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Enhancing competence in mobile robot development: integrating robotic technologies for future computer science teachers

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ABSTRACT: This study explores the effectiveness of theoretical and practical foundations for enhancing students' competence in developing mobile robots using integrated robotic technologies, focusing on training future computer science teachers. The study involved 167 students from higher educational institutions in Kazakhstan, divided into experimental and control groups. The experimental group received instructions on integrating robotic technologies (Arduino, Lego Mindstorms EV3 and machine learning) to facilitate project work creation, while the control group followed traditional teaching methods. Three key components were identified to assess the level of students' knowledge in the creation of mobile robots: motivational, content and practical components. The results underscore the importance of integrating robotics technologies into educational programmes, and the pivotal role of theoretical and practical foundations in preparing future computer science teachers. Further research is warranted to explore additional aspects of integrating robotics technologies into educational programmes.

Keywords: Robotics technologies, computer science, educational programmes, project work

INTRODUCTION

In the realm of future workforce preparation, educational institutions play a crucial role in enhancing their respective nations' technological and innovative competitiveness. The education of aspiring computer science professionals in basic robotics highlights the importance of adjusting to technological advancements [1]. This idea suggests that keeping up-to-date with the latest technology is crucial to maintain the relevance of one's knowledge, especially in fields where technology is constantly evolving. Scholars highlighted the distinct characteristics of robotics-based learning, emphasising active engagement, problem-solving prowess and practical experience. This educational approach has been shown to equip future specialists with innovative pedagogical strategies transferrable across various disciplines, thereby enhancing the efficacy of robotics education [2][3]. The importance of preparing students for future career prospects in fields, such as robotics and artificial intelligence has been emphasised by Nurpeisova et al [4], Babian and Xu [5], Wolfer [6], and Silapachote and Srisuphab [7].

Integrating robotic technologies further expands the potential of mobile robots in the educational process. Mobile robots can now be equipped with sensors and actuators to interact with their environment more complexly, and which enable robots to be used for various educational applications [8][9].

Training initiatives focused on robotics instruction predominantly emphasise singular technological platforms in contemporary educational contexts. In their respective investigations, Erdoğan et al delved into the feasibility of simulating robotic models utilising platforms, such as Arduino with Tinkercad [10].

On a similar trajectory, Kılıç and Seyfullah [11], along with Cao et al [12], directed their attention toward exploring the educational efficacy of Lego Mindstorms EV3 sets. Their scholarly endeavours revolved around scrutinising the instructional potentials inherent in these platforms within the academic environment, probing into their roles as tools for fostering learning and innovation in robotics education. Dr Beverly Park Woolf, a University of Massachusetts Amherst professor involves integrating machine learning algorithms into educational software to provide personalised learning experiences [13]. While such singular approaches facilitate foundational understanding, fostering competitive project-oriented endeavours requires proficiency across multiple technological domains. Consequently, the imperative for pedagogical frameworks emphasising integrating diverse robotics technologies within educational curricula becomes increasingly pronounced.

The research presented in this article aimed to provide comprehensive training to future educators in computer science, enabling them to create mobile robots by understanding the integration methodologies of diverse robotics technologies. The scientific hypothesis of the research can be stated as: if the theoretical and practical bases of training of future information technology specialists based on the integration of robotics technologies on mobile robots are introduced into the educational process of higher educational institutions, then the level of knowledge of the students on this issue would increase, and comprehensive skills would be formed to a high degree in a comprehensive approach.

RESEARCH METHODOLOGY

Experimental work was carried out to assess the effectiveness of the newly developed working curriculum, educational and methodological complexes, methodological manuals and electronic educational resources aimed at increasing the level of readiness of students in complex robotic technologies. The students participating in this study were divided into experimental and control groups as shown in Table 1. The experimental and control groups included students from three universities in Kazakhstan.

Table 1: Number of participants in the experiment.

	L.N. Gumilyov Eurasian National University	*S. Amanzholov* East Kazakhstan University	*I. Altynsarin* Arkalyk State Pedagogical Institute	Total for higher education institutions
Experimental group	49	39	-	88
Control group	18	52	9	79

The stages of the experiment are shown in Figure 1.

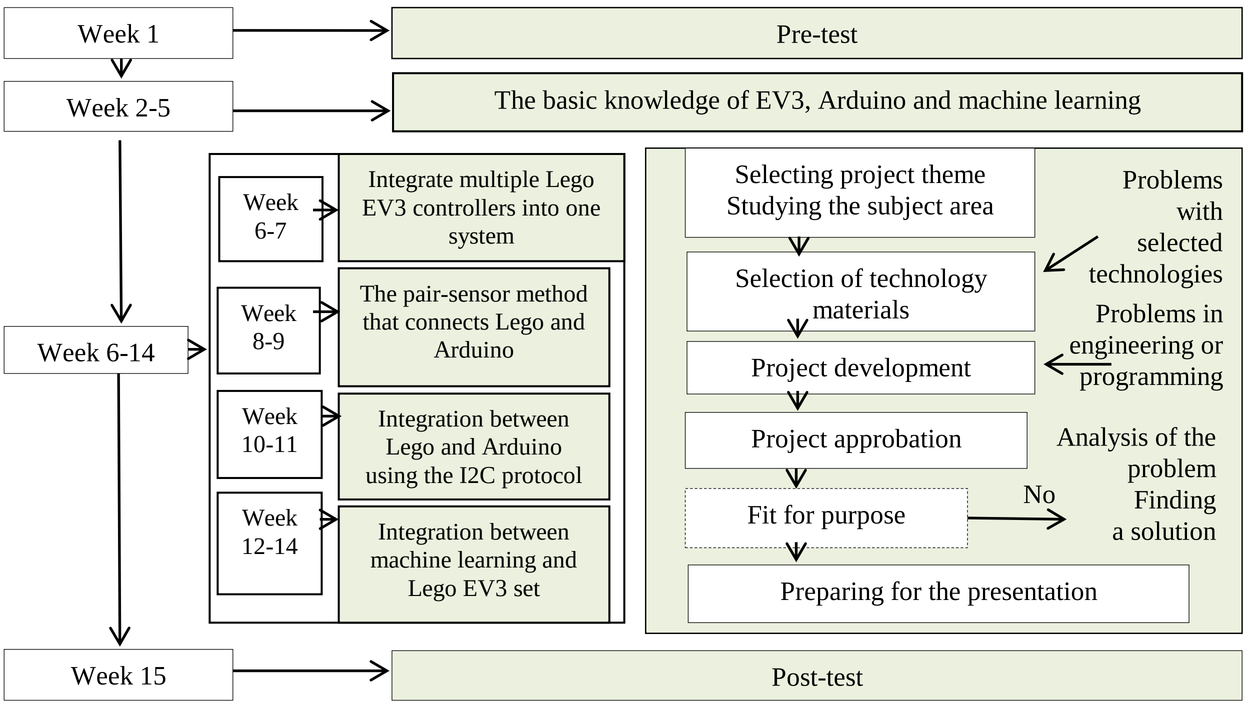

Figure 1: Experiment design and procedure.

The experimental work lasted 15 weeks. Special attention was paid to the content of the educational programmes: *6B01511 - Informatics*; *7M01511 - Informatics;* and *7M01525 - STEM Education* of *L.N. Gumilyov* Eurasian National University, and the educational programmes: *6B06103 - Computer Mechatronics*; *6B06101 - Informatics*; and *6B01501 - Informatics* offered at *S. Amanzholov* East of Kazakhstan University in Ust-Kamenogorsk included as a course. The determining test questions of the first week and the formative test questions of the last 15 weeks were taken from the experimental and control groups using the survey method. There were 25 questions, of which five were based on the motivational component, ten on the content component, and ten on the technical skills component. From the second to the fifth week, basic knowledge in EV3, Arduino and machine learning robotics technologies in education was provided. Between the sixth week and the 14th week, algorithms for establishing links between these robotics technologies were considered.

In addition, project work with the case justified each type of communication. The teacher's task was analysing case studies, giving educational tasks and answering students' questions. The main functions of the students were to master the basic knowledge of the proposed robotics technologies and to develop project work with the help of integration methods. The project works were selected by the students themselves in the experimental and control groups. However, in the experimental groups, the teacher was given feedback on which part of the project was wrong. In the last week, formative test questions were used as a survey method to learn all the information provided and evaluate the formation of new skills and abilities.

LEARNING MATERIALS

A concise overview details the practical development and integration between Lego Mindstorms EV3 and Arduino. The Lego Mindstorms EV3 and Arduino sets are combined using a pair-sensor method. The LED is used to transmit control by counting the flashes or to transmit simple signals. For binding, it is necessary to build a drawing, as shown in Figure 1 below. The distance between the sensors should be up to 1cm.

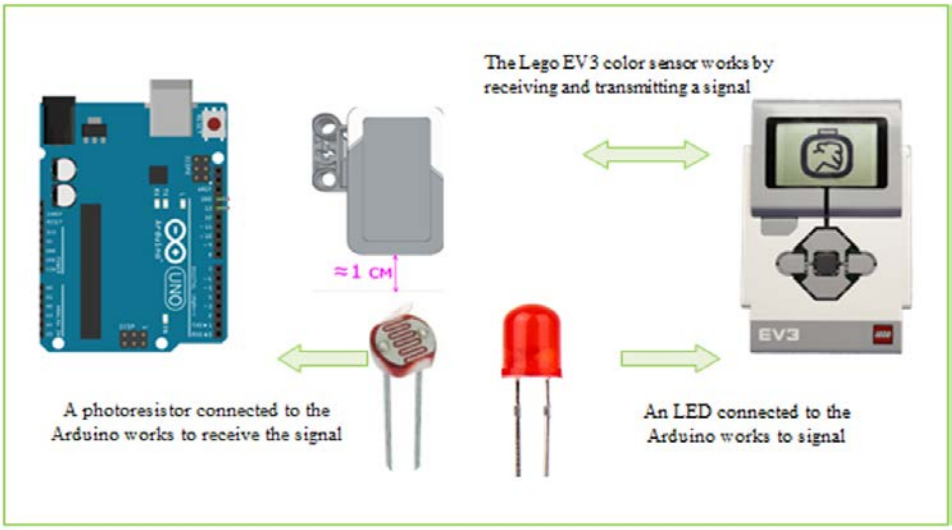

Figure 2: Pair-sensor connection diagram.

This method can work in two ways. First, one can look at how the Lego EV3 sends a signal to the Arduino and, accordingly, how the Arduino sends a signal to the Lego EV3. For this, three EV3 colour disconnection sensor measurement parameters are used. After establishing the physical connection, as in Figure 1, it is necessary to write program codes for both technologies. The programming codes in Figure 2 and Figure 3 are for signalling from Lego EV3 to Arduino.

Figure 3: Lego EV3's signal transmission code.

get_signal.ino

```
int v=0;
void setup()
{  pinMode(12,OUTPUT);
  pinMode(11,OUTPUT);
  Serial.begin(9600);}
void loop() {
do
{ v=analogRead(0);
  Serial.println(v);
digitalWrite(12,1);
  } while (v<800);
digitalWrite(12,0);
digitalWrite(11,1);
delay(1000);
digitalWrite(11,0);}
```

Figure 4: Arduino's signal reception code.

RESEARCH RESULTS

Three components were identified that determine the level of students' knowledge in the creation of mobile robots based on integrated robotics technologies [14]. For each component mentioned in Table 2, set criteria and indicators reflecting their values have been applied.

Table 2: Criteria and indicators for assessing the level of students' knowledge in mobile robot development using integrated robotics technologies.

Motivational component	Criterion: Student has mastered the design of mobile robots based on integrated robotics technologies and understands the importance of future use	
Indicators		
Lower	Medium	High
Shows minimal interest due to a lack of understanding of the importance of mobile robot design. In teaching knowledge, rarely participates in discussions at work because cannot effectively use methods, forms and teaching methods.	Understands the concepts of creating mobile robots at the necessary level. Sometimes takes part in discussions and resorts to the help of a second person or teacher in organising tasks that arise in the effective use of modern teaching methods, forms and methods.	Demonstrates a high level of motivation to create mobile robots. In education, actively participates in discussions, understands the importance of application, seeks additional resources and asks meaningful questions.
Content component	Criterion: Student has a high theoretical understanding of the development of mobile robots based on integrated robotics technologies	
Demonstrates a basic understanding of robotics technologies, such as Lego EV3, Arduino and machine learning. Does not understand the importance of linking multiple technologies.	Can use robotics technologies, such as Lego EV3 and Arduino, and build mobile robots with machine learning. Can use simple (Bluetooth, Wi-Fi) methods of connecting several technologies to create large-scale projects.	Demonstrates an advanced theoretical understanding of the principles of creating mobile robots through complex methods of several technologies. Effectively applies the theory to difficult practical situations, considers different points of view and demonstrates critical thinking.
Practical component	Criterion: Student has mastered the methods, techniques and forms of training for designing mobile robots based on integrated robotics technologies	
Integrates robotics, combines the main practical task of designing mobile robots based on technology. Needs a manual to perform practical exercises.	Can work independently on the usual projects for creating mobile robots. Shows some problem-solving skills when faced with difficulties.	Independently develops and creates prototypes of innovative robots. Shows strong abilities to solve problems and adapt strategies if necessary.

The experimental results obtained by the general experimental (EG) and control (CG) groups are combined into one diagram and presented in Figure 5.

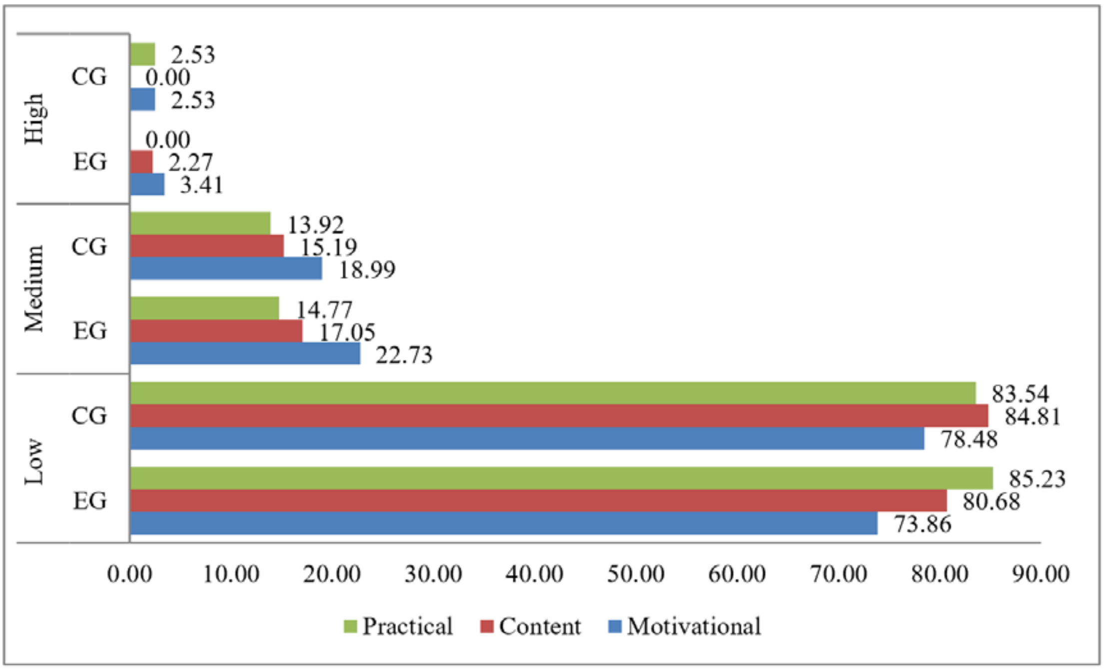

Figure 5: Diagram of the results of experimental and control groups obtained by the determining experiment.

From the results of the comparative analysis and diagrams, one can conclude that the level of knowledge of students of the experimental and control groups is very similar, that is, there is no difference, and one can prove this using Pearson's χ^2 criterion. To analyse the results in Figure 5 of the determining experiment (on motivational, content, practical components) by mathematical and statistical means, the authors of this article formed the following hypothesis: *H_0: the level of knowledge of students of the experimental and control groups is equal, that is, there is no difference, …the level of knowledge of students of the experimental and control groups H_1 is not equal, that is, there is a difference*. The rejection or acceptance of these hypotheses was determined using Pearson's criterion χ^2.

The Pearson's formula for finding criterion χ^2 as by Ermolaev [15] is:

$$\chi^2 = \sum_{i=1}^{k} \frac{(E_f - T_f)^2}{T_f}$$

Where E_f is the empirical frequency; and T_f is the theoretical frequency.

The empirical and theoretical frequencies were determined. Using the data of the obtained empirical and theoretical frequency distribution tables, Pearson's criterion χ^2 was calculated using the above formula as shown in Table 2.

Table 2: Table of calculation of Pearson's criterion χ^2 by the determining experiment.

Level			(E_f) Empirical frequency	(T_f) Theoretical frequency	$(E_f - T_f)^2$	$\frac{(E_f - T_f)^2}{T_f}$
Motivational component	EG	Low	65	66.92	3.69	0.06
		Medium	20	18.44	2.42	0.13
		High	3	2.63	0.13	0.05
	CG	Low	62	60.08	3.69	0.06
		Medium	15	16.56	2.42	0.15
		High	2	2.37	0.13	0.06
	Value of Pearson's criterion χ^2					0.50
Content component	EG	Low	71	72.72	2.95	0.04
		Medium	15	14.23	0.60	0.04
		High	2	1.05	0.90	0.85
	CG	Low	67	65.28	2.95	0.05
		Medium	12	12.77	0.60	0.05
		High	0	0.95	0.90	0.95
	Value of Pearson's criterion χ^2					1.97
Practical component	EG	Low	75	74.30	0.49	0.01
		Medium	13	12.65	0.12	0.01
		High	0	1.05	1.11	1.05
	CG	Low	66	66.70	0.49	0.01
		Medium	11	11.35	0.12	0.01
		High	2	0.95	1.11	1.17
	Value of Pearson's criterion χ^2					2.26

Pearson's criterion χ2 values for three components were found: $\chi^2 = 0.50$ for the motivational component, $\chi^2 = 1.97$, for the content component and $\chi^2 = 2.26$ for the experimental component. Degrees of freedom v = 2. The crisis values were obtained from the statistical application table:

$$P \leq 0.05 \text{ to } 5.99, \text{ and } P \leq 0.01 \text{ to } \chi^2_{cv} = 9.21$$

Here, it shows that if the value found is less than 5.99, it falls into the real rejection zone; if it lies between 5.99 and 9.21, it falls into the uncertainty zone; and if it is χ^2_{cv} = 9.21 or is more significant, it falls into the real acceptance zone. If the calculated values of χ^2 and the crisis value of χ^2_{cv} for the three cases are $\chi^2 = 0.50$, $\chi^2 = 1.97$, $\chi^2 = 2.26$, one may see that the values are less than 5.99. The value found on all three components fell into the rejection zone. So, the alternative hypothesis H1 deviates, and the null hypothesis H_0 is accepted. This means that there is no difference between the levels of education of students of both groups on an equal basis, which proves the initial assumption.

The next stage of the experiment was the formative stage. In this stage, were considered the final questionnaires and grades received for the introduced course of study in order to draw conclusions about the level of education of students. These data were entered into the Excel spreadsheet and processed using well-known mathematical and statistical formulas. Based on this, conclusions were drawn about the knowledge, skills and abilities of students.

As a result of the formative stage, the values of Pearson's criterion χ^2 were found for the motivational component $\chi^2 = 14.95$, the content component $\chi^2 = 10.50$ and the experimental component $\chi^2 = 12.92$. If the value found is less than 5.99, it indicates that it fell into the actual rejection zone; if it lies between 5.99 and 9.21, it is in the uncertainty zone; and if it is $\chi^2_{cv} = 9.21$, it is in the zone of real acceptance. If one compares the calculated values of χ^2 and the crisis value of χ^2_{cv} for the three cases, then 14.95 > 9.21, 10.50 > 9.21 and 12.92 > 9.21, the value found for all three components fell into the acceptance area. The null hypothesis H_0 has been rejected in favour of the alternative hypothesis H_1, affirming the deviation from the initially posited assumption.

The identified distinction in educational levels among students in the two groups implies that the integration of robotics technologies, specifically focusing on the theoretical and practical foundations for training prospective information technology specialists in the domain of mobile robots, within the educational curriculum of higher learning institutions leads to a demonstrable elevation in students' academic proficiency on this subject matter. This comprehensive approach not only enhances the students' knowledge but also cultivates a heightened mastery of skills to a significant extent, thereby substantiating the accuracy of the scientific forecast.

CONCLUSIONS

This research underscores the significance of integrating robotics technologies into educational programmes for future ICT specialists. The study demonstrated the effectiveness of a comprehensive training approach in enhancing students' knowledge and skills in creating mobile robots based on integrated robotics technologies. Educators can prepare students for the dynamic technological and innovation landscape by focusing on theoretical foundations and practical applications. The study involved 167 students from three universities in Kazakhstan, who were divided into experimental and control groups. The experimental group received theoretical and practical instruction on integrating robotic technologies such as Arduino, Lego Mindstorms EV3 and machine learning. In contrast, the control group received instruction using a traditional collaborative learning environment.

The study identified numerous implications for educational practices and future workforce preparation. Integrating diverse robotics platforms enhances students' theoretical understanding and practical competence in robotics education. This aligns with the demands of the evolving job market, where robotics and artificial intelligence skills are increasingly valuable.

Secondly, pedagogical frameworks emphasising active learning, problem solving and interdisciplinary integration are crucial in fostering students' engagement and motivation in robotics education. Project-based learning and collaborative programming provide students with hands-on experience and practical skills essential for success in information technology.

Lastly, the findings highlight the importance of continuous professional development for computer science educators. By equipping educators with contemporary tools and methodologies for teaching robotics, higher educational institutions can ensure the relevance and effectiveness of the education system in preparing students for the challenges and opportunities of the digital age.

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BIOGRAPHIES

Meruert Serik, Doctor of Pedagogical Sciences, is a Professor of *L.N. Gumilyov* Eurasian National University (ENU), in Astana, Kazakhstan. She began her academic journey at *E.A. Buketova* Karagandy State University (KarGU), Karagandy, Kazakhstan, which laid the foundation for her extensive career in education and research. Her professional journey began in the years 1983 to 1989 at the Mathematics Computing Laboratory of the Regional Bank in Karagandy. Subsequently, from 1989 to 2004, she served as an Associate Professor at KarGU. In 2004, she advanced to the position of Professor and Head of the Department of Information Technology, a role she held until 2006. From 2006 to 2011, she led the Department of Computer Science at KarGU. Since 2011, she has been a Professor in the Department of Informatics at ENU. Her scientific interests and contributions are: high-performance parallel computing, cloud computing, client-server technologies, knowledge informatisation, machine learning and neural networks. Professor Serik’s career spans over 40 years, and is marked by significant contributions to educational practices and technological advancements. Her work has been widely recognised and supported by numerous grants and projects aimed at integrating technology and education in Kazakhstan.

Symbat Nurgaliyeva obtained her Bachelor’s degree in computer science from *S. Amanzholov* East Kazakhstan State University, Ust-Kamenogorsk, Kazakhstan, in 2010. Subsequently, she pursued a Master’s degree in computer science at the same University, graduating in 2014. From 2020 to 2023, she was involved in and completed her doctoral studies at *L.N. Gumilyov* Eurasian National University in Astana, Kazakhstan. Currently, she is in the final stages of completing her doctoral dissertation, which focuses on enhancing the quality of education for future computer science teachers through the theoretical and practical integration of robotics technologies, specifically the use of mobile robots in the educational process. Robotics technologies in education, creation of mobile robots, machine learning and neural networks are the subjects of her scientific research.