Teaching PLC Programming Using Interdisciplinary Relations

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Abstract

Within the 'Fundamentals of Robotics' course, we developed a teaching aid for programming programmable logic controllers (PLCs), integrating interdisciplinary relationships across various educational areas. This tool aimed not only to teach students how to program PLCs but also to effectively apply knowledge from multiple subjects. We created an automated, low-maintenance freshwater aquarium care system, applying knowledge from engineering, science, and computer science disciplines such as technology, computer science, mathematics, physics, biology, and chemistry in its design and implementation. The paper also focuses on a detailed analysis of the educational standards of the relevant subjects needed in the development of this teaching aid. For primary school students interested in applying STEAM principles with their teachers in engineering subjects, it is necessary to determine the appropriate grade level for incorporating these activities into their education.

Keywords: PLC, Programming, STEAM, Interdisciplinary Relations, Educational Process

1 Introduction

Programmable Logic Controllers (PLCs) are a key component of industrial automation and are widely used to control a variety of industrial processes. In recent decades, the teaching of PLCs has become one of the important components of technical education because, due to the rapid advances in automation technologies, knowledge of their programming is essential for professionals in industrial manufacturing, energy, and other technical disciplines (Brettel et al., 2014). However, the implementation of PLCs in the teaching of programming requires a systematic approach that can effectively link theoretical knowledge with practical applications. This creates room for the use of interdisciplinary relations allowing students to not only understand the principles of PLC programming, but also understand its links to other

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disciplines, thereby enhancing their technical skills and critical thinking abilities. Interdisciplinary relations in the process of education allow the application of knowledge from different areas increasing the chances of better understanding and deeper immersion into the subject. According to Beers (2016), "interdisciplinary relations promote the integration of knowledge, thereby creating a more comprehensive understanding of the content and its connections to real-world problems". It follows that effective teaching of PLC programming can benefit from a cross-curricular approach, as it provides the opportunity to link theory with practical applications not only within technical subjects such as physics or electrical engineering, but also with aspects of mathematics, computer science and logical thinking.

1.1 The importance of PLCs in industrial practice and education

Programmable logic controllers are currently used in a variety of industrial applications, including production line control, process monitoring, and automation of technical devices. The importance of these systems highlights the fact that PLCs are among the key enablers of the transformation of the manufacturing process in the Industrial Revolution 4.0, as they enable increased efficiency and safety of industrial processes (Vogel-Heuser & Hess, 2016). Therefore, it is important for engineering students to understand not only the principles of their operation, but also the basic methods of their programming. Teaching PLC programming involves learning basic logic functions, analysing control processes and implementing them in programmable systems. In this context, the use of interdisciplinary relations is of key importance as it broadens the student's understanding of different aspects of control systems, while linking theoretical knowledge with practical experience.

According to some studies (e.g., Brettel et al., 2014), PLCs can be an effective tool for students to gain hands-on experience because they allow them to interact with real devices, which increases their motivation and interest in studying engineering subjects. This motivation can be further fostered by using an interdisciplinary approach that develops the ability to apply knowledge gained in one subject to solve problems in another. The use of methods such as projects and case studies can strengthen these relationships as students are forced to apply knowledge from different disciplines to solve complex problems.

1.2 Benefits and challenges of an interdisciplinary approach in teaching PLCs

Interdisciplinary approach in teaching engineering subjects such as PLC programming has many advantages including the opportunity to learn how to solve problems through the application of different knowledge while fostering the development of analytical and critical thinking skills. In teaching PLCs, it is important that students understand the basic principles of automation and can apply them in a broader context, thereby increasing their ability to creatively solve engineering problems. This approach allows students to gain a broader

perspective on the connection between theory and practice, leading to a better understanding of the practical applications of PLC systems (Vogel-Heuser & Hess, 2016).

However, a challenge in introducing interdisciplinary relations into the teaching of PLCs is often the need for coordination between subjects and their teachers. Different subjects that could be included in the teaching of PLC programming, such as mathematics, physics and computer science, have different methodological approaches, which can lead to problems with content integration. For an effective use of an interdisciplinary approach, teachers' collaboration with each other is essential to plan and coordinate content effectively so that space and opportunities are created for the application of knowledge from one subject in another context (Beers, 2016).

The use of interdisciplinary relations in teaching PLC programming represents a promising approach. It promotes the integration of theoretical knowledge with practical skills, thereby improving students' readiness for professional practice. This method emphasises practical tasks and projects that apply knowledge from various fields. Such an approach leads to a better understanding of the connections between different technical disciplines and increases students' motivation to study them.

1.3 Teaching PLC programming using interdisciplinary relations

Integrating different disciplines to establish natural relationships among them is a key trend in contemporary pedagogy, particularly within engineering and science subjects. This interdisciplinary approach enables students to acquire knowledge and skills that are practically applicable in real life, while also fostering their analytical, creative, and critical thinking abilities. The 'Fundamentals of Robotics' course, which we have integrated into the curriculum, emphasises the development of these skills through the teaching of programmable logic controllers (PLCs). In this context, we have created a specific teaching aid that supports pupils not only in acquiring technical knowledge, but also in linking it to knowledge acquired in various other areas. Our aim was to ensure that students not only learn the principles of PLC programming, but also that they are able to use knowledge from disciplines such as technology, computer science, physics, biology, chemistry or mathematics, thus gaining a more comprehensive view of the issue of automation and its applications.

The result of this effort was the construction of an automated freshwater aquarium care system that we designed to be low maintenance while incorporating various aspects of an interdisciplinary approach. This system allows students to learn the basic principles of automation and PLC programming directly while working with a specific piece of technical equipment, while motivating them to use their knowledge in different areas. The designed teaching aids integrate STEAM (Science, Technology, Engineering, Art, Mathematics) principles that promote the development of technical and critical thinking skills as well as creative problem-solving skills.

In addition to the actual development of the system and the implementation of the interdisciplinary approach, this paper focuses on a detailed analysis of the subject-specific

learning standards that are essential to the design of this teaching aid. We will present specific topics and areas that students should master in order to successfully complete the project. In addition, since our ambition is to integrate such teaching aids into the primary school educational process, we will also focus on finding an appropriate grade level in which these activities could be effectively integrated into the classroom. Equipped in this way, students will gain a solid foundation that is essential for their further studies in electrical, mechanical and technical fields, increasing their potential for success in professions where the ability to link different knowledge and apply it in practice is increasingly valued.

2 Analysis of Educational Standards

In this part of the article we deal in detail with the analysis of educational standards of those subjects that are essential in the creation of an educational aid. If teachers of the subject Technology in primary school together with their students would like to create an educational aid and apply STEAM principles in education, it is important to know in which grade it is appropriate to start with this work and which educational standards of each subject are closely related to the educational aid we have designed. In this way, interdisciplinary education is deepened. However, in the primary school, our teaching aid cannot be controlled by a PLC system; instead, it will be managed by a BBC micro: bit microcontroller, which the pupils are already familiar with.

This approach effectively integrates technical and scientific knowledge into the learning process, thereby fostering the development of students' critical thinking and practical skills. The use of the BBC micro: bit microcontroller is ideal for primary schools as it is accessible and easy to use, enabling pupils to acquire basic programming and technical skills at an early age. This way of teaching not only promotes interdisciplinary links between different subjects but also prepares pupils for future challenges in technology and innovation.

Product part	*Implementation of automation (lighting, filtration, power supply, heating, alarm)*
Educational standard for the subject Physics	
Year	*6*
Thematic unit	Investigating the properties of liquids, gases, solids and objects
Year	*7*
Thematic unit	Temperature. Investigation of the transformations of states of matter
	Heat
Year	*8*
Thematic unit	Light
	Force and motion. Work. Energy
Year	*9*

Thematic unit	Magnetic and electrical phenomena. Electric circuit
Educational standard of the subject Computer Science	
Year	*6*
Thematic unit	Communication and cooperation - working with a website
	Algorithmic problem solving - problem analysis
	Algorithmic problem solving - language for writing solutions
	Algorithmic problem solving - using a sequence of commands
	Algorithmic problem solving - using cycles
	Algorithmic problem solving - interpreting the solution notation
	Algorithmic problem solving - finding, correcting errors
	Software and hardware - working with files and folders
	Software and hardware - working in the operating system
	Software and hardware - working on a computer network and the Internet
Year	*8*
Thematic unit	Representations and tools - working with graphics
	Communication and collaboration - web search
	Algorithmic problem solving - problem analysis
	Algorithmic problem solving - a language for writing solutions
	Algorithmic problem solving - using sequences of commands
	Algorithmic problem solving - using cycles
	Algorithmic problem solving - using branching
	Algorithmic problem solving - using variables
	Algorithmic problem solving - using interaction tools
	Algorithmic problem solving - interpreting the solution notation
	Algorithmic problem solving - finding and correcting errors
	Software and hardware - working with files and folders
	Software and hardware - working in the operating system
	Software and hardware - working on a computer network and the Internet
Educational standard of the subject Technology	
Year	*5*
Thematic unit	Man and technology
	Man and production in practice
	Useful and gift items
Year	*6*
Thematic unit	Graphic communication in technology
	Electricity, electrical circuits
	Simple machines and mechanisms
Year	*7*

Thematic unit	Graphic communication in technology
	Technical materials and their working processes
Year	*8*
Thematic unit	Household electrical appliances
	Technical electronics
	Technical creation
Year	*9*
Thematic unit	Residential installations
	Creative activity

Table 1: Educational standards for the implementation of automation.

Summary of performance standards:

1) Physics:

a) Describing and verifying characteristics of substances and solids: Students learn about the characteristics of substances such as density, strength, shape, mass, and more. They investigate these experimentally and verify theoretical knowledge.
b) Measurement of physical quantities: Students learn to measure various physical quantities such as length, mass, time, temperature and electrical resistance.
c) Investigating the state transitions of substances: Students are introduced to state transitions (melting, solidification, boiling, condensation) and their effect on substances.
d) Heat and Light Propagation: Students learn about conduction, convection, and radiation of heat. They also explore the propagation of light and its characteristics.
e) Mechanical Work and Energy: Students explore the concepts of work, energy, and power. They distinguish between different forms of energy and its transformation.
f) Electrical and Magnetic Phenomena: Students learn about electric circuits, magnetic fields, electromagnetic waves and their applications.

2) Computer Science:

a) Algorithmic problem solving: Students learn to create algorithms to solve problems. It includes logical thinking, sequence of steps and programming.
b) Working with websites, software and hardware: Students are introduced to the use of computers, operating systems, applications and peripherals.
c) Working on a computer network and the Internet: Students learn about networks, protocols, security, and communication on the Internet.
d) Working with graphics: Students deal with creating and editing graphics as well as creating web pages.

3) Technology:

a) Man and technology (year 5): Observe the rules of health and safety, hygiene and behaviour.
b) Man and Production in Practice (year 5): Diagram of the body structure of plants and animals, comparison of body parts of moss and flowering plant, observation of the

external body structure of invertebrates. Describe the process of making a simple product. To present the design and making of a simple product from natural materials available in the region.

c) Utility and gift items (year 5): Make a sketch of a simple product, select technical materials and tools for making the product, design a work procedure for making the product, make the designed product, present the results of their work.
d) Graphic communication in technology (year 6): Determine from a technical drawing the dimensions of a depicted object, draw a representation of a simple object in one projection, assign dimensions to a depicted simple object, develop a project to compare different types of representations.
e) Electricity, electrical circuits (6th grade): Connect a simple electrical circuit on a building block, to describe the main principles of first aid procedure in case of electric shock, to connect separately other electrical circuits on an electrical building block according to the diagram.
f) Simple machines and mechanisms (year 6): Give examples of the use of simple machines, mechanisms and gears in practice, to compare some types of gears in mechanical toys.
g) Graphic Communication in Technology (year 7): Identify individual projections on a technical drawing, fill in a missing projection of an object on a technical drawing, draw a simple technical drawing of a product in three projections, explain the difference between a technical drawing and technical documentation, project the shape, dimensions, material and work procedure for a simple product of their own.
h) Technical materials and their working procedures (year 7): Design a technological procedure for making own product, implement selected working procedures of manual machining on products according to a technical drawing.
i) Household electrical appliances (year 8): Describe the principles of operation of selected electrical appliances, master the rules of use of selected electrical appliances in the home, calculate the electricity consumption of selected household appliances using the energy label.
j) Technical electronics (year 8): Connect a diode in the permeable and impermeable direction, to state the methods of controlling electrical appliances and devices in the home, to describe the principle of transmission of telecommunication signals.
k) Technical creation (year 8): Create technical documentation for own simple product in electronic form, design own product, implement on own product working procedures of manual machining of materials with the use of electrical circuits, develop a project of own simple combined product.
l) Residential installations (year 9): Explain the causes of possible faults in electrical installations and the resulting dangers to humans, list the most common plumbing and drainage faults.

m) Creative activity (year 9): Design a technological procedure for making a product, make a product using other working procedures, justify the need to use other working procedures of manual processing of selected materials in making a product, apply a simple electrical circuit on their own product, make their own more complex combined product according to their proposed project.

Summary of content standards:

1) Physics:

a) Characteristics of liquids and gases: Incompressibility, fluidity, divisibility, compressibility, and expandability.
b) Measurement and Experiments: Measurement of volume of liquids, mass of solids, temperature, and temperature time course.
c) Heat and Temperature: Heat propagation by conduction, convection, radiation, thermal conductivity, thermal conductors and insulators.
d) Light and Energy: Conversion of light to heat, sources of light, direct propagation of light, reflection and refraction of light.

2) Computer Science:

a) Algorithmic problem solving: Analysing a problem, using a language to write the solution, working with sequences of commands, cycles, branching and variables.
b) Software and Hardware: Working with files and folders, operating system, working on a computer network and the Internet.
c) Communication and collaboration: Searching for information on the web, working with graphics, and digitising graphical information.

3) Technology:

a) Man and technology (year 5): School rules, working regulations in the school workshop.
b) Man and production in practice (year 5): Product, origin of the product: idea – production process – product, design of a product to make life more pleasant for man
c) Utility and gift objects (year 5): raw material, material, semi-finished product, gift and utility object idea, design, sketch, dimensions, tools and instruments, work process.
d) Graphic communication in technology (year 6): Representation in technology, design, sketch, technical sketch, pictogram, technical drawing, dimension, chalking, types of lines, scale, representation of objects on one projection – scale, reading a simple technical drawing.
e) Electricity, electrical circuits (year 6): Electricity, production – energy conversion, sources, uses, circuits, elements and schematic markings, diagrams of electrical circuits, effects of electric current, first aid for electric shock.
f) Electrical energy, electrical circuits (year 6): Simple machines, mechanisms, gears – types and principles, uses (mechanical toys, mechanical devices and equipment in the home and in practice).

g) Graphic communication in technology (year 7): Representation of solids on three projections, technical documentation of the product, design, technical drawing of the own simple product.
h) Technical materials and their working processes (year 7): Technical materials - metals, wood, plastics, ceramic materials, glass, rubber, textiles, composite materials, properties and uses of wood working processes: cutting, splitting, drilling, gluing, joining with screws, joining wood by plating, surface treatment metal working processes: cutting, filing, drilling, riveting, bending plastics machining work processes: drilling, gluing, bending, forming, bolting, independent work, product by combination of materials
i) Electrical appliances in the home (year 8): Electrical appliances in the home, types of electrical appliances, principle of operation of electrical appliances, rules of safe use and operation, household economy, energy label (energy class) of electrical appliances, electricity consumption.
j) Technical electronics (year 8): Diode, transistor, integrated circuit, microchip, logic circuits, sensors and control elements, signal transmission, telecommunication technology.
k) Technical creation (year 8): Design, production technology, design and creation of technical documentation, design, PC, drawing programs.
l) Residential installations (year 9): Electrical wiring, high current, low current, basic elements of residential (house) installations, electrical installation materials, electricity consumption in the home, plumbing and drainage, basic elements and their function, regulation of consumption in the home, heating and air conditioning in the home, types of heating and heating, forms of energy, inspection and maintenance of residential installations.
m) Creative activities (year 9): Practical activities aimed at the manufacture of designed products, combined working themes, other available working methods in the field of woodworking, metalworking, plastics and electrical engineering, design and technical drawing of own more complex combined product, design.

Product part	*Care and observation*
Educational standard for the subject Biology	
Year	*5*
Thematic unit	Communities of organisms
	Nature and life
Year	*6*
Thematic unit	Living organisms and their structure
Year	*7*
Thematic unit	Vertebrate body structure and function
Year	*8*
Thematic unit	Basic life processes of organisms
	Heredity and variability of organisms

	Environment of organisms and humans
Year	*9*
Thematic unit	Inanimate nature and its exploration
Educational standard for the subject Chemistry	
Year	*7*
Thematic unit	Substances and their properties
	Transformations of substances
Year	*8*
Thematic unit	Important chemical elements and compounds
Year	*9*
Thematic unit	Thematic unit Carbon compounds

Table 2: Educational standards for care and observation.

Summary of performance standards:

1) Biology:

a) Communities of Organisms (year 5): Distinguish communities by organisms, construct food chains, and classify organisms into different communities.

b) Nature and Life (year 5): Distinguish between animate and inanimate parts of nature by example, decide which information to obtain by observation and which by experiment, choose a suitable tool for observing a particular natural phenomenon, observe natural phenomena with a microscope, magnifying glass.

c) Living organisms and their structure (year 6): Diagram the body structure of plants and animals, compare the body parts of moss and flowering plants, and observe the external body structure of invertebrates.

d) Structure and functions of the vertebrate body (year 7): Distinguish between the terms organ and organ system, explain the importance of organ systems for vertebrate life, justify the differences in the organs of the digestive system depending on food, compare external and internal fertilization, analyse the differences in the development of fish, amphibians, reptiles, birds, and mammals, plan and carry out behavioural observations of vertebrates.

e) Environment of organisms and humans (year 8): Identify how humans interfere positively and negatively with environmental components, monitor air, water, and soil pollution around school and home.

f) Inanimate nature and its cognition (year 9): Explain the dependence of organisms on inanimate nature and the influence of organisms on inanimate nature using examples, identify differences between minerals and rocks by observation.

2) Chemistry:

g) Substances and their characteristics (year 7): Systematic observation of properties of substances, distinguishing between mixtures and chemically pure substances, importance of water to life.
h) Transformations of Substances (year 7): Distinguishing reactants and products in chemical reactions, simple experiments on chemical combining and decomposition.
i) Important chemical elements and compounds (year 8): Orientation in the periodic table of elements (hereafter referred to as PTE), assess the impact of selected oxides, hydroxides, acids and salts on the environment, orientation in the pH scale, determine the pH of a solution using an indicator.
j) Carbon compounds (year 9): Differentiate between inorganic and organic substances, perform simple experiments to distinguish and identify inorganic and organic substances, characterise the importance of plastics, synthetic fibres, detergents and cleaning products.

Summary of content standards:

1) Biology:

a) Communities of organisms: distribution of communities, food chains, adaptation of organisms to the environment.
b) Nature and Life: Nature, animate and inanimate parts of nature, organisms, observation, experiment magnifying glass, microscope, telescope, microscopic slide, slide, cover slip, tweezers, preparation needle.
c) Living organisms and their structure: Structure of plants and animals, categorization of invertebrates, observation and presentation of results.
d) Structure and functions of the vertebrate body: Vertebrates, organ, organ system, reproduction and development of vertebrates, external fertilization, internal fertilization, development of the individual outside the body of the female, in the body of the female.
e) Basic life processes of organisms: Cell structure, nutrition, respiration, reproduction, and life cycle.
f) Environment of organisms and man: Environment, components of the human environment, ecology, environmental science, conditions of life.
g) Inanimate nature and its exploration: Inanimate and animate nature, minerals, ores, minerals.

2) Chemistry:

a) Substances and their characteristics: Observation of the properties of substances, distinguishing between mixtures and chemically pure substances, and the importance of water.
b) Transformations of substances: Chemical reactions, law of conservation of mass, chemical aggregation and decomposition.

c) Important chemical elements and compounds: Description of the Periodic table of elements (hereafter referred to as PTE), properties of substances and their relation to PTE, hydrogen, oxygen (ozone) iron, alkali metals (sodium, potassium).
d) Carbon compounds: Observation of the properties of organic substances: heating behaviour, solubility in water and organic solvents, flammability, composition of organic substances (most important elements of organic compounds), influence of substances on chemical processes in living organisms (vitamins, pharmaceuticals, poisons, drugs).

3 Educational Aid - Freshwater Aquarium

Building an educational aid such as an automated freshwater aquarium care system required several steps that included planning, design, selection of appropriate components, programming and testing. This process allowed not only the students but also the teachers to create a functional and sustainable system that enriched learning with practical skills. First, the basic objectives of the project and the requirements for the aquarium's functions had to be defined, such as controlling lighting, water temperature, oxygen supply, and monitoring pH and water level. It was useful to determine which functions would be controlled automatically and which would require manual adjustment, and what values (e.g. temperature range, ideal pH value) would be optimal for the chosen fish and plant species in the aquarium.

Based on the specifications, the necessary components had to be selected. The basis was a programmable logic controller (PLC), which made it possible to control the individual functions. Various sensors and actuators had to be connected to the PLC, such as a temperature sensor to monitor the water temperature, a filtration to clean the water and a heater to heat the water. The components were connected to the PLC and programmed to operate automatically or according to set intervals. Once the components were selected, it was necessary to design a basic electrical circuit that ensured that all components were properly connected and powered. This step involved working with voltage regulators and protection elements to ensure safe and reliable operation. Pupils created a circuit diagram and gained a basic understanding of wiring electrical components. They then needed to program the PLC to control the entire system in an automated manner. As part of the programming, the pupils created a sequence of steps that were regularly performed (e.g. switching the lights on during the day and off at night).

The PLC could also be programmed based on sensor data. The programming process allowed pupils to apply logical thinking and taught them the basics of automation processes. After programming, it was necessary to test the system and verify its correct functionality. In this step, it was checked that the PLC responded correctly to sensor changes and that the actuators functioned as required. Pupils identified faults and made the necessary calibrations – for example, setting the correct thresholds for switching the lighting or the temperature heater.

To complete the project successfully, it was important that the pupils produced documentation of the whole process. This included a detailed description of the individual components, a circuit diagram, a description of the program and the calibration procedure. Finally, the pupils presented the resulting system to others, which contributed to the development of their communication skills and ability to present technical solutions. The teaching aid thus constructed not only taught the pupils technical and scientific knowledge, but also developed practical skills in automation, teamwork, problem solving and project management.

Figure 1: Educational aid freshwater aquarium and control unit.

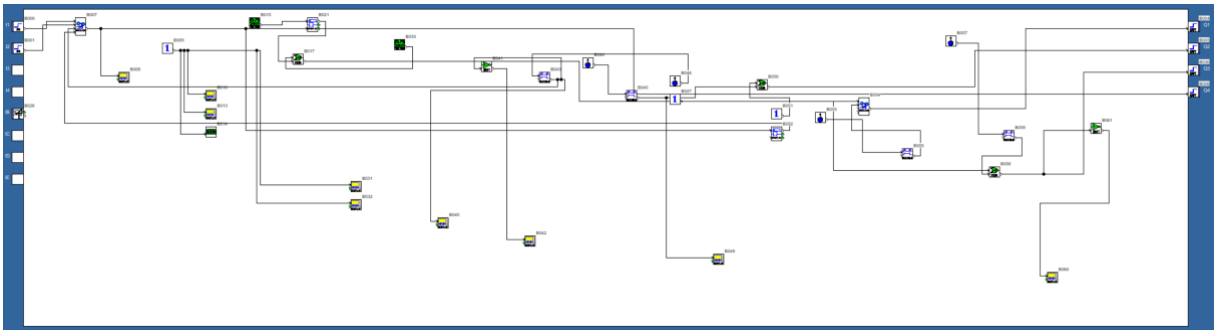

Figure 2: Control unit program.

The figure 4 shows a printout from the project documentation, where the program for the PLC is developed in detail. Individual diagrams, block diagrams and logical sequences that describe management processes are clearly visible in the foreground. The document contains a detailed description of the functions of each step, the inputs and outputs of the system, and the interconnection of logical operations.

4 Conclusion

The use of interdisciplinary relations in the teaching of PLC programming represents a promising approach that can promote the integration of theoretical knowledge with practical skills and thus improve students' readiness for professional practice. This approach emphasises the use of practical tasks and projects that allow the application of knowledge from different fields, leading to a better understanding of the links between various technical disciplines and increasing students' motivation to study technical subjects.

The integration of knowledge from different disciplines, such as technology, computer science, physics, biology, and chemistry, enables students to better understand complex technical problems and apply theoretical knowledge in practical situations. The creation of an automated freshwater aquarium care system demonstrates how theoretical concepts can be linked to practical applications, enhancing student motivation and engagement. This approach also promotes teamwork and project management, which are key skills for future professional practice.

Effective teaching of PLC programming can benefit from an interdisciplinary approach as it provides the opportunity to link theory with practical applications not only within technical subjects but also with aspects of mathematics, computer science and logical thinking.

The use of interdisciplinary relations in the teaching of PLC programming represents a promising approach that can promote the integration of theoretical knowledge with practical skills and thus improve students' readiness for professional practice. This approach emphasises the use of practical tasks and projects that allow the application of knowledge from different fields, leading to a better understanding of the links between the different technical disciplines and increasing students' motivation to study technical disciplines. Based on the results obtained, we recommend continuing to integrate interdisciplinary methods into technical education to ensure comprehensive preparation of students for the challenges of modern industry and technology.

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