INTEGRAÇÃO DE PROJETO ROBÓTICO NO PROCESSO DE APRENDIZAGEM NA ESCOLA**INTEGRATION OF ROBOTICS DESIGN INTO THE LEARNING PROCESS AT SCHOOL****ИНТЕГРАЦИЯ ЭЛЕМЕНТОВ МОДЕЛИРОВАНИЯ РОБОТОТЕХНИКИ В ПРОЦЕСС ШКОЛЬНОГО ОБУЧЕНИЯ**

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RESUMO

A aplicação dos métodos de ensino ao processo de aprendizagem na escola é determinada pelo fato de que cada professor ou desenvolvedor de currículo deseja que seus conceitos de ensino e a formação de princípios educacionais sejam implementados no ambiente educacional da maneira mais eficaz. Tais formas de interação são determinadas pelo fato de que cada professor procura integrar os elementos práticos da área disciplinar no processo educacional, tanto como estruturas metodológicas quanto como as formas complexas formalizadas de didática. O objetivo deste estudo foi identificar esse aspecto do problema pedagógico. A análise dos conhecimentos e habilidades anteriores mostra que o treinamento dos estudantes de classes seniores na área dos métodos de projetos de elementos de robótica tem um potencial significativo para a formação efetiva de competências de disciplinas. Os resultados obtidos no experimento pedagógico como um todo confirmaram a hipótese da pesquisa pedagógica: se aplicarmos o sistema especial de condições, formas e métodos didáticos para desenvolver as habilidades de design dos estudantes de classes seniores para projetar robótica e resolver os problemas e tarefas práticas, com base na construção e estudo da sequência de submodelos, isso aumentará a eficiência do ensino de design de robótica, formação de ideias sobre a natureza de modelo do conhecimento e desenvolvimento de suas habilidades cognitivas e criativas. Os resultados obtidos mostram que o curso de treinamento “Design de robótica como método de resolução de problemas aplicados” para estudantes ajuda a aumentar o nível de habilidades na área de tecnologia robótica dos estudantes de classes seniores no cada critério específico, o que confirma a justificativa pedagógica da introdução de condições didáticas identificadas e teoricamente justificadas para o desenvolvimento de habilidades de design de robótica em estudantes de classes seniores.

Palavras-chave: *educação, escola, modelagem, robótica, tecnologia, profissão.*

ABSTRACT

The application of teaching methods to the learning process at school is defined by the fact that every teacher or curriculum developer strives to ensure that his or her concepts of teaching and formation of the educational principles are implemented in the educational environment most effectively. Such forms of interaction cause the fact that every teacher strives to integrate the practical elements of the subject area into the learning process both as the exact structures and as the formalized complicated forms of didactics. This study aimed the revealing of this aspect of the pedagogical problem. The analysis of the previous knowledge and abilities shows that teaching the methods for the design of the robotics' elements to the senior school students has a significant potential for the active form of the subject competencies. The obtained results of the teaching experiment have generally proved the hypothesis of pedagogical research. If to apply a unique system of didactic conditions, forms and development methods of the senior school students' robotics design skills to robotic design and solution of

tasks and practical assignments based on the construction and research of the sequence of sub-models, then it will contribute to the increase in the effectiveness of the robotic design teaching, the formation of the students' ideas of the model nature of cognition, and the development of their cognitive and creative abilities. The obtained results show that teaching course 'Robotics Design as a Method for Solution of Application Tasks' to students contributes to the increase in the level of the senior school students' robotics design skills by each particular criteria, which proves the pedagogical rationale of introducing the revealed and theoretically substantiated didactic conditions for the development of the senior school students' robotics design skills.

Keywords: *education, school, design, robotics, technology, profession.*

АННОТАЦИЯ

Применение методов обучения к процессу обучения в школе определяется тем фактом, что каждый учитель или разработчик учебной программы стремится к тому, чтобы его или ее концепции преподавания и формирования образовательных принципов были реализованы в образовательной среде наиболее эффективным образом. Такие формы взаимодействия обуславливают тот факт, что каждый преподаватель стремится интегрировать практические элементы предметной области в учебный процесс как в качестве методических структур, так и в виде формализованных сложных форм дидактики. Целью данного исследования было выявление данного аспекта педагогической проблемы. Анализ предыдущих знаний и умений показывает, что обучение методам проектирования элементов робототехники ученикам старших классов имеет значительный потенциал для эффективного формирования предметных компетенций. Полученные результаты педагогического эксперимента в целом подтвердили гипотезу педагогического исследования: если применить специальную систему дидактических условий, форм и методов развития навыков конструирования учащихся старших классов для робототехнического проектирования и решения задач и практических заданий, основываясь на построении и исследовании последовательности подмоделей, это будет способствовать повышению эффективности обучения робототехническому проектированию, формированию у учащихся представлений о модельной природе познания и развитию их когнитивных и творческих способностей. Полученные результаты показывают, что учебный курс «Дизайн робототехники как метод решения прикладных задач» для студентов способствует повышению уровня навыков робототехники старшеклассников по каждому конкретному критерию, что подтверждает педагогическое обоснование внедрения выявленных и теоретически обоснованных дидактических условий развития у студентов старших классов навыков конструирования робототехники.

Ключевые слова: *образование, школа, моделирование, робототехника, технология, профессия.*

1. INTRODUCTION:

To find the indicators of the level of senior school students' robotics design skills, it is going to consider the particular skills that are the components of the competence (Kyei-Blankson, 2014; Ali *et al.*, 2018; Anamova *et al.*, 2019; Wu *et al.*, 2018; Tuna & Ahmetoğlu, 2019; Harada, 2020). By the capability of the senior school students in the robotics design, it means the personal competence combining the knowledge and skills, providing an opportunity to set a task in a particular way:

- to choose the design objects and to find the interconnections between the components of the research process;

- to translate the developed concepts into the language of formulas and signs, to understand the algorithms and mathematical methods for the computation of the characteristics of a robotics model;

- to interpret the obtained data, and to

formulate the particular conclusions (Scherer & Beckmann, 2014).

In the context of the study, the structure of the robotics design competence is presented as an aggregate of three interconnected components: theoretical, practical, and personal (Danesi, 2016; Molchanova *et al.*, 2018; Caballero-Gonzalez *et al.*, 2019).

To define the indicators and the levels of the robotics design skills among the senior school students, the process of a senior school student's personal development was investigated (Miller *et al.*, 1995; Damaševičius *et al.*, 2018; Karpenko *et al.*, 2019). In this period of personal development, the primary type of individual activity is learning. In the senior adolescent age, learning is a specific kind of events, where the subject affected by specific external factors and results of his/her activities: acquires the social experience; knowledge; forms the opinions and the view of the world in general which results in the change of his/her behavior; psychic processes; personal traits (Turuntaev, 2018). The successfulness of

acquiring the learning skills, including the robotics design activities, depends on the level of the student's preparedness, so it was chosen the approach concluded in the transition from one level of differentiation to another as the base for the definition of the indicators of the skills' level – a more complicated approach that differs from the previous one (Nilsson & Pareto, 2010; Chekanova & Gazizov, 2019; Gerosa *et al.*, 2019; Bayanov *et al.*, 2019; Marengo *et al.*, 2019; Sarsar & Çakır, 2020).

To develop the program of active development of the robotics design skills among the senior school students at the study of natural mathematical disciplines, it is necessary to define the main indicators, criteria, and levels of these skills (Fessakis *et al.*, 2018; Stepanov, 2019; Haiguang *et al.*, 2020; Yudin *et al.*, 2020). In the context of our study, the development of a school student as an integral process was analyzed, which may be considered only concerning a particular system because it is the result of the action of its elements (Ko *et al.*, 2012; Rativa, 2018; Habib, 2020). If set the objective to study the development process of a particular component, this process should be presented in the form of a system, having divided it into the components and highlighting the environment (Dmitrieva *et al.*, 2018; Kvesko *et al.*, 2018; Kim & Kim, 2020). There is a gradual transition from one level to another, particularly:

- the sophistication of the structural elements causing the refinement of the structure itself;
- the creation of a perfect arrangement of the relationships between the structural elements;
- simultaneous improvement of the fundamental aspects and the structure itself.

2. LITERATURE REVIEW:

In the learning process at school, at any level, deal with the concepts, statements, and supplements of a theoretical nature (Daskolia *et al.*, 2018; Loureiro *et al.*, 2019). The digestion of knowledge connected with the robotics design is narrowed to the assimilation of a particular system of concepts, statements, and proofs (Yacsar, 2004). But the purpose of learning is concluded not only in the digestion of the theoretical knowledge, but also in the transfer of skills how to apply this knowledge not only in the metabolism of particular proofs, but also in the formation of the ability to reason, prove, and solve practical tasks (Pohjolainen *et al.*, 2018; Ponce *et al.*, 2019).

The analysis of the previous knowledge and abilities shows that teaching the methods for the design of the robotics' elements to the senior school students has a significant potential for active formation of the subject competencies (Barnes *et al.*, 2017). The intentional development of the senior school students' robotics design skills while solving the application tasks requires a mainly organized learning process and its provision with the methods (Ruth, 2018).

According to the results of the conducted research, it should be revealed the directions for the increase in the effectiveness of the education aimed at the development of the senior school students' robotics design skills in the learning process of the natural mathematical disciplines formed in the didactic conditions (Ramalho & Crato, 2012). Based on the theoretical analysis of the role and place of the method for the robotics design in the modern science, it may be stated that particularly this method and its methodology take one of the leading positions in the system of modern science, being a new universal component of the methodology in any science (Pohjolainen *et al.*, 2018). The main didactic principle is to ensure the compliance of the education to the current level of science. So teaching the basics of the method for the robotics design becomes highly relevant because learning the elements of this method implies not just the digestion of particular rules and ways of action, but the development of a specific form of thinking (Campos, 2013).

The entire process of development of natural science is the process of development of the model knowledge about the objects and processes (Sevinc & Lesh, 2018; Daniela and Lytras, 2019). Particularly during the acquisition of the natural disciplines, the models was created and equipped, learn their properties, and foresee the processes in a wide range of possible conditions (Larson, 2013; Stehling *et al.*, 2016; Eteokleous, 2019; Yang, 2019; Muñoz *et al.*, 2020). The particular means of solving the application tasks is the process of 'solving' the model. In this regard, teaching the robotics design to the students, on the one hand, qualitatively changes the particular approach towards the solution of the tasks, and on the other hand – develops the new type of thinking (Scherer & Beckmann, 2014; Guderian, 2017; Fonseca Ferreira *et al.*, 2018; Jäggle *et al.*, 2018; Oudeyer, 2019; Strutynska, 2019).

3. MATERIALS AND METHODS:

To reveal the similarities and differences in the characteristics of the experimental and control groups, the following hypotheses was formulated: the hypothesis of the absence of differences (null hypothesis) and the hypothesis of the significance of differences (alternative hypothesis). To choose the hypothesis (null or alternative), the statistical criteria are applied. Particularly, to measure the data by the order scale, it is reasonable to apply the Pearson's χ^2 (chi-square) criterion of homogeneity. The empirical value of the statistical criterion χ^2_{emp} is calculated (Melis, 2005; Soliman, 2019).

To assess the effectiveness of the traditional (mediated) method and the one was suggested for the development of the knowledge and skills of the robotics design, the indicators of the increment in the initial level of the students' knowledge and expertise was used. At such an approach, the suggested didactic model is considered more productive, more increase in the level of experience, skills, and general intellectual development have been achieved as a result of its application. The correctness of the effectiveness assessment of implemented didactic model significantly depends on the extent of the correctness of the level of skills and knowledge as well as the positive changes among the students of the cognitive sphere. To quantitatively assess the set level, the notion of the information-sense element of the text (ISET), which is based on the structural properties of the educational information, was used. The level every student's knowledge and skills before and after the evaluation of the systematic system for the formation of the robotics design skills was assessed employing coefficient (Equation 1) where S is the general number of the earlier digested ISET, S_i – general number of ISET, which were digested and revealed by the i -student before the beginning of the experiment and after the formation stage.

The average value of the increment in the students' knowledge and skills taught by means of a corresponding methodical system is defined by the following equation (2). Where n is the number of students in the group, K_{1i} and K_{2i} are the similar values of the coefficients of the i -student's skills and knowledge revealed during the final and initial assessment, respectively.

The structure of our methods for effectiveness assessment of the methodical systems for the formation of the robotics design skills (suggested and traditional indirect ones)

consists of the following components:

1) the definition of the initial level of knowledge and skills and the mathematical development of each student of the experimental and control group;

2) the definition of the final level of the abovementioned parameters of each student in the experimental and control groups (after the teaching experiment);

3) the revealing of the absolute increment in the level of knowledge and skills, the fixation of the positive tendencies in the development of the cognitive sphere of each student of the experimental and control groups;

4) the computation of the average values of the initial and final levels of the knowledge and skills;

5) the computation of the average values of the absolute increment in the level of knowledge and skills, the fixation of the positive tendencies in the general and intellectual development;

6) the revealing of the relative increment in the level of knowledge and skills for the students of each group.

7) mathematical processing of the obtained results (comparison of the values of relative increments in the levels of knowledge and skills, as well as positive tendencies in the development of the cognitive sphere among the students of the experimental and control groups).

4. RESULTS AND DISCUSSION:

The changes in the level of the skills and knowledge of students are reflected in Table 1 and Table 2. The coefficients of the level of the robotics design skills were defined according to the equation (1). Where S_i is the number of digested elements of the knowledge for i -student, S is the general number of the knowledge elements containing in the suggested control work. The average coefficient is calculated according to the following equation (3). The average value of the increment in the level of knowledge and skills among the students of each group is computed according to the equation (2). Where K_{1i} is the coefficient of the level of the robotics design skills defined for i -student during the final control, while K_{2i} – during the initial control, respectively (Table 3), the effectiveness assessment of the teaching stage of the experiment may be presented as a diagram in Figure 1.

Let's calculate the scores in the control and

experimental groups. The average rating in the experimental group is $x_1=77$, in control one – $x_2=63$. The value of dispersions: in the experimental group – $\sigma_1^2=14.318$, in the control group – $\sigma_2^2=16.667$. The null hypothesis is formulated at the proposition that the deviation of the average values is accidental, i.e., equation (4). The alternative theory suggests that the teaching methods in the experimental group are more productive, i.e., equation (5).

At such a formulation of the alternative hypothesis, the one-sided control of the null hypothesis through the student's t-test is conducted. The statistical characteristic of the control of the null hypothesis is the normalized deviation of the average values (Equation 6), which is subject to the distribution of the student's probabilities with the number of freedom degrees $k=n_1+n_2-2=206$. The assessment of the average dispersion out of the group ones is equal to

$$\sigma^2 = \frac{\sum_{i=1}^m \sigma_i^2 n_i}{n_1 + n_2 - 2} = 16,138, \text{ then } t = 25.24.$$

The critical value of the one-sided student's t-test at the level of significance $\alpha=0.05$ and $k=206$ is equal to $t_{0.95}(206)=1.97$, which is less than the actual one. So, the null hypothesis is rejected. With the 0.95 probability, one may state that the methods applied in the experimental group are more effective. The coefficient of the effectiveness of the suggested methods, in this case, is defined according to the following equation 7. Where K_e is the coefficient value of the level of the E students' robotics design knowledge and skills according to the results of the final assessment, while C is the coefficient value for the control group. So, the result of the teaching stage of the experiment is the effective coefficient of our robotics design methodical teaching system for students, which is equally as follows $\eta = \frac{0,488}{0,355} = 1,37$.

The fact that the obtained values of coefficient η are equal to $\eta > 1$ shows the relative effectiveness of our systematic teaching system. In the process of the element-by-element analysis conducted by the program, the requirements that should satisfy the digestion of the students' knowledge and skills were defined. These requirements imply the knowledge of the essential attributes of the robotics design notions, and their connection and correlation with the other ones.

To test the effectiveness of the developed

educational model of teaching robotics design in the process of the experimental research, it should be defined the following criteria:

- 1) the changes in the emotional Motivation of the students towards learning robotics design;
- 2) the level of the robotics design skills among the students;
- 3) the effect of the suggested didactic model on the level of knowledge of the adjacent disciplines, such as mathematics, economics, and physics. Let's consider each criterion in detail.

Criterion 1: The change in the emotional Motivation of the students while learning robotics design. Parameter: The students' emotional Motivation. Testing method: Surveying students on their emotional Motivation before and after the experiment. Hypothesis: Teaching our developed educational model to the students will improve the emotional Motivation of the students from the experimental group, which will evidence the growth of their interest and the positive inner Motivation to the robotics design. Mann-Whitney U test. The experiment, according to the first criterion, was performed in three stages:

- 1) the development of the survey form for the definition of the emotional state of the students;
- 2) the research of the absence of the differences between the E and C groups before the experiment;
- 3) the research of the emotional state of the students of the E and C groups after the experiment.

Below is the description of each stage. Stage 1: The development of the survey form to define the students' emotional Motivation. The didactic model of teaching the robotics design method to the senior school students, which contains the motivational component of the learning process was developed, including as follows:

- the theoretical material reflecting the specificity of the application of the robotics design method in the learning process of the students;
- the application tasks by the natural science disciplines;
- the practical creative tasks, including the project works.

As a result, the creation of the positive inner Motivation for learning the robotics design method, and the growth of the interest in solving

the application tasks was expected. In order to investigate the effect of the motivational component on the students during the optional course learning, the survey form to define the students' emotional state based on the analysis of the psychodiagnostic methods for the social-psychological research was developed.

Stage 2: The research of the differences between the E and C groups before the experiment. Therefore, it is necessary to compare the average parameters of the emotional disposition of the students from the E and C groups towards learning the proprietary methodology in the form of a didactic model of the optional course 'Robotics Design as a Method for Solution of Application Tasks'. Let O_1 and O_2 be the survey of the students from the experimental group and from the control group respectively regarding their emotional state before the experiment. By applying the Mann–Whitney U test, let us test the equality $O_1=O_2$ (by the example of the E and C groups of the 11th graders).

The number of students in the E group is 16 ($n_1=16$), while in C – 19 ($n_2=19$). Scores (minimum 3, maximum 12), set by the students of both groups to the experiment are shown in Table 4. According to the data of the table, let us find the average score separately for the E and C groups and denote them as X_{exp} and X_{cont} respectively.

Based on the average indicators $X_{exp}=6.44$ and $X_{cont}=6.47$, it should be supposed that the emotional states in both groups are almost the same. In order to test this supposition, let us suggest two hypotheses:

1. H_0 – differences between X_{exp} and X_{cont} are accidental (or they absent). So, our groups are similar.

2. H_1 – differences between X_{exp} and X_{cont} are reliable and significant. They may be caused by a greater range of the individual indicators' values, and then it is necessary to measure either the control or the experimental group.

The testing order of the suggested hypotheses is as follows:

1. The data of both groups are united into a new table in the order of increasing indicators.

2. Each value of the obtained sequence receives its rank. If there are several similar numbers in the sequence, then the rule of the connected ranks is applied.

3. The sum of ranks ($\sum R$) separately for the experimental ($\sum R_{exp}$) and control groups ($\sum R_{cont}$) was found (Table 5). It was found that

$\sum R_{exp} = 286,5$. The U-test value according to the following equation 8 was calculated. Where n_1 is the number of students in the experimental group; n_2 is the number of students in the control group; n_{Rmax} – the number of students in the group with a larger sum of ranks; R_{max} – maximum rank-sum.

4. Using table 'Critical Values of the U-Test ($p = 0.05$)', the critical value of the U-test for $n_1=16$; $n_2=19$: $U_{crit}=92$ was found.

If $U > U_{crit}$, then H_0 hypothesis is accepted. If $U < U_{crit}$, then H_1 hypothesis is accepted. In our case, $U=146.5$. So, $146.5 > 92$. Therefore, H_0 hypothesis is accepted: the differences between our groups are insignificant.

Stage 3: The research of the emotional Motivation of the students from the E and C groups after the experiment. Based on our supposition, the emotional state of the students from the experimental group should raise, which evidences the growth of their interest in the solution of the application tasks, and the formation of the positive inner motivation to the robotics design.

Let O^*_1 and O^*_2 be the survey of the students from the experimental and the control group respectively regarding their emotional state after the experiment. After the conduction of the teaching experiment, it is necessary to compare the average indicators of the emotional state of the students from the E and C groups in order to test that $O^*_1 \neq O^*_2$ —the scores set by the students of both groups after the experiment are presented in Table 6.

After the experiment, the average score of the students' emotional state in the experimental group grew up to 7.88 scores ($X^*_{exp}=7.88$), while in the control group, it became equal to 6.37 ($X^*_{cont}=6.37$). If to base on the average indicators, then one may suppose that the positive emotional state in the experimental group grew from $X^*_{exp}=6.44$ (before the experiment) to $X^*_{exp}=7.88$ (after the experiment) not accidentally, but thanks to the learning process based on our methods. To test this hypothesis, let us suggest two following hypotheses:

1. H_0 – differences between X^*_{exp} and X^*_{cont} are accidental. The experiment failed.

2. H_1 – differences between X^*_{exp} and X^*_{cont} are reliable, significant. So, the emotional state in the experimental group grew thanks to the work of the teacher based on our methods.

The data of both groups are united into a

new table (see Table 7) in the order of increasing indicators. Each value of the obtained sequence received its rank. The sum of the ranks separately for the E and C groups was found. It was found that $\sum R_{exp}^* = 371$. According to the formula, the $\sum R_{cont}^* = 257$

value $U=69$ was calculated. And so, $U < U_{crit}$ ($69 < 92$), therefore the hypothesis H_1 is accepted: the emotional state in the experimental group has increased thanks to the teacher's work based on our methods. The experiment is successful.

Criterion 2: The level of the students' robotics design skills. Parameter: The level of the E and C group students' robotics design skills. Testing method: The comparison of the final test results in the E and C groups. Hypothesis: The level of the students' robotics design skills (students' academic performance) increases thanks to their teachers' work based on our methods—Statistical Criterion: Student's t-test.

At the end of the academic year, the 11th graders of the E and C groups were offered to perform a final test. The results of the 11th graders' performed test are presented in Table 8. So, according to the results of the final test of the E students compared with the C group, one may make the following conclusions:

- 1) there are no 1 and 2 scores;
- 2) the number of students received from 3 to 5 scores decreased;
- 3) the number of students received from 6 to 10 scores increased.

The results of the E and C group students' final test are reflected in the form of a diagram in Figure 2. It should be combined the obtained results in accordance with the levels of the 11th graders' skills and present them in Table 9. Thus, in the E group compared with the C one:

- 1) the number of students with a low level of skills decreased by 18.6 %;
- 2) the number of students with a moderate level of skills decreased by 9.2 %;
- 3) the number of students with a sufficient level of skills increased by 25.7 %;
- 4) the number of students with a high level of skills increased by 2.1 %;
- 5) the qualitative parameter of the academic performance increased from 17.2 % to 45%.

The dynamics are reflected as a diagram in Figure 3. After the experiment, the average score

of the 11th graders' algebra academic performance increased from $X_{exp}=4.9$ to $X_{exp}^*=6.3$, while the parameter of the C group remained unchanged ($X_{cont}=4.8$; $X_{cont}^*=4.8$). So, one may suppose that the academic performance of the 11th graders in the experimental groups grew not accidentally but thanks to their teachers' work based on our methods. To test this supposition, let us suggest two hypotheses:

1. H_0 – differences between X_{exp}^* and X_{cont}^* are accidental. Experiment failed.

2. H_1 – differences between X_{exp}^* and X_{cont}^* are reliable, significant. The algebra academic performance of the 11th graders in the experimental groups increased thanks to their teachers' work based on our methods.

The hypotheses will be tested through the student's t-test for independent samples. The testing procedure of the suggested hypotheses is as follows:

– σ_{exp} and σ_{cont} was calculated according to the following equation (9);

– the m value separately for the E and C groups was calculated according to the following formula equation (10);

– the value of the student's t-test was found according to the following equation (11);

– the number of degrees of freedom, which depends on the number of students in both samples (Equation 12) was found. In our case: $n_1=n_2=435$. Therefore, $v=435+435-2= 868$.

– using table 'Borders of the Student's T-Test Values', the level of statistical significance. If $t_{emp} \geq t_{tabl}$ was defined, then hypothesis H_1 ; if $t_{emp} < t_{tabl}$ was accepted, then H_0 was accepted.

The obtained data of the 10th graders' groups after the experiment are presented in Table 10. At the level of statistical significance $p=0.001$, $t_{emp} \geq t_{tabl}$ was ssen, i.e. $13.49 > 1.96$. So, hypothesis H_1 was accepted: the experiment is successful. The acceptance of the alternative hypothesis provides the grounds to state that the experimental profession-oriented method of development of the robotics design skills among the 11th graders is more effective than the traditional one. At the end of the academic year, the 11th graders of the E and C group were offered to perform a final test. The results of the 11th graders' performed test are presented in Table 11. So, according to the results of the final test of the E students compared with the C group, one may make the following conclusions:

1) the number of students received from 2 to 5 scores decreased;

2) the number of students received from 6 to 10 scores increased;

3) more than half of the students received from 6 to 7 scores.

The results of the E and C group students' final test are reflected in the form of a diagram in Figure 4. It should be combined with the obtained results per the levels of the 11th graders' skills and present them in Table 12. Thus, in the E group compared with the C one:

1) the number of students with a low level of skills decreased by 10.2%;

2) the number of students with a moderate level of skills decreased by 18.1%;

3) the number of students with a sufficient level of skills increased by 24.9%;

4) the number of students with a high level of skills increased by 3.4%;

5) the qualitative parameter of the academic performance and increased from 17% to 45.3%.

The dynamics are reflected as a diagram in Figure 5. After the experiment, the average score of the E 11th graders' academic performance increased from $X_{exp}=4.7$ to $X_{exp}^*=5.9$, while in the C group, the parameter remained almost unchanged ($X_{cont}=4.9$; $X_{cont}^*=4.8$). So, one may suppose that the 11th graders' academic performance in the experimental groups increased not accidentally but thanks to their teachers' work based on our methods. To test this supposition, let us suggest two hypotheses:

1. H_0 – differences between X_{exp}^* and X_{cont}^* are accidental. Experiment failed.

2. H_1 – differences between X_{exp}^* and X_{cont}^* are reliable, significant. The algebra academic performance of the 11th graders in the experimental groups increased thanks to their teachers' work based on our methods.

The hypotheses will be tested the same as the previous calculations through the student's t-test for independent samples. The obtained data of the students' groups after the experiment are presented in Table 13. At the level of statistical significance $p = 0.001$, $t_{emp} \geq t_{tabl}$ was seen, i.e. $9.48 > 1.96$. So, hypothesis H_1 is accepted: the experiment is successful. The acceptance of the alternative hypothesis provides the grounds to state that the experimental profession-oriented method of development of the robotics design

skills among the students is more effective than the traditional one.

Criterion 3: The effect of the suggested didactic model on the level of knowledge in the adjacent disciplines, particularly: mathematics, economics, and physics. Parameter: The achievement by the E and C group students of the sufficient and high levels of the robotics design skills at the solution of the application tasks. Testing Method:

– the comparison of the final test results in the E and C group by the sufficient and high levels;

– the comparison of the E and C group students taking part in the creative tasks and defense of their own projects.

Hypothesis: teaching our methods to the students contribute to the increase in the sufficient and high levels of their robotics design skills, which shows the development of their interdisciplinary qualities in robotics design. High level of development of the students' interdisciplinary qualities is proved by their capability of solving more complicated application tasks, i.e. the achievement by them of sufficient and high levels of academic performance. The results of the conducted experiment by the second criterion showed as follows:

1) for the 10th graders:

– the number of the E students with the sufficient level of skills increased by 112 people (by 25.7 %) compared with the C ones;

– the number of E students with high level of skills increased by 9 people (by 2.1 %) compared with C.

2) for the 11th graders:

– the number of the E students with a sufficient level of skills increased by 108 people (by 24.9 %) compared with the C ones;

– the number of the E students with high level of skills increased by 15 people (by 3.4%) compared with the C ones.

5. CONCLUSIONS:

Teaching robotics design to students based on proposed didactic model has contributed to the increase in the number of students taking part in the creative tasks and defense of their projects in the E group compared with the C one by 121 people and 123 people respectively for the 10th and 11th graders. Thus, the hypothesis of the experiment by the third criterion has been

confirmed.

Accordingly, the obtained results of the teaching experiment have generally proved the hypothesis of the pedagogical research: if to apply a special system of didactic conditions, forms and development methods of the senior school students' robotics design skills to robotic design and solution of tasks and practical assignments based on the construction and research of the sequence of sub-models, then it will contribute to the increase in the effectiveness of the robotic design teaching, the formation of the students' ideas of the model nature of cognition, and the development of their cognitive and creative abilities.

The obtained results show that teaching course 'Robotics Design as a Method for Solution of Application Tasks' to students contributes to the increase in the level of the senior school students' robotics design skills by each particular criteria. This proves the pedagogical rationale of introducing the revealed and theoretically substantiated didactic conditions for the development of the senior school students' robotics design skills.

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$$K_i = \frac{S_i}{S} \quad (\text{Eq. 1})$$

$$\Delta \bar{K} = \frac{\sum_{i=1}^n (K_{1i} - K_{2i})}{n} \quad (\text{Eq. 2})$$

$$\bar{K} = \frac{\sum_{i=1}^n K_i}{n} \quad (\text{Eq. 3})$$

$$H_0: x_1 = x_2 \quad (\text{Eq. 4})$$

$$H_1: x_1 > x_2 \quad (\text{Eq. 5})$$

$$t = \frac{x_1 - x_2}{\sqrt{\sigma^2 \left(\frac{1}{n_1} + \frac{1}{n_2} \right)}} \quad (\text{Eq. 6})$$

$$\eta = \frac{K_e}{K_k} \quad (\text{Eq. 7})$$

$$U = n_1 \times n_2 + \frac{n_{R_{\max}} \times (n_{R_{\max}} + 1)}{2} - R_{\max} \quad (\text{Eq. 8})$$

$$\sigma^2 = \frac{\sum_{i=1}^n (X_i - X^*)^2}{n - 1} \quad (\text{Eq. 9})$$

$$m = \frac{\sigma}{\sqrt{n}} \quad (\text{Eq. 10})$$

$$t = \frac{X_{\text{exp}}^* - X_{\text{cont}}^*}{\sqrt{m_{\text{exp}}^2 + m_{\text{cont}}^2}} \quad (\text{Eq. 11})$$

$$v = n_1 + n_2 - 2. \quad (\text{Eq. 12})$$

Table 1. Dynamics of Changes in the Level of the Skills and Knowledge of the Students regarding the Robotics Design during the Teaching Experiment

Kind of Assessment	$\bar{K}$		$\Delta \bar{K}$		$\Delta \bar{K} / \bar{K}$	
	E	C	E	C	E	C
Initial	0.372	0.352	0.027	0.001	0.073	0.003
Intermediate	0.440	0.353	0.039	0.001	0.089	0.003
Final	0.488	0.355	0.048	0.002	0.098	0.006

Table 2. Average Value of the Measured Levels of the Knowledge and Skills regarding Robotics Design during the Teaching Experiment

Measured Parameters	Groups	
	E	C
$\bar{K}$	0.345	0.351
$\Delta \bar{K}$	0.143	0.004
$\Delta \bar{K} / \bar{K}$	0.414	0.011

Table 3. Results of the Teaching Stage of the Experiment (based on the Results of the Initial and Final Assessments) by the example of the School Students

Kind of Assessment	Number of Students			
	performed the assessment work		coped with the assessment work	
	E	C	E	C
Initial	103	108	36 (34.5 %)	36 (34.1 %)
Final	102	103	87 (85.7 %)	66 (64.3 %)

Table 4. Emotional Motivation of the 11th Graders before the Experiment

n_1 and n_2	Scores E	Scores C	n_1 and n_2	Scores E	Scores C	n_1 and n_2	Scores E	Scores C
1	6	10	8	5	6	15	5	5
2	9	6	9	5	7	16	8	7
3	7	3	10	3	5	17		7
4	8	4	11	5	6	18		9
5	6	8	12	5	6	19		8
6	6	7	13	7	8			
7	9	6	14	9	5			

Table 5. Ordered Table of the Experimental Data

No.	Group	Emotional state	Rank	No.	Group	Emotional state	Rank	No.	Group	Emotional state	Rank
1	E	3	1.5	13	E	6	15.5	25	C	7	22.5
2	C	3	1.5	14	E	6	15.5	26	E	8	28
3	C	4	3	15	C	6	15.5	27	E	8	28
4	E	5	8	16	C	6	15.5	28	C	8	28
5	E	5	8	17	C	6	15.5	29	C	8	28
6	E	5	8	18	C	6	15.5	30	C	8	28
7	E	5	8	19	C	6	15.5	31	E	9	32.5
8	E	5	8	20	E	7	22.5	32	E	9	32.5
9	C	5	8	21	E	7	22.5	33	C	9	32.5
10	C	5	8	22	C	7	22.5	34	C	9	32.5
11	C	5	8	23	C	7	22.5	35	C	10	35
12	E	6	15.5	24	C	7	22.5				

Table 6. Emotional Motivation of the 11th graders after the Experiment

n ₁ and n ₂	Scores E	Scores C	n ₁ and n ₂	Scores E	Scores C	n ₁ and n ₂	Scores E	Scores C
1	8	10	8	6	5	15	8	6
2	10	7	9	7	6	16	10	6
3	8	4	10	6	6	17		6
4	9	4	11	8	6	18		9
5	6	7	12	7	6	19		9
6	7	6	13	7	7			
7	10	6	14	9	5			

Table 7. Ordered Table of the Data after the Experiment

No.	Group	Emotional state	Rank	No.	Group	Emotional state	Rank	No.	Group	Emotional state	Rank
1	C	4	1.5	13	C	6	10.5	25	E	8	25
2	C	4	1.5	14	E	6	10.5	26	E	8	25
3	C	5	3.5	15	E	6	10.5	27	E	8	25
4	C	5	3.5	16	E	6	10.5	28	E	9	29.5
5	C	6	10.5	17	E	7	20	29	E	9	29.5
6	C	6	10.5	18	E	7	20	30	C	9	29.5
7	C	6	10.5	19	E	7	20	31	C	9	29.5
8	C	6	10.5	20	E	7	20	32	E	10	33.5
9	C	6	10.5	21	C	7	20	33	E	10	33.5
10	C	6	10.5	22	C	7	20	34	E	10	33.5
11	C	6	10.5	23	C	7	20	35	C	10	33.5
12	C	6	10.5	24	E	8	25				

Table 8. Results of the 10th Graders' Final Test after the experiment

Scores	E		C	
	Number of students	Number of students (%)	Number of students	Number of students (%)
1	0	0.0	2	0.5
2	0	0.0	15	3.4
3	20	4.6	84	19.3
4	36	8.3	143	32.9
5	57	13.1	67	15.4
6	126	29.0	49	11.3
7	117	26.9	36	8.3
8	45	10.3	25	5.7
9	21	4.8	10	2.3
10	13	3.0	4	0.9
11	0	0.0	0	0.0
12	0	0.0	0	0.0
Total	435	100	435	100

Table 9. Distribution of the 10th Graders by the Level of Skills after the experiment

Group	Number of students	Levels of the students' skills			
		Low (1 – 3 scores)	Moderate (4 – 6 scores)	Sufficient (7 – 9 scores)	High (10 – 12 scores)
E	435	20	219	183	13
		4.6 %	50.4 %	42.0 %	3.0 %
C	435	101	259	71	4
		23.2 %	59.6 %	16.3 %	0.9 %

Table 10. Data of the 10th Graders after the experiment

Data of E						Data of C					
X _i	Number of students	(X _i -X _{exp}) ²	σ ² _{exp}	σ _{exp}	m _{exp}	X _i	Number of students	(X _i -X _{exp}) ²	σ ² _{exp}	σ _{exp}	m _{exp}
1	–	–	2.38	1.54	0.074	1	2	14.44	2.99	1.73	0.083
2	–	–				2	15	7.84			
3	20	10.89				3	84	3.24			
4	36	5.29				4	143	0.64			
5	57	1.69				5	67	0.04			
6	126	0.09				6	49	1.44			
7	117	0.49				7	36	4.84			
8	45	2.89				8	25	10.24			
9	21	7.29				9	10	17.64			
10	13	13.69				10	4	27.04			
11	–	–	11	–	–						
12	–	–	12	–	–						
t _{emp} ≈13.49											

Table 11. Results of the 10th Graders' Final Test after the experiment

Scores	E		C	
	Number of students	%	Number of students	%
1	0	0.0	3	0.7
2	8	1.8	19	4.4
3	30	6.9	60	13.8
4	34	7.8	148	34.0
5	35	8.1	81	18.6
6	131	30.1	50	11.5
7	130	29.9	37	8.5
8	29	6.7	26	6.0
9	20	4.6	8	1.8
10	18	4.1	3	0.7
11	0	0.0	0	0.0
12	0	0.0	0	0.0
Total	435	100	435	100

Table 12. Distribution of the 11th Graders by the Level of Skills after the experiment

Group	Number of students	Levels of the Students' Skills			
		Low (1 – 3 scores)	Moderate (4 – 6 scores)	Sufficient (7 – 9 scores)	High (10 – 12 scores)
E	435	38	200	179	18
		8.7 %	46.0 %	41.2 %	4.1 %
C	435	82	279	71	3
		18.9 %	64.1 %	16.3 %	0.7 %

Table 13. Data of the 11th Graders after the experiment

Data E						Data C					
X _i	Number of students	(X _i -X _{exp}) ²	σ ² _{exp}	σ _{exp}	m _{exp}	X _i	Number of students	(X _i -X _{exp}) ²	σ ² _{exp}	σ _{exp}	m _{exp}
1	–	–	3.01	1.73	0.083	1	3	14.44	2.82	1.68	0.081
2	8	15.21				2	19	7.84			
3	30	8.41				3	60	3.24			
4	34	3.61				4	148	0.64			
5	35	0.81				5	81	0.04			
6	131	0.01				6	50	1.44			
7	130	2.21				7	37	4.84			
8	29	4.41				8	26	10.24			
9	20	9.61				9	8	17.64			
10	18	16.81				10	3	27.04			
11	–	–	11			–	–				
12	–	–	12			–	–				
t _{emp} ≈9.48

Figure 1. Effectiveness Assessment of the Teaching Stage of the Experiment

Figure 2. Comparative Analysis of the E and C Group 10th Graders' Final Test Results

Figure 3. Comparative Analysis of the Level of the Robotics Design Skills among the 10th graders

Figure 4. Comparative Analysis of the E and C Group Students' Final Test Results

Figure 5. Comparative Analysis of the Level of the Skills among the Students after the Experiment