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Experiential Robotics with Artificial Intelligence and Machine Learning Elements: A Pathway to Programming Proficiency and Industry 4.0 Competencies in Education

This study examines the educational effect of integrating artificial intelligence (AI) into robotics projects based on experiential learning to increase the level of programming competencies and develop the digital skills of future teachers. The implementation of a robotics project with AI elements, such as intelligent navigation and sensory decision-making, was aimed at overcoming the difficulties of students of pedagogical specialties in correlating the theoretical foundations of programming with solving real problems. It is based on Kolb's experiential learning model, which ensured the step-by-step involvement of students: from the development of AI algorithms for controlling a mobile robot and conducting laboratory tests to the analysis of results and their reflection. In addition, students organized group work, prepared technical reports, and presented the results in video presentations. An important aspect of the project was the use of real educational scenarios, which allowed students to better understand the practical value of AI technologies and see their direct application in the modern school environment. The project also stimulated communication, peer learning, and collaborative problem-solving, forming a supportive learning atmosphere. Statistical analysis of the final grades showed a significant improvement in students not only in the field of programming and solving practical problems, but also in the ability to design intelligent solutions, which forms important methodological and digital competencies that are in demand in teaching practice and in the educational environment of Industry 4.0.

Keywords: Artificial intelligence, Experiential learning, Kolb model, Robotics project, Software competencies, Industry 4.0, Digital pedagogical literacy, teaching practice

Introduction

In the era of the Fourth Industrial Revolution (Industry 4.0), the integration of artificial intelligence (AI) and robotics into the educational process is becoming an essential prerequisite for the preparation of competitive graduates. Although coding remains a key skill, current needs stress wider abilities, such as creating and running data systems. Robotics projects help build coding skills and allow students to work on real-world tasks that involve flexible actions and complex controls [1]. This integration forms students' logical and critical thinking, as well as promotes the development of supra-professional competencies that meet the requirements of Industry 4.0, including digital literacy, computational thinking, and the ability to innovate using advanced technologies. At the same time, experiential learning approaches, in particular the Kolb model, provide an effective methodological basis for combining theoretical knowledge with practical activities. By involving students in robotics projects with AI integration, pedagogical educational programs form not only the necessary technological skills for future specialists, but also leadership qualities for working in smart, interconnected and intelligent educational and industrial ecosystems.

In university practice, programming is mainly taught through lectures and laboratory workshops, the main task of which is to master the basic concepts of programming languages [2]. Despite the fact that this approach contributes to the assimilation of theoretical knowledge, it has significant limitations. First, it provides minimal opportunities for students to relate software concepts to real, data-driven applications. Secondly, the lack of practical involvement does not allow students to fully understand the value of programming in the development of intelligent systems and in the context of Industry 4.0. In contrast, experiential learning

through robotics projects with the integration of artificial intelligence opens up innovative ways to overcome these shortcomings. Students gain practical problem-solving skills by building and deploying robotic systems that use navigation, sensors, and adaptive control. This approach lets them use what they've learned in programming to solve real-world problems. By doing this, they not only get better at programming but also build important skills such as critical thinking, problem-solving, and creative thinking, all of which are needed to succeed in Industry 4.0 [3].

Modern research in the field of education increasingly points to the effectiveness of active learning methods to increase students' motivation to learn programming. One of the promising areas is the integration of artificial intelligence and robotics into the educational process [4]. Unlike traditional forms of presentation, robotics projects with AI elements immediately demonstrate the practical importance of programming, linking abstract algorithms with real tasks of control, recognition or adaptive behavior of a robot. This approach ensures interdisciplinary learning: students not only master the syntax and logic of code, but also learn how to apply machine learning, data analysis, and intelligent control methods in pedagogical scenarios. Programming can be seen as a way to tackle hard problems. This can get students more interested, help them build digital skills, and let them learn job skills that are helpful for today's industrial needs.

The use of tools such as collaborative programming environments, resource-based models, robotics simulation microcosms, as well as virtual and augmented reality technologies, forms a research learning style. The integration of AI feedback mechanisms further enhances learning outcomes by developing self-regulation and problem-solving skills that meet the requirements of Industry 4.0 competencies.

The use of robotic systems in teaching programming shows high efficiency in the development of coding skills and the formation of computational thinking among students [5]. In the study [6], pedagogical students created algorithms for low-cost robotic platforms using the Python language to control robot behavior. To assess motivation, the Self-Determination Theory (SDT) was used, which focuses on three key components: autonomy, competence, and social interaction. The results showed that working with robotics and AI tools increased students' sense of independence in developing solutions, increased confidence in their programming skills, and increased the level of cooperation within teams. In another study [7], an online laboratory using Lego Mindstorms was proposed, where students performed five tasks to control the movement of a robot. More than 80 % of the participants noted that the robotics modules greatly facilitated the learning of programming principles. Modern approaches are developing through the integration of AI and gamification elements [8], which allows students to develop key Industry 4.0 competencies, including creativity, critical thinking, and adaptive learning.

Another promising method of developing programming skills and building Industry 4.0 competencies is experience-based learning. Kolb's experiential learning model is a framework often used in this approach. Research suggests it works well when teaching educators with different learning preferences [9]. For instance, one study [10] used this model to structure mechanics of materials lab sessions. The researchers found that practical exercises really helped students grasp the theory. In [11], the application of the Kolb model in a mobile cloud learning environment contributed to the development of social collaboration, improving teamwork and problem solving skills. In the context of integrating robotics and artificial intelligence, the Kolb cycle provides students with a systematic way to engage in real-world tasks such as programming autonomous robots, testing algorithms, and analyzing AI solutions. This pilot process not only increases the level of technical training, but also develops the socio-technical competencies required in the context of Industry 4.0. Complementary experiential learning methods such as pair programming [12], pedagogical design assignments, game learning with elements of AI realism, and quasi-experimental educational designs also demonstrate the potential of active practice-oriented strategies in bridging the gap between programming theory and its practical, augmented AI, application.

This paper puts forward a way of teaching that mixes a robotics project with Kolb's learning ideas in a programming class for education students. As part of this approach, students developed AI-based software codes and algorithms for controlling autonomous robots and their sensor systems. Instead of focusing solely on microcontrollers, attention was paid to the role of robotics and artificial intelligence as key technologies in Industry 4.0, used not only in automation and robotics, but also in modern intelligent systems, from smart manufacturing to adaptive educational technologies. The implementation of this approach allowed students to test their programming skills in practical conditions, develop problem-solving abilities and gain experience working with AI-based decision-making systems, thereby bridging the gap between theoretical knowledge and their real-world applications.

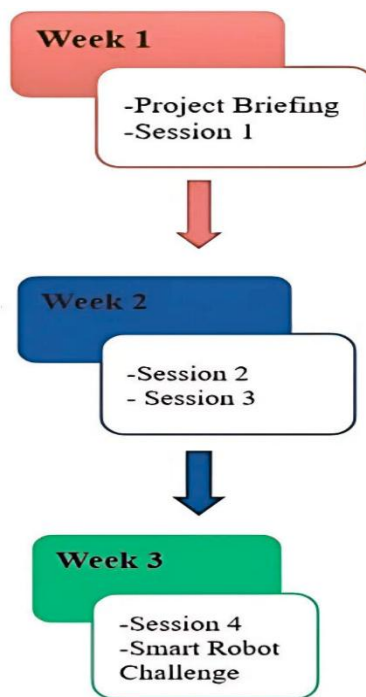
This research provides two key insights. First, it uses Kolb's experiential learning model in a robotics programming project to give structure to learning. Second, it checks if this method actually helps students get better at programming and build skills needed for Industry 4.0. The suggested system aids students in linking what they learn in class to real-world practice by using tasks that involve robot movement and decisions. In this project, students improved their coding skills and looked at outside elements that affect how well software is developed, like how sensors work, using data models, and changing solutions when things change.

The methodological logic of this study is based on the need to engage students in experimentation, analysis of results, and reflective interpretation. Such a learning cycle supports a gradual deepening of understanding and contributes to the formation of sustainable professional skills. In this regard, the proposed robotics project is considered not only as a programming task, but also as a practice-oriented learning environment that prepares future teachers for the challenges of digital transformation, intelligent automation, and Industry 4.0.

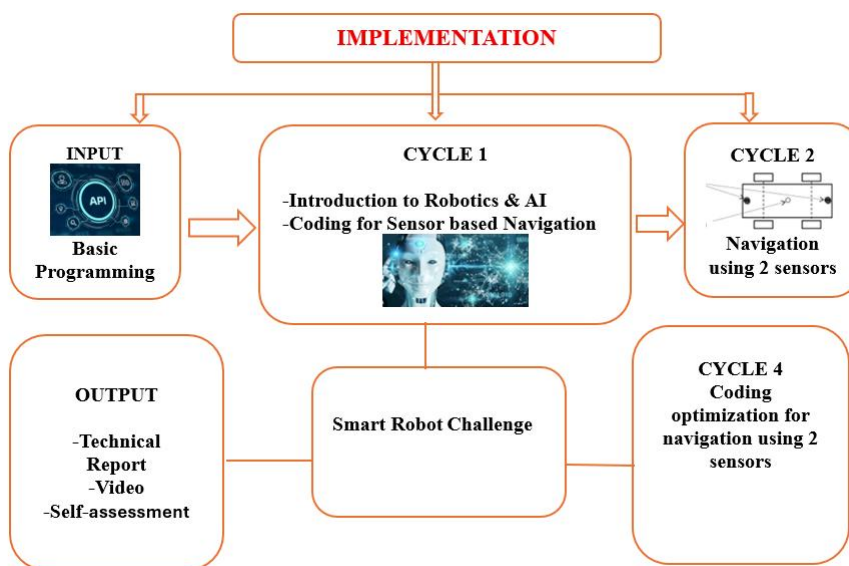
Methods and materials

The robotics programming project with the integration of artificial intelligence was developed to evaluate the effectiveness of Kolb's experiential learning model in shaping programming skills and Industry 4.0 competencies. As part of the project, students completed the task of creating intelligent navigation algorithms for mobile robots, which facilitated the transition from theoretical knowledge to practical application. The project was implemented over three weeks with weekly three-hour classes and began with an introductory workshop on robot navigation, AI control strategies, and microcontroller systems. The students were divided into small groups (up to five people), which ensured joint problem solving and teamwork. Over the course of four training sessions, participants developed navigation programs step by step, moving from simple rule-based algorithms to more complex solutions using AI to support decision-making. The final stage was the "Smart Robot Challenge — Kazakhstan" competition, held at the Faculty of Information Technology (L.N. Gumilyov ENU, Astana) together with the student robotics club. The essence of the competition was for the mobile robot to autonomously navigate the maze from the start to the end point, while demonstrating the accuracy of navigation and the stability of algorithms. The competition consisted of four rounds, in each of which the route configuration was changed, and the format was organized according to the "single elimination" principle. At each stage, the teams loaded their programs into the robot's microcontroller and conducted real-time tests. The effectiveness was assessed by the speed of execution, the absence of collisions, and the effectiveness of the algorithm. The creation of a competitive environment in the format of a national competition not only increased the motivation of students, but also allowed them to model the real challenges of Industry 4.0 in Kazakhstan, where innovation, adaptability and the introduction of intelligent automation into the educational process are key factors.

As shown in Figure 1, the contact sessions were structured according to the stages of the experiential robotics project with AI integration. Figure 2 illustrates the implementation framework of robotics and AI education based on Kolb's experiential learning cycle. Each teaching session corresponded to one complete experiential learning cycle, ensuring systematic progression from concrete experience to reflective observation, abstract conceptualization, and active experimentation. Throughout the project, students went through all four stages of the experiential learning cycle: doing, experiencing, thinking and concluding. This approach allowed them to gradually improve their programming skills, master robot control algorithms, and integrate AI technologies to solve navigation problems in conditions close to the requirements of Industry 4.0 and educational practice in Kazakhstan.



1-Figure. Contact sessions for the experiential robotics project with AI integration



2-Figure. Implementation Framework for Robotics and AI Education

As an entrance stage, students took a 15-week course of lectures and practical classes on the basics of programming languages and gained a basic understanding of the robotic system. This prepared them for the practical application of knowledge in the integrated environment of robotics + artificial intelligence. The students started by performing a basic experiment: for the first time, they programmed the Arduino Uno microcontroller. The task was to connect ultrasonic distance sensors and adjust the speed control of the robot wheels.

After loading the program into the microcontroller, the students turned on the robot and observed the response of the hardware — data from the sensors and the behavior of the motors.

At this stage, the students compared the expected results based on their algorithms with the actual reaction of the robot. In case of inconsistencies, they systematically debugged the program and repeated the tests until the robot demonstrated the required behavior. The students analyzed the collected data and made

changes to the conceptual models. Real pedagogical factors were taken into account here: sensor noise, wheel alignment, and the need to use AI to optimize signals and navigation. This learning cycle allowed students not only to master programming skills, but also to form the key competencies of Industry 4.0 — the ability to work with AI in robotic systems, think critically, solve complex pedagogical problems and apply knowledge in conditions of real uncertainty.

Results and their analysis

To assess the effectiveness of the project, quantitative data were collected to analyze changes in the level of programming proficiency and related pedagogical competencies. The main sources of data were the grades for the project, the midterm exam, and the final exam. The evaluation of the project included several components: a technical report (50 %), a video presentation (30 %), student engagement and teamwork (10 %), as well as the results of the Smart Robot Challenge (10 %). This structure made it possible to assess not only the level of programming skills, but also the key competencies of Industry 4.0 — critical thinking, communication and joint solution of pedagogical problems. The midterm and final exams had two parts. The first part (50 %) tested basic programming knowledge. The second part (50 %) assessed how well students could use their programming skills to solve practical robotics problems. The midterm exam conducted before the project was completed was considered a pre—test, and the final exam after the project was completed was considered a post-test.

We checked how well the proposed method worked by comparing two groups of students. One group ($n = 128$) did a robotics programming project that followed Kolb's experiential learning model, which involved doing experiments, thinking about the results, and understanding ideas. The control group ($n = 96$) represented the previous stream of students who did not participate in the project based on the Kolb model. The control group did a standard project using problem-based learning. The instructor set the teams and topics beforehand, and the way the work was done was less structured. The main goal was to produce the required results, such as sample programs, peer reviews, and presentations, but with little guidance on how to do it.

To check how the project impacted student programming skills, we looked at pre-test and post-test scores from both student groups. This approach allows us to identify significant differences in the development of programming skills and the ability to apply them to solve practical problems. The results show that the students of the experimental group who participated in the robotics project with AI integration and using Kolb's experiential learning model had an average score of 50.8 % on the pre-test and 62.4 % on the post-test. Thus, the average increase in knowledge was +11.6 %, which confirms the effectiveness of the proposed methodology. At the same time, the students in the control group had an average score of 51.7 % on the pre-test and only 47.3 % on the post-test, which gave a negative increase of -4.4 %. A comparative analysis shows that the introduction of a robotics project with elements of artificial intelligence and based on the Kolb model contributes to a more significant development of students' programming competencies. In terms of relative value, the effectiveness of the experimental technique was higher by about 16.0 % compared to the traditional approach. The comparative results of pre-test and post-test scores for both groups are presented in Table 1.

Table 1

Pre-test and Post-test Results of Experimental and Control Groups

Group	Pre-test Mean (%)	Post-test Mean (%)	Mean Gain (%)
Experimental	50.8	62.4	+11.6
Control	51.7	47.3	-4.4

To check the data, a null hypothesis (H_0) was created:

H_0 : There is no real difference in academic results between students in a robotics program using Kolb's method (experimental group) and those in a normal program (control group).

To check this, the test scores from before and after the programs were looked at using a t-test. The stats can be seen in Tables 2 and 3. Table 2 shows that at the start, there was no real difference in scores between the experimental group ($n = 128$, $M = 50.8$ %, $SD = 16.4$) and the control group ($n = 96$, $M = 51.7$ %, $SD = 15.9$), with a p-value of 0.487. This means both groups had about the same level of programming skill before starting.

But, the after-program scores in Table 3 show a real difference between the groups. The experimental group had an average score of 62.4 % (SD = 17.2), while the control group had 47.3 % (SD = 16.1), with $p < 0.001$. The experimental group's scores went up by +11.6 % on average, while the control group's scores went down by -4.4 %. This suggests that the students in the robotics program with hands-on learning did much better in programming than those in the normal program.

So, the original idea that there would be no difference was wrong. The data shows that using a robotics program based on hands-on learning helps students learn programming and other important skills for Industry 4.0. The results of the independent samples t-test for the programming pre-test are shown in Table 2.

Table 2

Results of the programming pre-test (experimental and control groups)

Group	n	Average value (M), %	Standard deviation (SD)	p-value
Experimental	128	50,8	16,4	
Control	96	51,7	15,9	0,487

Note. The differences are not statistically significant.

The post-test results and statistical comparison between the experimental and control groups are summarized in Table 3.

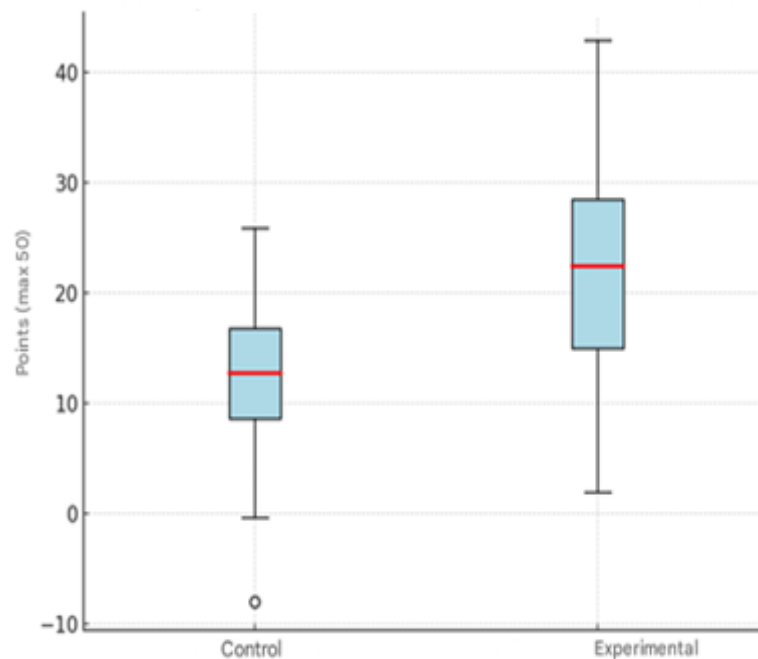
Table 3

Programming posttest results (experimental and control groups)

Group	n	Average value (M), %	Standard deviation (SD)	Increase/decrease, %	p-value
Experimental	128	62,4	17,2	+11,6	
Control	96	47,3	16,1	-4,4	<0,001

Note. The differences are statistically significant at the level of $p < 0.001$.

The assignments asked students to: (1) change a teaching issue into a series of steps using flowcharts; (2) create and run Python programs aiding decisions based on their flowcharts; and (3) check their program logic with variables in a robot setup. The distribution of total scores for practical programming tasks is presented in Figure 3. As shown in Figure 3, the median scores for the control and experimental groups were 12.0 and 22.5 respectively, demonstrating a substantial performance advantage of the experimental group. The median scores for the control and experimental groups were 12.0 and 22.5, showing about a 10.5-point difference for the experimental group. This supports the idea that using robot-based teaching projects works well and matches the study's results, which suggest that robots in learning can boost grades by about 16–17 %.



3-Figure. Distribution of total scores for practical programming tasks

The independent samples t-test showed a statistically significant between-group difference in final assignment performance. The experimental group achieved a higher mean score ($M = 62.4\%$, $SD = 17.2$) than the control group ($M = 47.3\%$, $SD = 16.1$), with a mean difference of 15.1 percentage points, $p < 0.001$. This result indicates that participation in the experiential robotics project with AI integration was associated with higher programming performance and stronger problem-solving outcomes.

Table 4

T-test results for final assignments (posttest)

Group	n	Mean (M), %	Standard deviation (SD)	Mean difference	p-value
Experimental	128	62.4	17.2	15.1	< 0.001
Control	96	47.3	16.1		

Note. The p-value refers to the between-group comparison based on an independent samples t-test.

This study checked if students doing well on the robotics project also did well on the final exam. To explore the link between students' projects and their final exam grades, Spearman's rank correlation was used. This method is useful for seeing how teaching methods affect learning. Data were gathered from 128 students and ranked by project grade and final exam score; a low rank means a lower grade, and a high rank a higher grade. Table 5 shows the correlation coefficient, how sure we are of the results, and the number of students. The Spearman correlation coefficient ($\rho = 0.267$) shows scores on projects are related to final exam scores ($p = 0.0087$, 95 % confidence interval). The correlation is not super strong, but it could be because of both individual work and teamwork in the project. Still, the fact that students who did well on the project also tended to get higher scores on the exam suggests that using robotics projects can help students learn programming and other skills needed for Industry 4.0. The results of Spearman's rank correlation analysis between project performance and final exam scores are presented in Table 5.

Spearman's Correlation Analysis results (project and final exam)

Indicator	Meaning
Spearman Correlation Coefficient	0,267
p-value	0,0087
N	128

Conclusion

This work details an educational robotics project aimed at improving programming skills and building Industry 4.0 skills in education students. Rather than just teaching basic programming like syntax, it helps students create solutions to real educational and tech problems. Through projects, students grow their ability to solve problems, think creatively, and understand systems, which are all very important in today's schools.

Based on the results, integrating robotics projects into programming courses helps students apply what they learn in theory. By designing, testing, and improving software, they get experience with complex systems, data processes, and changing conditions. This hands-on learning helps them understand ideas better and develop skills that can be used not just in programming, but also in teaching overall.

The approach shows how valuable hands-on, project-based learning can be in teacher education. Taking part in robotics projects boosts teamwork, thinking, and independent learning. These are key for preparing teachers to work in tech-filled classrooms. By combining tech problem-solving with educational aims, this method helps students build job-related skills and gives future teachers what they need to include technologies in their classrooms as part of Industry 4.0.

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Ж. Зулпыхар, Н. Карелхан, М. Рахметов, Р. Жилмагамбетова

Жасанды интеллект пен машиналық оқыту элементтері бар эксперименттік робототехника: білім беруде бағдарламалау дағдылары мен Индустрия 4.0 құзыреттіліктерін дамыту жолы

Зерттеу болашақ мұғалімдердің бағдарламалау құзыреттілігін арттыру және цифрлық дағдыларын дамыту үшін практикалық оқытуға негізделген робототехникалық жобаларға жасанды интеллектті (AI) біріктірудің білім беру әсерін қарастырады. Интеллектуалды навигация және сенсорлық шешім қабылдау сияқты жасанды интеллект элементтері бар робототехникалық жобаны жүзеге асыру педагогикалық мамандықтар студенттерінің бағдарламалаудың теориялық негіздерін нақты мәселелерді шешумен байланыстырудағы қиындықтарын жеңуге бағытталған. Ол мобильді роботты басқару және зертханалық сынақтарды жүргізу үшін жасанды интеллект алгоритмдерін әзірлеуден бастап нәтижелерді талдауға және оларды көрсетуге дейін студенттерді кезең-кезеңімен тартуды қамтамасыз ететін колбаны оқытудың эксперименттік моделіне негізделген. Сонымен қатар студенттер топтық жұмысты ұйымдастырды, техникалық есептер дайындады және нәтижелерін бейне презентациялар түрінде ұсынды. Жобаның маңызды аспектісі студенттерге жасанды интеллект технологияларының практикалық құндылығын жақсырақ түсінуге және олардың қазіргі мектеп жағдайында тікелей қолданылуын көруге мүмкіндік беретін нақты білім беру сценарийлерін пайдалану болды. Жоба сонымен қатар қарым-қатынасты, өзара оқытуды және проблемаларды бірлесіп шешуді ынталандырды, оқудың қолайлы атмосферасын қалыптастырды. Қорытынды бағалардың статистикалық талдауы студенттердің бағдарламалау және практикалық мәселелерді шешу саласында ғана емес, сонымен қатар педагогикалық практикада және Индустрия 4.0 білім беру ортасында сұранысқа ие маңызды әдіснамалық және цифрлық құзыреттіліктерді қалыптастыратын интеллектуалды шешімдерді жобалау қабілетінде де айтарлықтай жақсарғанын көрсетті.

Кілт сөздер: жасанды интеллект, эмпирикалық оқыту, Колба моделі, робототехникалық жоба, бағдарламалық құзыреттілік, Индустрия 4.0, цифрлық педагогикалық сауаттылық, педагогикалық практика.

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Экспериментальная робототехника с элементами искусственного интеллекта и машинного обучения: путь к развитию программных навыков и компетенций Индустрии 4.0 в образовании

В этом исследовании рассматривается образовательный эффект интеграции искусственного интеллекта (ИИ) в робототехнические проекты, основанный на практическом обучении, для повышения уровня компетенций в области программирования и развития цифровых навыков будущих учителей. Реализация робототехнического проекта с элементами искусственного интеллекта, такими как интеллектуальная навигация и сенсорное принятие решений, была направлена на преодоление трудностей студентов педагогических специальностей в соотношении теоретических основ программирования с решением реальных задач. Она основана на экспериментальной модели обучения Колба, которая обеспечивала поэтапное вовлечение студентов: от разработки алгоритмов искусственного интеллекта для управления мобильным роботом и проведения лабораторных тестов до анализа результатов и их отражения. Кроме того, студенты организовали групповую работу, подготовили технические отчеты и представили результаты в виде видеопрезентаций. Важным аспектом проекта было использование реальных образовательных сценариев, которые позволили учащимся лучше понять практическую ценность технологий искусственного интеллекта и увидеть их непосредственное применение в современной школьной среде. Проект также стимулировал общение, взаимное обучение и совместное решение проблем, формируя благоприятную атмосферу обучения. Статистический анализ итоговых оценок показал значительное улучшение у учащихся не только в области программирования и решения практических задач, но и в умении проектировать интеллектуальные решения, что формирует важные мето-

дологические и цифровые компетенции, востребованные в педагогической практике и в образовательной среде Индустрии 4.0.

Ключевые слова: Искусственный интеллект, эмпирическое обучение, модель Колба, робототехнический проект, Программные компетенции, Индустрия 4.0, цифровая педагогическая грамотность, педагогическая практика.

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