], referring to engineering education in the bachelor stage of study, showed how it is possible to implement Seymour Papert's constructionism [34] and technology integration in education. Additionally, in our case, the students—future teachers for primary education according to the mentioned study in the following presented activities—actively constructed their knowledge from their experiences and interactions with the environment and set 4D Frame Mechatronics Kit. The work with this kit is a kind of preparation by students for their future work with different modern technical devices in the frame of technical education, which is possible to see in Garcia-Loro et al. [56]

First, stage 1 with the following activity will be presented:

Activity number 1: The students created a device according to a known electronic device design algorithm. Source: author's own elaboration.

Sample number 1 of the record of the qualitative research:

STEAM area: Engineering, Technology, Art, Mathematics.

Target group of students—Future primary education teachers: group number 1 (five students).

Activity objective: Own carousel (4D Frame Mechatronics Kit).

Didactic resources and aids: The students created a device according to a known electronic device design algorithm (manual).

Time and space of activity: 90 min in the classroom.

Research procedure: Via indirect intentional observation, the effectiveness of teamwork, design skills, ability to look up information on the Internet, problem-solving skills, students' ability to evaluate the device design, and the level of constructive discussion among students was observed.

Methodical procedure of the observed activity:

In the initial stage, the teacher distributed building blocks to the student groups. Each group received instructions (provided by the kit manufacturer) for a particular device. The students were tasked with discussing the assigned device. In this case, the group focused on robots. They recorded their ideas, actively providing examples of real-life robots such as those used in manufacturing and sharing their knowledge of robotic toys. Additionally, the group conducted research on the Internet to gather more information about robots.

The interactive phase of activity 1 was based on the following steps:

1. Students divided their work into several stages where they documented their work with photographs, and finally documented the functionality of the device with a short video (Figure 1);
2. Preparation of the engines (Figure 2);
3. Preparation of the structure and connecting the basic construction to the carousel (Figure 3);
4. In the frame of step 4 are the following activities of the students including connecting other parts to the basic structure: constructing the rear section, connecting the rear section to the whole. The students also completed the rotating parts, connecting the cables to the component with the electric battery (Figure 4);
5. The last step for the students in creating the device is connecting it to the computer and to the application (Figure 5).
6. The last step for the students in creating the device is connecting it to the computer and to the application (Figure 6).

Once the device was assembled, the students proceeded to the post-active phase, which was conducted within the classroom. Students were to discuss the challenges encountered during construction based on the provided instructions. They engaged in conversations about the mistakes made and the success of their solutions. To document their reflections, they collectively wrote their feedback in the protocols.



Figure 1. Studying the plan. Preparation of the necessary material. Source: Students' work during the activity, authors' own source.

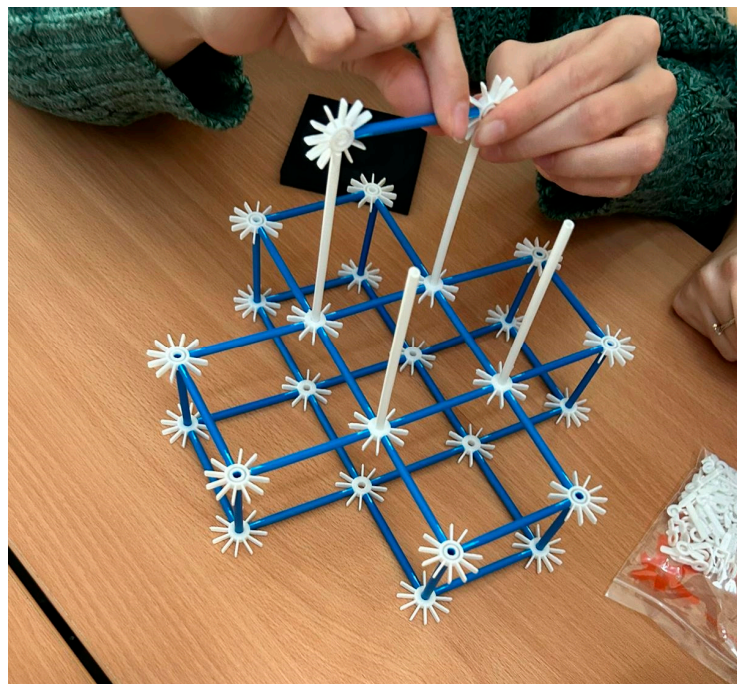


Figure 2. Preparation of the necessary parts for the students' equipment. Source: Students' work during the activity, authors' own source.

The following activity was oriented to the preparation of the device according to the students' proposal.

Activity number 2: Students created a worksheet for children aged 6–11. They created their own design, for which they drafted instructions—documentation. Source: Author's own elaboration.

Sample number 2 of the record of the qualitative research:

STEAM area: Engineering, Technology, Art, Mathematics.

Target group of students—Future primary education teachers: group number 4 (six students).

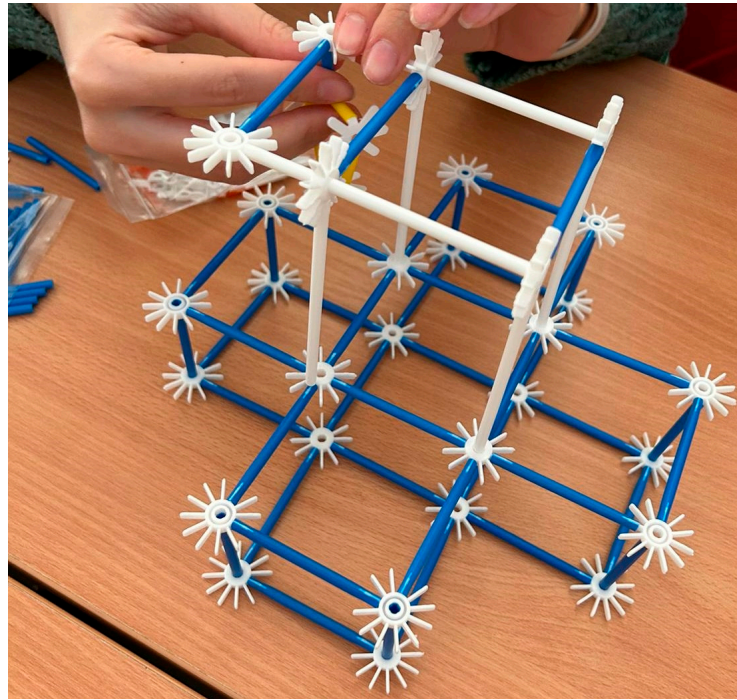


Figure 3. Working with pieces of the device. Source: Students' work during the activity, authors' own source.

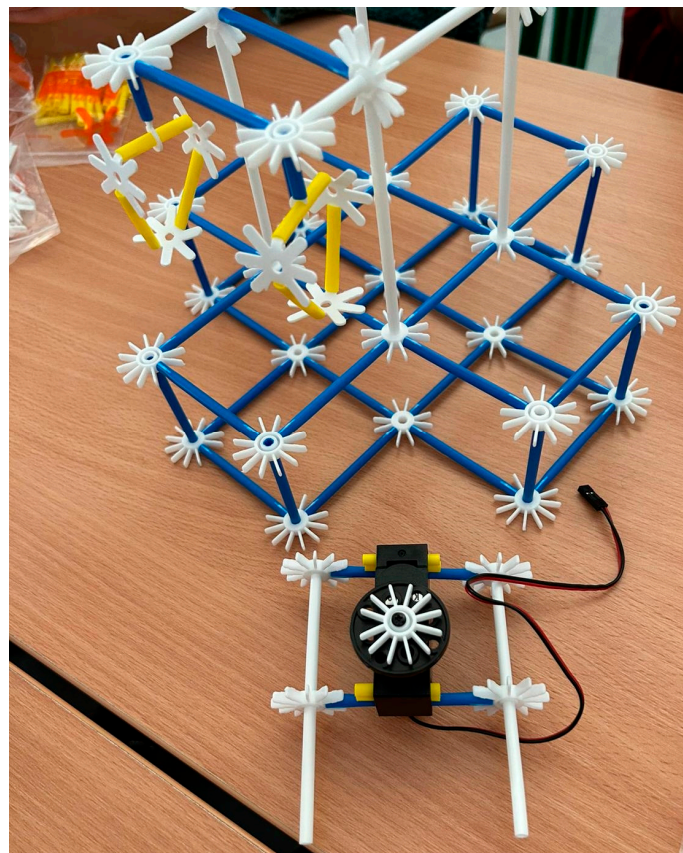


Figure 4. Activity of students in step 4. Source: Students' work during the activity, authors' own source.

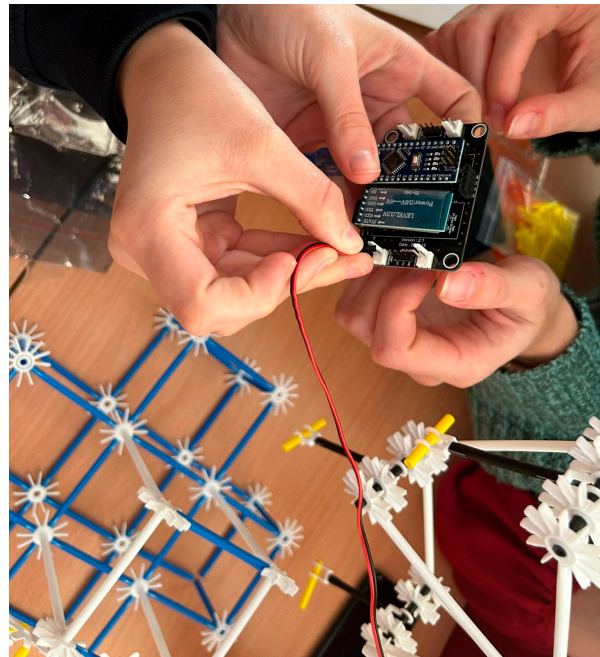


Figure 5. Activity of students in step 5. Source: Students' work during the activity, authors' own source.

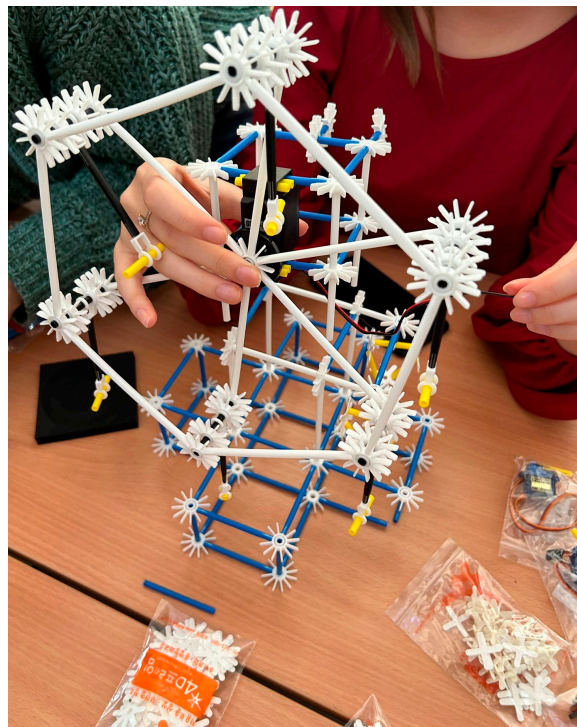


Figure 6. Preparation of the finished device. Source: Students' work during the activity, authors' own source.

Didactic resources and aids: The task of the students was to invent and build a device that could be created from the parts of the F frame Mechatronics kit. They were to discuss the inventions they knew and that were associated with their construction. Next, they had to create a manual (photo-guide or video-guide) for their device. At the end, they discussed how the equipment they created could be used in teaching and learning settings. The students also provided a video where they documented the functionality of their device.

Time and space of activity: 90 min in the classroom.

Research problem: During the observation, we examined the students' creativity, ability to build a device under the specified conditions (given a specific kit), effectiveness of teamwork, design skills, the ability to search for information on the Internet, problem-solving skills, the students' ability to evaluate the device design, level of constructive discussion among the students, the students' manual, and digital skills.

Methodical procedure of the observed activity:

Pre-active phase: In the initial phase, the teacher distributed the building block that the students had been working on in the previous week to their respective groups. The students were initially tasked with discussing inventions that shared similarities with the device that they had assembled the previous week by following the provided instructions. This particular group focused on household devices such as a blender, microwave, juicer, etc. They documented their ideas and attempted to search the Internet for information on when and by whom these devices were invented. Unfortunately, they were unable to find this information as their skills to quickly locate specific information on the Internet were not sufficient.

The interactive phase of activity 2 was based on the following steps:

1. Within this group, the students reached a consensus to build a smoothie mixer. They determined that they had a sufficient number of parts from the kit to execute their plan. Although the teacher asked them to create sketches, the students chose not to do so. Instead, they began constructing the device directly. When certain parts did not function as intended, they addressed the issues through mutual discussion. It can be said that they only had a shared vision of the device, and they constructed it through a trial-and-error approach. Ultimately, they successfully built the device in a manner that left all group members satisfied. During this phase, the group exhibited a highly enthusiastic mood and euphoric emotions (Figure 7);

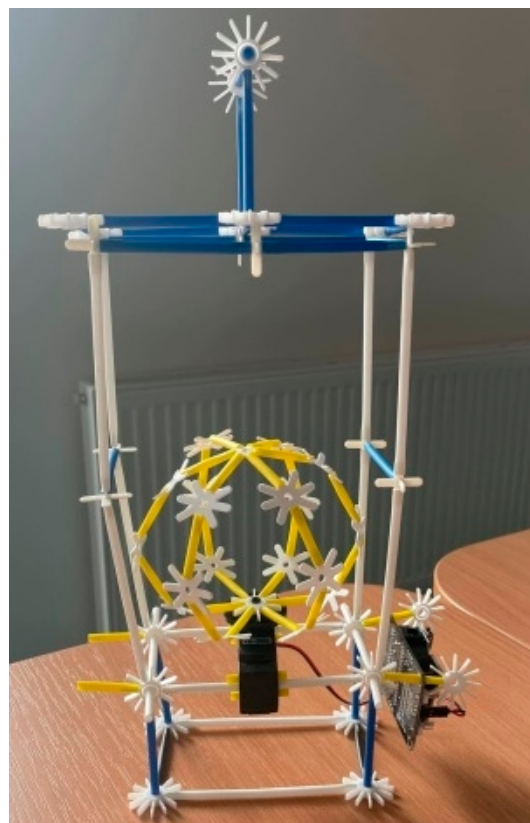


Figure 7. Preparation of the “smoothie mixer” device. Source: Students’ work during the activity, authors’ own source.

2. Subsequently, the students developed a photo tutorial for their design. During this process, it became apparent that they could not recall certain steps. Consequently, they decided to disassemble the device and, in turn, capture photos to include them in the instructions in reverse order. A cognitive boost was observed within this group as they tackled this task. The students asserted that they had devised an algorithm for constructing the whisk of the smoothie blender (Figures 8–10);
3. Once the device was assembled, the students transitioned to the post-active phase, which occurred in the classroom. Students were to discuss the challenges encountered during construction based on the developed instructions. They engaged in conversations about the mistakes made and the success of their solutions. Collectively, they documented their feedback, which we provide below (sample):

“We were inspired by the wheel, which we used as the basis for the construction of the whisk of our smoothie blender. Our blender is functional, we’ve included a video that demonstrates its functionality. We are proud of our work. We enjoyed working together on this activity. We think this activity would be suitable for primary school children. But for some of us it was difficult to find specific information about the history of the mixer”.

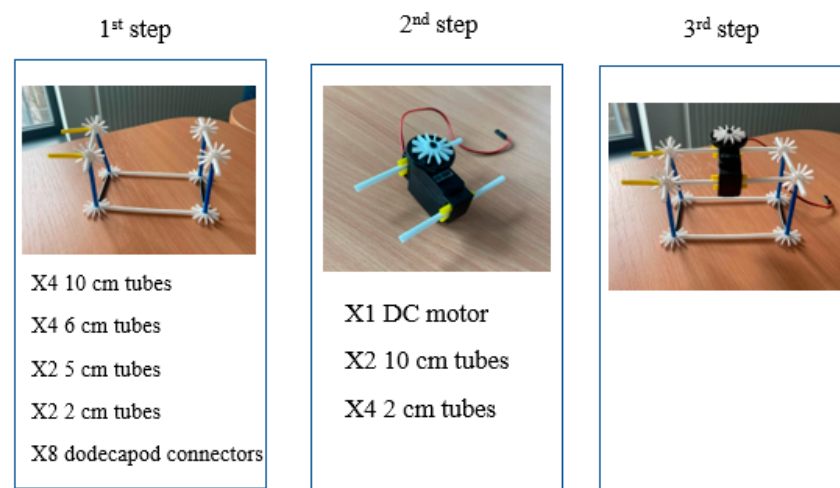


Figure 8. Algorithm provided by the students to prepare their device (steps 1st–3rd). Source: Students’ work during the activity, authors’ own source.

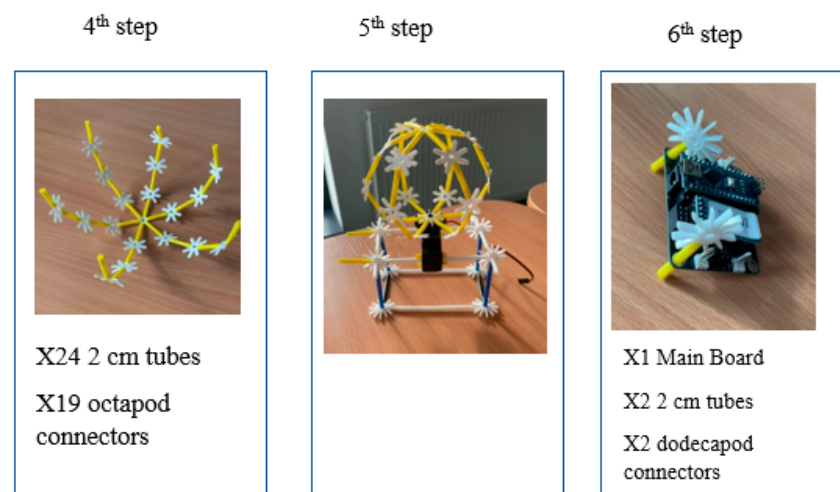


Figure 9. Algorithm provided by the students to prepare their device (steps 4th–6th). Source: Students’ work during the activity, authors’ own source.

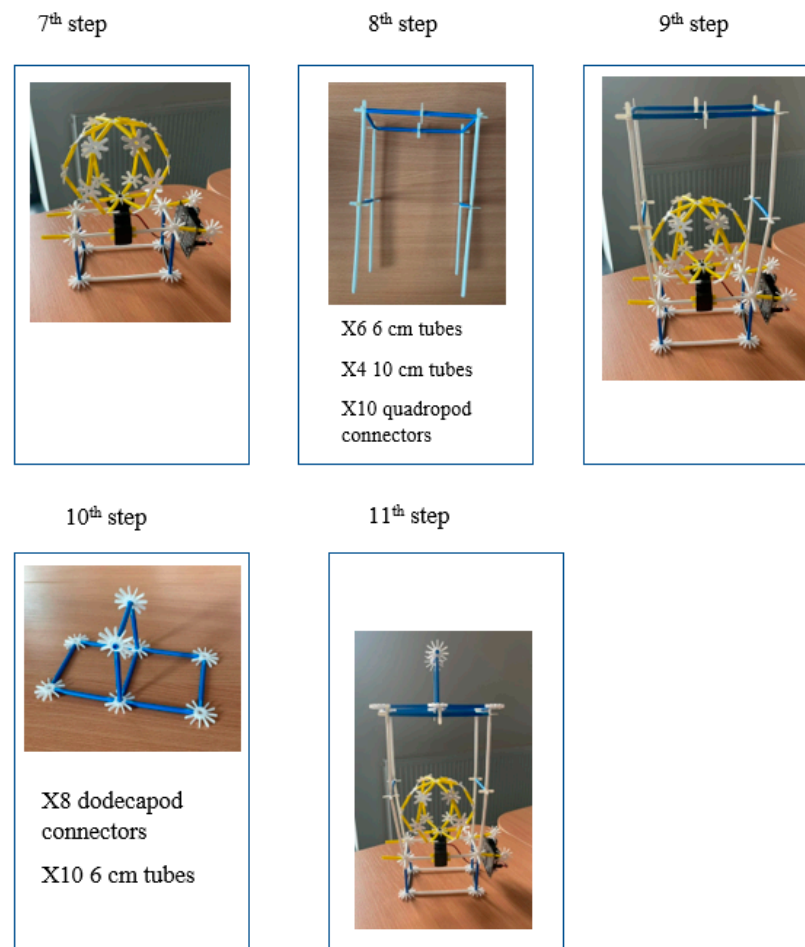


Figure 10. Algorithm provided by the students to prepare the device (steps 7th–11th). Source: Students' work during the activity, authors' own source.

5. Discussion and Conclusions

The results of the qualitative research indicate that the application of the STEAM approach in technical education through the usage of the 4D Frame Mechatronics Kit holds promise for the training of future primary school teachers. When addressing the optimization of future teacher training, it is crucial to recognize that the didactic understanding of the principles of STEAM and the 4D Frame Mechatronics Kit is best achieved through practical learning experiences. The research subjects, who took the role of learners, were able to identify the principles and conditions of teaching and learning, which teachers should ensure, based on their understanding and reflection of their own learning strategies and procedures within the activities.

According to the research subjects, when it comes to teaching and learning conditions, teachers should first consider the difficulty of the problem to be solved in a way that aligns with the learners' zone of proximal development. This means letting learners enter complex tasks by assigning tasks that are too difficult to be solved by an individual and require teamwork. The didactic optimization according to the research subjects means encouraging teams to divide tasks and use their individual strengths. Teachers should further assist learners in understanding the tasks appropriately (e.g., by using efficient learning materials or aids). The subjects or research also highlighted the importance of optimizing the first experience with such a teaching and learning scenario by providing clear, authentic instructions and procedures in an editorially and technically understandable format. The subjects' research found it important to promote interdisciplinary projects where learners could combine knowledge from different subjects. The subjects also recognized the learning

potential in understanding the content of manuals and instructions, enabling the learners (pupils) to practice deductive cognitive operations.

An essential aspect of the STEAM concept, as identified by the research subjects, is the connection of problems to the real world. Didactic optimization, according to the research subjects, means assigning tasks that are relevant to the learners' lives and that interest them, connecting tasks with real problems and situations that motivate learners to learn and engage. The implementation of these strategies can significantly support the development of key skills in learners and contribute to their motivation and success in education. In terms of teaching/learning phases (pre-active, active, and post-active), the research subjects emphasized the importance of teacher planning to ensure adequate time for understanding tasks, evoking the subject matter, engaging in exploratory activities, establishing group collaboration, and reflecting on learning. Didactic optimization, according to the research subjects, lies in creating an environment where respectful communication is key, as is supporting learners to express their opinions in a constructive way and how to respond positively to criticism, ideas, prompts etc., within discussion clubs. Evocation of the problem/theme could be ensured by leading lessons focused on the efficient search for information on the Internet by critically evaluating sources and distinguishing between reliable and unreliable information and using methods such as the 'Socratic Seminar', where the emphasis is on asking questions and seeking answers. During the active phase, the collaboration of the learners was identified by the research subjects as a crucial goal, based on help and complementation among individual members, to achieve a joint product. Understanding these aspects is deemed important for specifying the teaching goals and subsequent didactic interventions by the teacher. Didactic optimization, according to the research subjects, means providing space and time for experimentation and innovation, encouraging learners to find new ways of solving problems and creating products, motivating them for future activities by giving prompts and providing positive feedback and recognition for achievements and progress, and encouraging learners by celebrating their achievements, etc. The future teachers exhibited a positive attitude toward the implemented activities, emphasizing their motivational aspects and the development of STEAM competences. Identified potentialities of this concept, as mentioned by the research subjects, included motivational aspects based on solving real challenges/problems, (re)searching, discovering, and appreciating and supporting the authorship of products. Additionally, they highlighted the play and activating potential, encompassing manipulative activities, construction, collective bargaining and negotiation, active problem-solving, and learning on an individual or group basis.

A summary of the key findings based on indirect observation includes the following:

- Creativity and effective teamwork were apparent in every student group;
- Students in each group demonstrated excellent skills in designing the device;
- Proficient search on the Internet for information about the devices was identified, though some encountered challenges in finding specific details such as the history of a particular device;
- Exceptional team problem-solving skills were showcased;
- High-level constructive discussions among students were observed;
- Groups approached the creation of a new device and the documentation of instructions with creativity;
- Upon successfully creating a new device, they exhibited motivation for similar activities in the future.

These findings also imply that the implemented activities have the potential to improve both the digital and manual skills of the students. The use of the 4D Frame Mechatronics Kit emerged as a valuable didactic tool in STEAM education. In our case (compared with Fenyvesi et al. [46]), the 4D Frame Mechatronics Kit supported primary education students with cooperative problem-solving techniques during their activity connected with generating and testing the device constructions necessary to solve their task. The realized research was devoted to building the pedagogical thinking of future primary education teachers

in the framework of the STEAM concept with the use of the mentioned mechatronics kit, which supported their technical literacy in the subject “Technical Education in Primary Education”. The implementation of the STEAM method (Science, Technology, Engineering, Arts, and Mathematics) through the designed activities within a teacher training course proved to be suitable in providing a didactically rich environment for pedagogical thinking and understanding to be developed.

However, it is essential to recognize the limitations of these findings, which are specific to the student sample and the kit used. Future research is anticipated to involve other groups of students and pupils in primary schools with a focus on didactic design, integrating STEAM and PBL principles (compared with Žilková and Partová [57]).

The limitation of the study was based on the fact that there was limited opportunity to test the use of the 4D Mechatronic Kit with pupils in this study, because under Slovak conditions, there are not enough pieces of the 4D Mechatronic Kit in schools. Thus for the time being, our first goal of the research was to implement the 4D Mechatronic Kit in a study of future primary education teachers. In the future, the goal of the research will be the usage of the 4D Mechatronic Kit in the conditions of primary education with pupils.

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Institutional Review Board Statement: The research of this study was realized according to the Internal regulation Nr. 32/2022 “The internal quality assurance system for higher education of the Comenius University Bratislava”, part Eight „The Code of research ethics and rules of creative activity at Comenius University Bratislava”. The report protocols and focused interviews were anonymous, and we didn’t collect any personal data from students. For this reason, according to Internal regulation Nr. 32/2022 ethics approval is not required for this type of study.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are unavailable due to privacy and ethical restrictions according to Internal regulation Nr. 32/2022.

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