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Project-Based STEM Learning Using Educational Robotics as the Development of Student Problem-Solving Competence

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Abstract: The study focuses on teaching students using educational robots in the field of STEM. The study focused on the influence of project-based teaching on the development of student competences, especially problem-solving competences. The research part of the study describes the conducted pedagogical experiment—teaching pupils the programming of educational robots. The experiment compared two groups of students in the 8th grade of elementary school, using the "Skills for Life" test, which is used to test student competencies. Project-based teaching in STEM fields using educational robotics is very popular among students and, according to research results, has an impact on the development of student competencies. The results of the presented study clearly demonstrate the positive influence of project-based teaching using educational robots on the development of student competencies, especially the important key competencies for solving problems. The key competence to solve problems is applicable both in the areas of STEM education, but also in the everyday life of the student.

Keywords: STEM; educational robotics; project-based learning; key competencies; problem-solving competence

MSC: 97P10

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1. Introduction

Interest in the use of educational robots in schools is growing. In the Czech Republic, after the approval of the new concept of teaching informatics in elementary schools [1], interest in educational robots increased even more. Many schools and teachers incorporate robotics kit programming into their teaching and often struggle with what teaching methods and forms to use. In this study, we focus on the educational domain of STEM using project-based learning to develop students' competencies. Individual science subjects are often demanding and sometimes rejected by students [2]. When science and technology subjects are combined in STEM using learning robots, learning is very interesting and attractive to students [2–4].

1.1. STEM and Educational Robotics

Views on STEM (Science, Technology, Engineering and Mathematics) education differ, but there is an agreement that STEM education is considered both curriculum and pedagogy [5,6]. STEM is effective in student learning [6] and is not only about knowledge of specific topics, but develops students' key skill competencies [6–10]. This is important for our study. STEM and sometimes STEAM (Science, Technology, Engineering, Arts and Mathematics) education is gradually expanding into the curriculum in national education systems [2,6–15]. Mathematics is a key part of STEM fields and is also an important part of computer science. The contribution of educational robotics in the field of STEM to a better understanding of a theoretical area of mathematics such as graph theory is indisputable [16].

Educational robotics is a powerful and flexible educational tool with a great motivational factor [17]. Educational robotics can be classified according to the type of implementation, according to use in teaching or according to other criteria [17,18]; in the presented research, we focus on building robotics kits. The use of construction robotics kits is ideal for STEM education and for incorporating project-based learning. Construction robotic assemblies can be classified by component material, component use, or programming language. In the research presented, we use the Lego Mindstorm EV3 construction robot kit, which is one of the most used construction robot kits in elementary schools. The educational kit includes a control unit with two types of motors, two touch sensors, a color sensor, a gyroscope and an ultrasonic sensor. This device with a large number of plastic construction parts enables the construction of robotic models as desired. The kit is also ideal for students who are starting to build mechanical models, but also for experienced students who can program the assembled robot model in different languages and environments and further expand it with additional sensors and I/O ele-messages [16,19].

1.2. Project-Based Learning and Key Competences

According to its founder W. Kilpatrick, project-based learning is a complex teaching method. A project is an important element of project-based learning and is a clearly designed task that is related to real life [14,15]. Projects are usually carried out in groups, but can also be carried out individually. When solving a project in a group, students acquire new roles and learn to use and develop communication and socio-personal competencies important for teamwork [14–19]. An active and motivated approach of students is important when working on a joint project. Project-based learning has several phases—when solving a project, we encounter a four-phase breakdown and the E-U-R model, which has three phases. The four-phase division of projects includes the following phases: project planning, project implementation, presentation of project outputs and project evaluation. The first phase includes the planning and schedule of the entire project, setting the goals that lead to the project product, and part of the planning is the development of the project schedule. The second phase is the implementation phase, when students divide roles and solve individual tasks that lead to the implementation of the entire project. In the presentation phase, students present the output of the project, which can take various forms, from a written presentation to a report for classmates to a public performance. The last phase is the reflective phase, in which the teacher provides students with reflection and evaluation of their work on the project [20–25]. In the three-phase constructivist E-U-R model, the phases are Evocation, Awareness and Reflection. In the first phase, students work with what they already know and what they need to know; students create a structure, a preconcept. In the next phase, students compare and expand the structure of the preconcept. In the final phase of the project, students reflect on the contribution of their work on the project [24,26–28]. Projects can be further classified according to various criteria such as designer, duration, purpose, etc. [20].

Contemporary society places high demands on the individual; as Zounek states, school should be a place for acquiring the necessary competences [29]. Individual key competencies are described in the Framework Educational Program for Basic Education in the Czech Republic. “Key competences represent a set of knowledge, skills, abilities, attitudes and values important for the personal development and application of each member of society.” [30]. In our research, we focus on problem-solving competence, which we perceive as interdisciplinary competence. Peter Knecht, in his publication, focused on developing competence in teaching, and uses Eckhard Klieme’s definition of student competence to solve problems such as “goal-oriented thinking and acting in situations for which routine procedures are not available” [31]. This competence is part of computational thinking, which can be defined in different ways, according to Jeanette Wing or the International Society for Technology in Education (ISTE) and the Computer Science Teachers Association (CSTA), and these definitions are often expanded and modified [32–35]. We think that students develop this competence when solving tasks using educational robots repeatedly in different stages, from the construction of the robot model, through to the creation of the control program, to the improvement of the final solution with the robot.

2. Materials and Methods

In this article, we describe the proposed research, which is based on the quantitative testing of pupils' competences in the form of a pre-test and post-test, implemented in a pedagogical experiment. To test the pupils, a test called Skills for Life was used, which is designed to test the selected competences of pupils in the second grade of primary school. In the pedagogical experiment, we divided the pupils into experimental and control groups, whose test results were statistically compared. In the experimental group, the project-based teaching of programming took place using a robotic kit.

2.1. Research Objectives and Hypotheses

Therefore, the research objective for this investigation was as follows:

RO: Analyze the effect of project-based learning of programming robotic kits on students' problem-solving competence.

To further the research investigation, we set the following hypotheses to be tested and accepted or rejected as appropriate.

H1: *Pupils taught by project-based learning of robotic kit programming are more successful in solving the problem-solving test than pupils taught the traditional way.*

H2: *Students taught project-based programming with robotics kits achieve a higher development of problem-solving competence.*

The research tool used was a pedagogical experiment, which uses the division of pupils in control and experimental groups to compare the monitored variables in these groups. In the research investigation, pupils were divided into groups, according to the current conditions and possibilities in primary school. In the control group of pupils, normal programming lessons were taught using Lego Mindstorms robotic kits. In the experimental group, project-based programming learning using the same Lego Mindstorms robotic kit was used.

The scheme in Figure 1 of the research survey includes a pre-test and post-test of student competences focused on problem-solving competence, social-personal competence, communicative competence and working with information. Before the teaching of programming, a pre-test was given for each group separately, followed by the teaching of programming with the use of robotic kits in both the experimental group and the control group. After the teaching block, students in individual groups were given a post-test of student competencies. The block of teaching programming included teaching the theoretical basis and practical teaching in solving complex tasks including programming and construction parts. The results of pre-tests and post-tests of student competencies are statistically processed and visualized using graphs in the next part of the work.

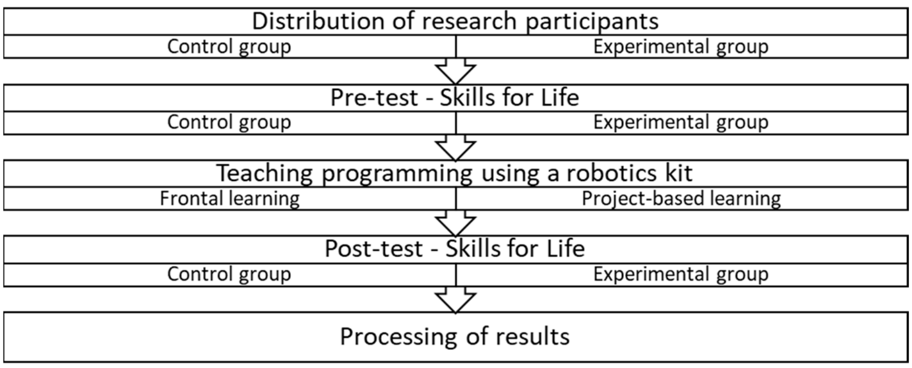

Figure 1. Schematic of the pedagogical experiment with the division of pupils into control and experimental groups and the inclusion of pre-test and post-test.

2.2. Testing Student Competences

To test student competences, we used the adaptive online test, Skills for Life. This is a test from the Scio company, which is dedicated to testing pupils and students in schools. The test is divided into three areas, the first area focuses on working with information, the second on relationships and communication, and the third area focuses on problem solving. This test is used by the Scio company for testing pupils in the second grade of elementary school. Individual areas of the test focus on individual student competencies: problem-solving, communicative and social-personal. Pupils had enough time for the test, 60 min was recommended—most pupils managed to complete the test within 45 min.

Basic information about the Skills for Life test is available on the website [36] of the Scio company, where it is possible to order student testing, and at the same time it is possible to view and try to solve freely available sample tasks from the test. The test contains 3 x 15 different questions, which were selected according to the students' previous answers. The test is adaptive. There are questions with a choice of answers from multiple options or matching answers, questions with multimedia content that contain, for example, videos, and placement questions with interactive images and tables. A sample of the test and individual tasks can be found here [36]. Student testing took place in the ScioDat [37] online testing environment, where each student had their own account, where they were able to take tests and monitor their results. Managing the accounts and assigning individual tests to classes and students were managed by the school administrator in the same environment, who also had an overview of the testing of individual students as well as entire classes.

The Skills for Life test is adaptive—according to the student's answers, it assigned additional questions in order to offer the student the opportunity to achieve the best possible result. The test is divided into three parts that follow each other, the first part is working with information, the second part is relationships and communication, the third part is problem solving.

Immediately after completing the test, the student received the results of their testing in one pdf file. The file contained results divided into individual areas of the test: working with information, relationships and communication and problem solving. In the results, the student also found his/her acquired level in each area. The levels that a student could get in the test were: Beginner, Explorer, Discoverer, Pro and Specialist. In addition to the obtained level, the student received a textual qualitative evaluation of their result, followed by a description of how they could improve to a higher level in the given area of the test. A sample of the test results is in Appendix A. The school testing administrator had an overview of all the test results, and at the same time, had them processed in clear tables, where the results of the students of the given class were compared with the results of other students from elementary schools and multi-year high schools in the same grade who took the same test that they participated in.

2.3. Description of the Research Sample and its Selection

The research set of participants in the research investigation was selected according to the availability and current possibilities in the accessibility of elementary schools with regard to government regulations in the fight against the COVID-19 pandemic. In our work, we focused on second-grade pupils of primary schools. We had set several criteria for selecting the research sample:

- Territorial delimitation;
- Elementary school has a second grade;
- The elementary school has suitable spaces and equipment for teaching with robotic kits;
- Only for second grade students.

Regarding these established school selection criteria and with regard to government measures, an urban primary school was selected for the research part of this work, which was equipped with classrooms with modern digital technology, such as an interactive hall or a television studio. The basic characteristics of the elementary school, which was taken from the annual report, are: "The elementary school is a complete school from the 1st to the 9th grades. It includes a total of 17 main classes. About 350 pupils and about 40 teachers and assistants attend the school. It is taught in one building. Disabled access is provided here." [38]. Inclusive education takes place in the chosen elementary school, where disabled students are part of regular classes. Some pupils use the help of assistants—these students were also included in our research.

The research part, which was implemented according to the proposed scheme in Figure 1, was implemented in the 8th grade, where there was a pair of classes labeled A and B. The students were not divided into classes according to any key, nor according to grades, so there was a random distribution of students in the classrooms. In the year, one class was selected as the control group and the other as the experimental group—the selection of these class-groups was, again, completely random.

First, the pre-test of the Skills for Life test was implemented, followed by programming lessons, and then the post-test of the Skills for Life test was implemented. The teaching was carried out according to the schedule, personnel, material and time possibilities of individual classes (groups) and teachers, who carried out the teaching of programming using a robotic kit.

2.4. Implementation of Teaching Programming Using Robotic Kits in the Experimental and Control Groups

Teaching programming using a robotic kit took place in the final months of the 2020/2021 school year, i.e., during May and June. The teaching took place simultaneously in the experimental and control groups according to the schedule possibilities. Teaching repeatedly took place in teaching blocks of two hours, the so-called two-hour sessions.

The Lego Mindstroms EV3 robotic kit in the basic educational set, which is suitable for teaching in the second grade of primary schools, was used for teaching. The content of the Lego Mindstorms EV3 educational set is more than sufficient for basic robotics projects. The compatible LEGO MINDSTORMS Education EV3 program was used for programming and controlling the robot; this program uses icons (blocks) of individual structural elements of the robot—motors, sensors, display, etc., and program elements—cycles, conditions, custom blocks, etc., with which we could set individual parameters. By connecting the individual icons, the students created a program, which they then uploaded to the robot.

The content of the curriculum for teaching programming was also created with regard to the new RVP ZV in the subject Informatics in the field of Algorithmization and programming, for example, task decomposition, cycles, branching, program verification, error finding, algorithm and program modification.

Individual topics of lessons:

- Work with the control unit;
- Programming the movement of the robot;
- Use of cycles in robot movement;
- Use of branching and sensors in robot movement;
- Solving complex tasks using a robot.

During the lesson, students worked in smaller groups of 2–3 members, which was the optimal number for working with a robotic kit, and the students' preferred group size [39]. The division into working groups took place according to student preferences.

A sample task for the students was driving the robot along the black line. In this task, the students were looking for the ideal location of the light sensor in the robot's construction. Subsequently, the students created a control program that used the values from the light sensor so that it could drive along the black line. The students debugged and modified the program for different black lines such as straight line, zigzag line, crossing lines, dashed line, wide and narrow line. After improving the control program, the students showed and compared their solutions for driving the robot along the black line. This sample task was very enjoyable for the students in both the experimental and control groups. In the experimental group, this task was very popular and motivated the students to solve it quickly. The students in the groups wanted to have the best possible solution, so they focused a lot on the construction of the robot and the appropriate placement of the sensor. Each group of students had a different robot construction. The control program for the robot differed according to its design and the location of the motors, but also in the approach to solving this task. There were more different control program solutions between the groups. At the end, the students presented their projects and solutions. In the control group, there were a number of pupils who were initially similarly enthusiastic, but the pupils' motivation was short-lived, which was demonstrated in the phase of solving the control program of the robot for driving along the black line. The students debugged and improved their control program to a lesser extent, and the solution to this task was not so imaginative. The solutions to the sample task in both the control and experimental groups were primarily functional and the robot always traveled along the black line.

Other example tasks are, for example, the detection of an obstacle with an ultrasonic sensor and its subsequent embrace—a task for using repetition in a program using the example of an autonomous robotic mower—next, the robot rides in the trajectory of geometric shapes.

2.5. Differences in Teaching of Experimental and Control Groups

Pupils in the control and experimental groups used the same Lego Mindstroms EV3 robotic kits, which they programmed in the same LEGO MINDSTORMS Education EV3 desktop application. The distribution of teaching topics and their continuity was the same. The main difference was in the use of project teaching in the experimental group, which was guided by the division of teaching into four phases according to Kratochvílova [26]. These were the following phases: project planning, project implementation, project output presentation and project evaluation, which were discussed in more detail in the previous article. Project teaching was new for some pupils, and therefore, it was sometimes more demanding, especially from a time point of view. According to the teacher's suggestions, the students started with planning the project in a group, where mutual communication in the group was important, followed by the implementation part, where the actual implementation with the robot and its programming were already taking place. Pupils presented their projects in the form of robots and program solutions and assigned tasks to each other. This phase of project teaching was positively evaluated by the pupils. This was followed by the last phase of evaluation, whereby we used mutual student evaluations together with self-evaluations.

In the control groups, programming lessons also took place in smaller working groups of pupils, but the lessons were collectively managed by one teacher, who influenced its course and pupils' activities.

2.6. Statistical Processing of the Obtained Data

We anonymized the obtained data from the Skills for Life test after processing them into tables for individual monitored groups and parts of the test. We further processed them into graphs, which we used to visualize the data from the pre-test. For the basic description of the obtained data, we used descriptive statistics, using basic indicators such as: average, median, mode, maximum and minimum [40]. Furthermore, we used the calculation of the five-number characteristic of the data [41] for subsequent visualization of the distribution of levels through a box plot [41,42].

To verify the hypotheses, we first suggested using the parametric Student's t-test at the significance level $\alpha = 0.05$; however, when verifying the normality of the data using the Shapiro—Wilk normality test [43,44] and the Kolmogorov—Smirnov test [45,46], we found that these are not normally distributed data and the Student's t-test cannot be used for these data. Therefore, we chose the non-parametric two-sample Mann–Whitney test at the significance level $\alpha = 0.05$. After testing the established hypotheses, we checked and verified new testing using a contingency table. For testing, we used the chi-square test of independence for the pivot table. Taking into account the data in the contingency table (theoretical frequencies of data, total frequency n) and in its combined four-field form, we proceeded to use tests for a four-field table for part of the results. For the calculation, we used Fisher's combinatorial test [46–49].

3. Results

In this article, we describe the results obtained from the research investigation in the context of the pedagogical experiment.

3.1. Pre-Test and Post-Test

At the beginning of the pedagogical experiment, the students were divided into two groups, experimental and control. To compare and unify the levels in the two groups under study, they were reduced based on the results of the Skills for Life pre-test. The results and the distribution of the pupils according to the levels achieved in the pre-test can be seen in Figure 2, where the agreement between the two groups is clearly visible. In the figure below, we can see a comparison of the results with the group of other pupils who took this test in the Czech Republic.

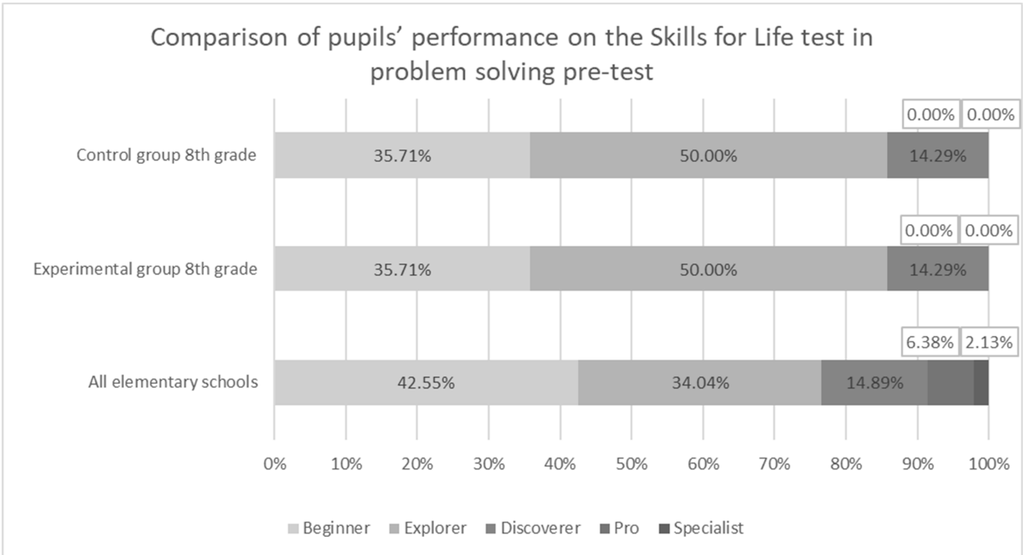

Figure 2. Comparison of pupils' performance on the Skills for Life test in problem solving pre-test.

The pre-test in each group was followed by a programming lesson using the Lego Mindstroms EV3 robotic kit. At the end of the programming instruction, the Skills for Life post-test was implemented in each treatment group. The graph in Figure 3 shows the distribution of levels obtained by the students in the problem-solving area of the test. The graph shows the differences between the control and experimental groups of pupils.

3.2. Testing of Research Hypothesis 1

To test the validity of Hypothesis H1 (students taught by project-based learning of programming with robotic kits are more successful in solving the problem-solving test than students taught in the traditional way.), we formulated the null and alternative hypotheses.

H_{01}: *There is no statistically significant difference between the average level obtained from the post-test of skills in the experimental group and the average level obtained in the control group.*

H_{A1}: *There is a statistically significant difference between the average levels obtained in the two groups.*

To test the hypotheses, we chose a two-sample nonparametric Mann–Whitney test at a significance level of $\alpha = 0.05$.

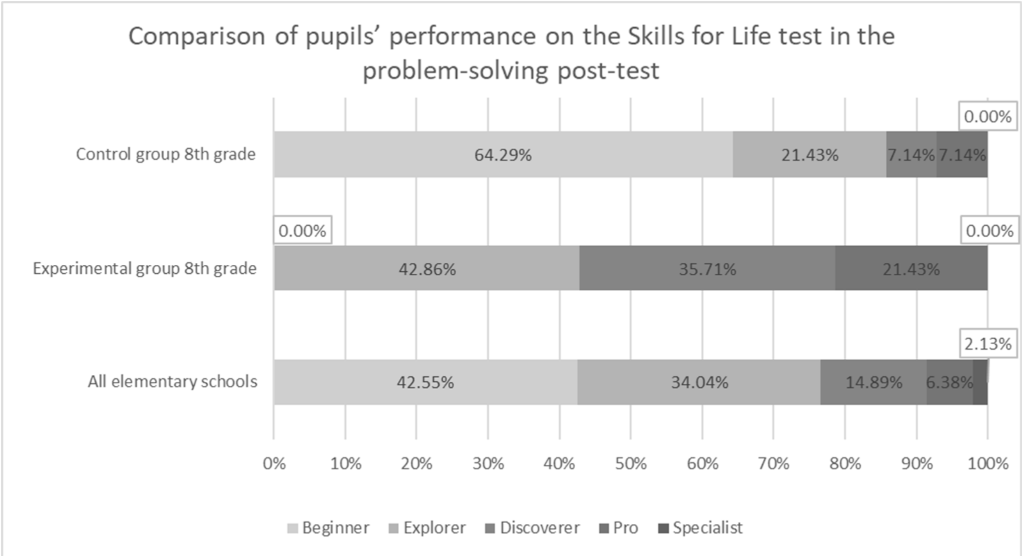

Figure 3. Comparison of pupils' performance on the Skills for Life test in the problem-solving post-test.

For further calculations, we constructed a table showing the levels obtained by students in the Skills for Life test for the problem-solving domain, comparing the experimental and control groups in grade 8. The names of the students were anonymized. From this table, we constructed a table of the pooled ranking of individual students according to their obtained levels for the further calculation of the Mann–Whitney test. Subsequently, from this table, using the formula, we calculated T_E and T_C [46].

$$T_E = 135$$

$$T_C = 271$$

We then performed check calculations and verified the validity of the relationship, where n = 14 and m = 14.

$$T_E + T_C = 1/2\,(n + m)(n + m + 1)$$

The calculation of U_E and U_C followed

$$U_E = nm + 1/2\,n(n + 1) - T_E = 196 + 105 - 135 = 166$$

$$U_C = nm + 1/2\,m(m + 1) - T_C = 196 + 105 - 271 = 30$$

We then performed further check calculations and verified the validity.

$$U_E + U_C = nm$$

$$166 + 30 = 196$$

At the same time, we determined the test criterion according to:

$$U = \min(U_E, U_C) = 30$$

Critical region:

$$U < w_{\alpha;m;n}$$

We found the value of $w_{\alpha;m;n}$ for specific values of $\alpha = 0.05$; m = 14 and n = 14 in the Mann–Whitney test tables [50]. The observed value from the tables was $w_{0.05;14;14} = 55$, which we compared and found.

$$30 < 55$$

Therefore, we rejected hypothesis H_{01} and accepted the alternative hypothesis H_{A1}; it is true that there is a statistically significant difference between the means obtained in the two groups.

To verify the results of the Mann–Whitney test, we proposed to use another test, namely, the chi-square test of independence for a four-field table, which we created based on the rules on merging columns and rows in a contingency table. However, considering the values in the created table, i.e., size n = 28 and the number of theoretical frequencies less than 5, we had to proceed using Fisher's combinatorial test for the four-field table [46].

To test the validity of Hypothesis H_1 (students taught by project-based learning of programming with robotic kits are more successful in solving the problem-solving test than students taught by the traditional method.), we formulated the null and alternative hypotheses using Fisher's combinatorial test.

H_{01}: *There is no statistically significant difference between the average level obtained from the post-test of skills achieved by the experimental group and the average level achieved by the control group.*

H_{A1}: *There is a statistically significant difference between the average levels obtained in the two groups.*

The chosen significance level is $\alpha = 0.05$.

From the table created, we performed probability calculations for each table configuration, which were then summed to obtain the resulting probability. We compared the value of the resulting probability with the selected significance level $\alpha = 0.05$ and decided to accept or reject the hypothesis. For our table, the value of the resulting probability is $p = 0.046$, which is lower than $\alpha = 0.05$, therefore, we rejected hypothesis H_{01} and accepted the alternative hypothesis H_{A1}; it is true that there is a statistically significant difference between the means obtained in the two groups.

The previous calculations confirmed the effect of project-based learning on students' competencies and confirmed the research hypothesis H_1: students taught by project-based learning of robotic building block programming are more successful in solving the problem-solving test than students taught the traditional way.

3.3. Testing of Research Hypothesis 2

To test the validity of hypothesis H2 (students taught project-based programming with robotic kits achieve higher development of problem-solving competence.), we again formulated the null and alternative hypotheses.

H_{02}: *There is no statistically significant difference between the mean level from the skills pre-test and the mean level from the skills post-test achieved by the experimental group.*

H_{A2}: *There is a statistically significant difference between the average levels achieved in the two groups.*

To test the hypotheses, we chose the nonparametric two-sample Mann–Whitney test at the significance level $\alpha = 0.05$. For further calculations, we constructed a table of the pooled ranking of individual students according to their obtained levels; for further calculation of the Mann–Whitney test, we calculated T_{Pr} and T_{Po} [51].

$$T_{Pr} = 143$$

$$T_{Po} = 263$$

We then performed check calculations and verified the validity of the relationship, where n = 14 and m = 14.

$$T_{Pr} + T_{Po} = 1/2\ (n + m)\ (n + m + 1)$$

The U_{Pr} and U_{Po} calculations followed

$$U_{Pr} = nm + 1/2\, n(n + 1) - T_{Pr} = 196 + 105 - 143 = 158$$

$$U_{Po} = nm + 1/2\, m(m + 1) - T_{Po} = 196 + 105 - 263 = 38$$

We then performed further check calculations and verified the validity.

$$U_{Pr} + U_{Po} = nm$$

$$158 + 38 = 196$$

At the same time, we determined the test criterion according to:

$$U = \min(U_{Pr}, U_{Po}) = 38$$

Critical area:

$$U < w_{\alpha;m;n}$$

We found the value of $w_{\alpha;m;n}$ for specific values of $\alpha = 0.05$; m = 14 and n = 14 in the Mann–Whitney test tables [50]. The observed value from the tables was $w_{0.05;14;14} = 55$, which we compared and found.

$$38 < 55$$

Therefore, we rejected hypothesis H_{01} and accepted the alternative hypothesis H_{A1}; it is true that there is a statistically significant difference between the means obtained in the two groups.

To verify the results of the Mann–Whitney test, we proposed to use another test, namely, the chi-square test of independence for a four-field table. However, considering the values in the created table, we had to proceed using Fisher's combinatorial test for the four-field table [46].

To test the validity of hypothesis H2 (students taught project-based programming with robotic kits achieve higher development of problem-solving competence.), we again formulated the null and alternative hypotheses.

H_{02}: *There is no statistically significant difference between the mean level from the skills pre-test and the mean level from the skills post-test achieved by the experimental group.*

H_{A2}: *There is a statistically significant difference between the average levels achieved in the two groups.*

For our table, the value of the resulting probability is $p = 0.046$, which is lower than $\alpha = 0.05$; therefore, we rejected hypothesis H_{02} and accepted the alternative hypothesis H_{A2}, and it is true that there is a statistically significant difference between the means obtained in the two groups.

The result of Fisher's combinatorial test for the four-field table verified the validity of the Mann–Whitney test result for the comparison of pre-test and post-test of the experimental group in grade 8.

4. Discussion

Statistical verification of the research hypothesis H1 through the Mann–Whitney test with validation using Fisher's combinatorial test led to the rejection of hypothesis H_{01} and acceptance of the alternative hypothesis H_{A1}. The result of this verification is that there is a statistically significant difference between the control and experimental groups of students tested in the experiment. This demonstrated the effect of project-based learning on the development of students' competencies in learning programming using robotic building blocks. Through the Skills for Life test that was used to test problem-solving competence, the experimental group showed better results. There is debate about the impact of project-based learning on improving learning. Our research supports the positive impact of project-based learning on the development of student competencies. It also demonstrated the effect of teaching through educational robots on the development of students' skills in the areas of computational thinking and problem solving. These findings may lead to a greater expansion of STEM instruction and the integration of multiple disciplines into collaborative learning with educational robots. Comparing our findings with the results of study [52], our findings are clearly more demonstrable. This is due to the demonstration of the positive influence of project-based learning on the development of pupils' competences. In the study [52], a similar main research scheme of a pedagogical experiment with an experimental and control group and testing of skills and knowledge using pre-tests and post-tests was used. However, the positive effect of project-based learning could not be demonstrated for several described reasons.

Statistical verification of research hypothesis H2 through Mann–Whitney test with validation by Fisher's combinatorial test led to the rejection of hypothesis H_{02} and acceptance of alternative hypothesis H_{A2}. The result of this verification is that there is a statistically significant difference between the pre-test and post-test for the students in the experimental group. This confirmed the findings of the first hypothesis tested. The result shows the benefits of project-based learning on the development of problem-solving competence in primary school students. When comparing our findings and results, we can partially identify with study [53], which was implemented in the project-based learning of science subjects, and with this study [54], which focused more on teaching with educational robots. Specifically, this is a group of pupils in grade 8 of primary school. Pupils in this grade often make decisions about their life path and further studies. Therefore, teaching programming with educational robots in STEM areas can motivate them to become more interested in particular science subjects. From the feedback from the students, this teaching was very positively evaluated. Pupils are keen to build on this teaching with further learning in STEM areas, and are particularly interested in educational robotics, computer science and mathematics. Some opinions and views may coincide with the findings here [55] and in a study focused on robotics [53]. We intend to continue this exploration and present and clarify further findings.

Our study demonstrated the impact of project-based learning on the development of students' problem-solving competencies, thus, clarifying the research aim of our study.

A major contribution of this study is the verification of the positive impact of project-based learning on the development of students' competences. In our study, we were able to test problem-solving competence using a suitable Skills for Life test. We observe this selected key competence as multidisciplinary, so the results of our work are of great help to other researchers in this field. Additionally, especially for the multidisciplinary field of STEM education and for the field of teaching with educational robotics. Linking these disciplines in project-based learning with a focus on developing students' competencies is beneficial.

5. Conclusions

In our study on project-based learning in STEM fields using Lego Mindstorms educational robots, we presented research focused on student competencies with an emphasis on problem-solving competencies. The study included a pedagogical experiment implemented at a primary school. The implementation of the research at the elementary school was quite demanding and will be the basis for further research in this area, which we want to implement. One of the benefits of this study is the use of a suitable tool for testing student competence in solving problems so that it can be used in project-based learning using educational robotics. The life skills test is suitable for pupils in the second grade of primary school. In our middle school, there is no other suitable validated test in the pupils' mother tongue. Another benefit is the verification of the positive effect of project-based learning on the development of student competencies. Here, we propose to conduct a longitudinal study on a similar group of pupils. We managed to meet the goals set for this study and proposed other options and plans.

We intend to further investigate the impact of project-based learning used in STEM or STEAM on student competencies. We want to expand the research with more observation years in primary and secondary school. We also want to focus on the gender imbalance in programming areas. In addition, we want to focus more on students' competencies in areas of computational thinking. We think it is important to focus some of the research on distance or hybrid programming in STEM and STEAM fields in comparison to traditional face-to-face or project-based learning. We are already starting to observe and test some of the proposed areas with primary school pupils.

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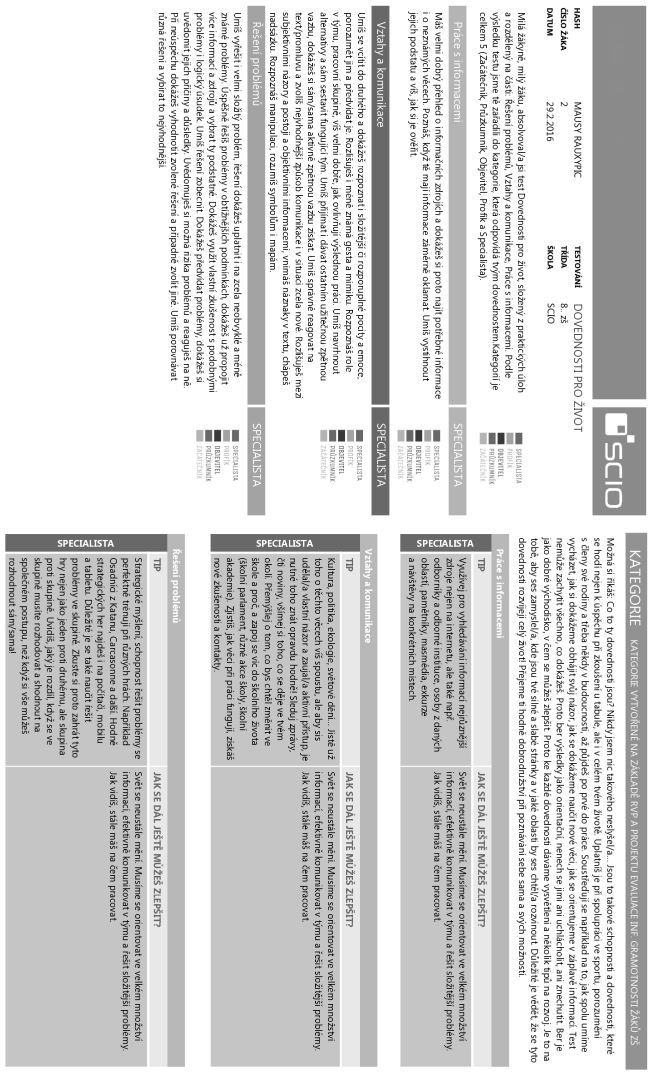
Appendix A



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