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REVIEW OF CRITICAL SKILLS ANALYSIS IN NC PROGRAMMING EDUCATION

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Abstract: *New trends and solutions in the field of automation and robotization, about which a person uninitiated in the field has no idea, force to deepen the education of students for better readiness for practice. The expansion of students' education needs to focus on real practical activities using various technical procedures, tools, aids and devices. Sometimes robotics or automation is appropriate for a manufacturing activity or workplace, other times it is not. In order for the student or worker to be able to make the most effective use of the basic knowledge of logic and the appropriate skills in writing appropriate, functional and safe code in a given programming tool, the student must have a thorough knowledge of the equipment and its functions whose operation is being controlled. For proper development of technical knowledge, inclusion of simulation of NC programming, simulation of manufacturing system in the classroom is necessary. The research project needs to address the development of a multimedia textbook of NC programming for the creation of a suitable tool to support professional study information, to enable easy retrieval and easy orientation in the area under study. The research seeks input information for linking theory and practice in a multimedia design. The area is aimed at enhancing the learning of students. To focus on real practical activities using various technical procedures, tools, aids and equipment.*
Key words: *NC programming, CAD model, simulation, experiences of programming, algorithm*

1. INTRODUCTION

In this article, the author highlights the need to make the teaching of NC programming more effective and to use new approaches in the pedagogical process. It focuses on the use of simulations and other modern approaches in teaching. The analysis and synthesis of knowledge based on the study of literature and personal experience of the researcher was used. With the growth of automation, the job market demands skills from employees, namely independent problem solving, critical thinking and independent creativity. Times are constantly evolving and skills that are sufficient for the engineering industry may become obsolete or completely unnecessary in a few years. The industry sees a great future in the use of digital skills such as thinking in algorithms. In time, programming will not be seen as a specialized activity, but will be one of the basic skills like reading or writing. To acquire these skills, a great deal of collaboration with technology companies is being developed with technology companies to intervene as much as possible in the practical readiness of students and teachers in the dissemination of computer knowledge. Each sector can determine exactly what students or employees are needed for practice, what they should improve in order to compete in the labor market. The research elaborates the sequence of creation of the NC program for the production of the selected component and points out the problems that students but also educators may encounter when preparing students for practice, which is subsequently developed in the paper.

2.CURRENT STATE OF NC PROGRAMMING

To obtain education in the programming and adjustment of CNC machines and industrial robots and manipulators, it is necessary to get acquainted at a basic level with their subsystems and construction. Theoretical and practical knowledge and skills in programming and

setting up NC machine tools and welding robots and their use in production are essential. The education system is designed so that students acquire practical skills in close connection with the theoretical knowledge they have received in the study of technical drawing, engineering technology, mechanical engineering, technical measurement, and graphic systems. The aim is to continuously promote technical thinking and gain experience in operating and programming modern technological equipment. Technical possibilities always influence the practice of machinery and software.

The degree of skill in programming NC machines is defined at different levels:

- independently programming the machine operations;
- programming an industrial robot according to the technological process of manufacturing parts;
- to perform visual and gauge inspections;
- independently performing inter-operational inspection;
- operate conventional machines and equipment;
- operate and program automated machines and equipment;
- operate a PC;
- operate applications and specific software;
- actively use professional terminology.

In the educational process, these are comprehensive bases for work in practice, but is it also sufficient for a worker to work independently in the industry? Is it possible to expect ideal conditions in the pedagogical process and industry? How does theoretical skill affect success in the actual industry? All answers are expressed by feedback from employers who continuously support the university's cooperation and practice with university students.

3. INTRODUCTION TO PROGRAMMING, ALGORITHMS

Not everyone can program; it's a skill that must be learned and dedicated to for a long time. It is also why the programming profession is in high demand, as there are never enough programmers.

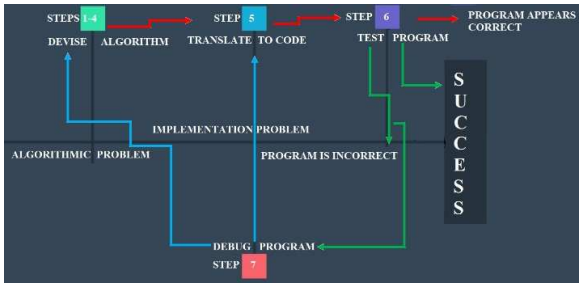


Fig. 1 The step programming process [5]

Programming refers to a constructive thought activity and a branch of computer science that deals with creating new programs and applications in a programming environment that uses a programming language. Such a program consists of three parts-algorithmizing the problem, making the program itself, and writing and fine-tuning it on the computer [2]. Figure 1 shows shown the steps of the programming process.

The literature describes a program as "an algorithm written in a programming language" [4]. An algorithm is a procedure for solving a problem using commands. An algorithm must satisfy several features - finiteness, elementary, determinism, resultative, sturdy and efficiency. Thus, an algorithm needs to be usable in practice, simple, understandable and unambiguous, its operation (response) time should be brief, and of course, it must solve the given problem [3]. When creating an algorithm, the following sequence must be followed: get familiar with what we want to achieve, write down the sequence, how to arrive at the result with logical steps, generalize these steps and test them [5]. An algorithm is actually a precise sequence of steps and instructions that goes from (changeable) input data to a result [5].

The term algorithmization refers to the ability of a human to actively create algorithms designed for a non-thinking device. It also requires a thorough knowledge of the problem environment, experience in formulating algorithms, and the ability to use the limited resources of a particular language. Programming is a constructive thinking as well as a practical activity where are working new software products that can be implemented on a computer. Programming develops the ability to think, to organize ideas and to be able to delegate their implementation to a computer.

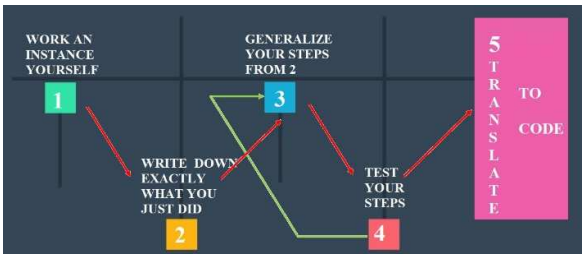


Fig. 2 Step-by-step process of algorithm creation [5]

Figure 2 shows the steps to be used in designing a general algorithm. If the algorithmization is properly designed by verification, the functionality of the written codes will be achieved. The backward steps can be used to ensure that the codes are fine-tuned for the NC program. Programming planning is about developing an algorithm to solve the problem. Translating the algorithm into code is relatively straightforward once the algorithm is designed (and tested). Once the program is implemented in code, that implementation will need to be tested – and probably debugged. The debugging process is much easier if there is a clear plan for what the program is supposed to do at each step [5]. When designing an algorithm, students must have experience analyzing input, output, auxiliary, and system variables, exploring flowchart solutions, and experience with C source code processing. The simplest type of algorithm is sequential algorithms. An algorithm consists of one or more calculations performed sequentially, and no step is ever repeated. In a branching algorithm, it is possible to define conditions that allow one to skip an input-output state, to switch a particular state, or to provide a two-three-way branching where one of several conditions is executed. In figure 3 displaying designing used algorithmic tasks, it is possible to use a control structure in a loop that consists of a condition and a loop body. According to the cycle repetition control, it is possible to define a cycle with a given number of repetitions, a cycle with a condition at the beginning, and a cycle with a condition at the end [14].

4. WHAT IS CNC?

CNC is in practice referred to as "computer numerical control", which with the use of

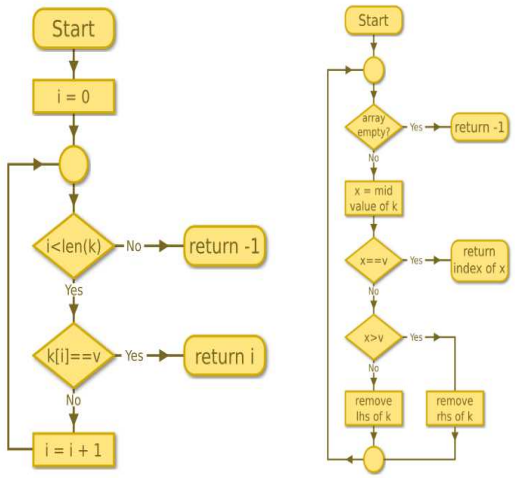


Fig. 3 Examples of algorithms (linear, binary) [16]

computer control and machine tools takes parts of the material from the input blank and ensures the production of the workpiece according to the selected technological parameters. NC systems can be divided into groups according to different criteria. As a rule, the basic criterion used is the complexity of the path along which the control system can guide the tool relative to the object of action in the technological process (workpiece, cut-out, etc.). According to this criterion, NC systems with discontinuous control (discontinuous) and systems with continuous control are distinguished. Continuous control systems are further subdivided into coordinate setting systems and orthogonal systems. The basic function of coordinate setting systems (PTP: Point-to-Point Control) is the setting (positioning) of the object of action (work piece) relative to the tool successively to individual predetermined points, usually hole coordinates. They are most commonly used on numerically controlled drilling and boring machines, but also on punch presses or spot welding machines. Orthogonal systems (LP: Longitudinal Path Control) are used on lathes, milling machines and machining centers. Continuous Path Control (CP) systems are characterized by the fact that the relative motion of the tool and work piece during machining is controlled continuously and simultaneously in at least two controlled axes.A variety of materials can be used for machining,

including metals, plastics, wood, glass, foam and composites. [6].

Since CNC machines use flexible automation, any change to the manufactured part can be made flexibly by changing the used program. The input information in the program is written using numbers and characters, and the individual parts of the program can be characterized as separate sequences of characters called blocks.

CNC machining design procedure:

- Design and creation of CAD model in available sofware;
- Conversion of models to CNC software;
- Creation (generation) of NC program (code) for the CNC machine;
- Simulation and machining process.

When working with CAM software, time is saved by working in parallel, where the machine can also work while the machining program is being created. A new machining program is built on an independent computer that does not need to be connected to the production machine. CAM software for more complex 3D parts is much more advantageous and faster than shop floor programming. NX, SolidCAM, Autodesk, Inventor and PowerMILL are the most commonly used CAM software. When switching to CAM programming, the generated NC code can contain errors that will cause significant damage to either the tooling, the workpiece or the failure of the entire machine. It was, therefore, necessary to generate NC codes and check them before they would be used in production. Verification systems that check the toolpaths of the generated NC code in the event of an impact report an error. In addition to checking toolpaths, verification systems can also be used to modify toolpaths or to optimize the cutting process. Verification systems are Vericut, Eureka & Autodesk HSM Edit and others.

4.1 Methodology of NC programming

The most used methodologies for programming NC machines can be:

-ISO programming;

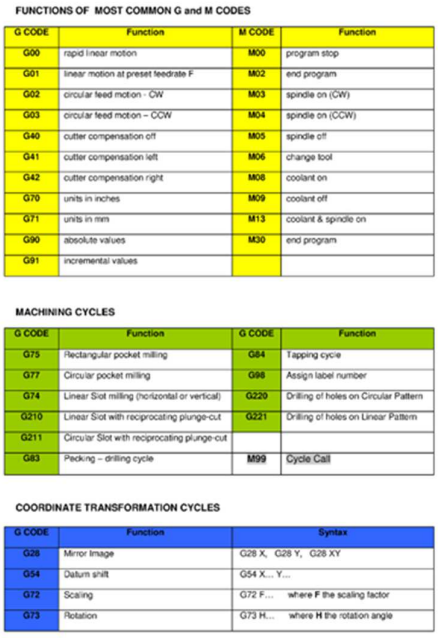
-Programming using machining cycles;

-Parametric programming;

-Workshop programming;

-NC program creation with CAD/CAM software.

ISO programming or G-code depends on the programmer's knowledge of the commands, their function and their use for each technology. The programmer must establish the procedure and principle of programming control systems. The composition of alphanumeric characters is arranged in blocks, which are made up of commands. Each command comprises an address and meaning part containing technological, geometric, preparatory and auxiliary information. The essential functions are divided into G and M codes in program design [17]. Their role is made up of address and numerical designations. They form the main part of the programming language that controls the machine tool. G -codes, which control the machine directly in terms of tool positioning for machining purposes. The basic codes that students must know are showing in figure 4 [1]. M-codes, which provide auxiliary functions to control the machine [15]. When setting up the machine for machining, it is necessary to set the correct zero point in the X, Z axes. When determining the toolpath, it is important to determine the coordinate system of the tool, where the X, Z axes are the basis. Determining the reference point "R" in the working area of the machine is defined by the limit switches.



FUNCTIONS OF MOST COMMON G and M CODES

G CODE	Function	M CODE	Function
G00	rapid linear motion	M00	program stop
G01	linear motion at preset feedrate F	M02	end program
G02	circular feed motion - CW	M03	spindle on (CW)
G03	circular feed motion – CCW	M04	spindle on (CCW)
G40	cutter compensation off	M05	spindle off
G41	cutter compensation left	M06	change tool
G42	cutter compensation right	M08	coolant on
G70	units in inches	M09	coolant off
G71	units in mm	M13	coolant & spindle on
G90	absolute values	M30	end program
G91	incremental values		

MACHINING CYCLES

G CODE	Function	G CODE	Function
G75	Rectangular pocket milling	G84	Tapping cycle
G77	Circular pocket milling	G98	Assign label number
G74	Linear Slot milling (horizontal or vertical)	G220	Drilling of holes on Circular Pattern
G210	Linear Slot with reciprocating plunge-cut	G221	Drilling of holes on Linear Pattern
G211	Circular Slot with reciprocating plunge-cut		
G83	Pecking – drilling cycle	M99	Cycle Call

COORDINATE TRANSFORMATION CYCLES

G CODE	Function	Syntax
G28	Mirror Image	G28 X, G28 Y, G28 XY
G54	Datum shift	G54 X... Y...
G72	Scaling	G72 F... where F the scaling factor
G73	Rotation	G73 H... where H the rotation angle

Fig. 4 Functions of most common G and M codes [16]

The position of the sled is defined by the sled's run-up to the reference point. The coordinate system is coordinate controlled. The X-coordinate lies in the direction of lateral movement. The Z coordinate lies in the longitudinal direction. Negative values are towards the workpiece and positive values are away from the workpiece [15]. When determining the workpiece zero point from the machine zero point, it must be defined according to the machining/tooling process. Then the tool must be measured at two distances, namely on axis and between the tool tip and the reference point. The length corrections are measured semi-automatically, the radius and tool position manually (Fig.5).

5. STUDENT AND CAD MODEL DESIGN

During the learning process, the student must acquire the skills to develop a 2D or 3D CAD design of a component in addition to programming skills. In the educational process, students use available software that allows designing CAD models, allows you to create a model or view parts and products in detail along with the necessary technical specifications such as dimensions and geometry. Its easy-to-use working environment allows you to design and create different models and compose them into finished products [8]. Since the program works on the cloud, users can access their creations on any device where the software is installed. It is possible to make selected projects available to specific users. In addition to CAD modelling, the software offers several working modules such as drawing, animation, simulation, manufacturing modules and many others, and they are constantly being developed and expanded.

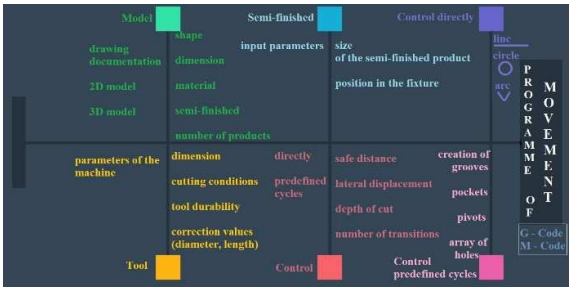


Fig. 5 Input conditions for defining NC machining

Usually, when the software is switched on, the solid modelling module is active (Fig. 6) [7].

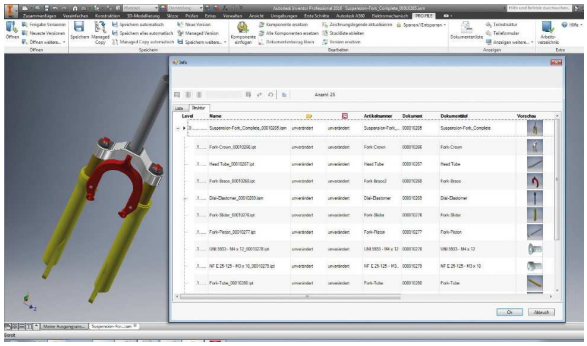


Fig. 6 The PRO.FILE product data and document management system [13]

6. WOKFLOW CAD-CAM-CNC

To validate the model's design, it is necessary to design an NC program on a virtual device, e.g.,Virtual Laboratories and Technical Simulators, i.e. to develop an NC program and validate the design in innovative software for e-learning and simulation of physical processes and phenomena (Fig.7) [9].

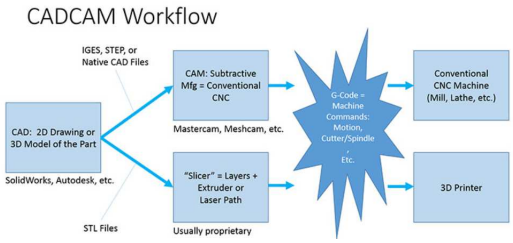


Fig. 7 Workflow CAD_CAM _CNC [11]

6.1 Using the CNC Lathe simulator

The student can gain skills and practical logic on how to work with G-code while working with the virtual CNC programming environment [9]. The simulation model is a lathe equipped with a CNC system. Material processing is performed in two axes in the horizontal plane (Fig 8).

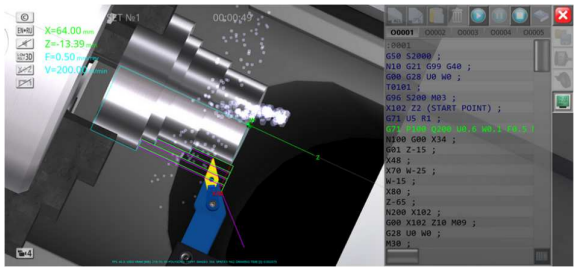


Fig. 8 Lathe simulation environment for training [9]

Important functions of the application: preparation of control program texts in standard GM-code format, control programs checking, playback on the computer screen of three-dimensional graphical models of the main components of the lathe .[9].

6.2 Using the CNC Milling simulator

Depending on the material machining process, it is possible to apply milling of parts using standard (ISO) G-code. The student works to create a graphical model of cutting tool trajectories in three-dimensional space and gains experience in selecting basic milling parameters [9].

The student virtually gains experience in the creation of the NC program, namely:

- setting the zero point of the workpiece, the tool itself and its correction;

- setting cutting conditions and spindle spinning;

- description of the geometry of the cutting paths;

The preparation and content part is repeated several times (possibility of using "call already defined blocks") due to changing cutting conditions, tool change, etc. The whole program is divided into steps, each representing one block (line) of the program. The blocks are numbered in ascending order, and one block contains one or several commands. A block consists of a block number and individual words. The block number begins with the letter N (number) and is followed by the digits, which are not separated. The individual words consist of an address part consist of a single letter and a meaning part composed of a sequence of numbers and are separated by at least one space, but the word parts are not separated (Fig.9) [9].

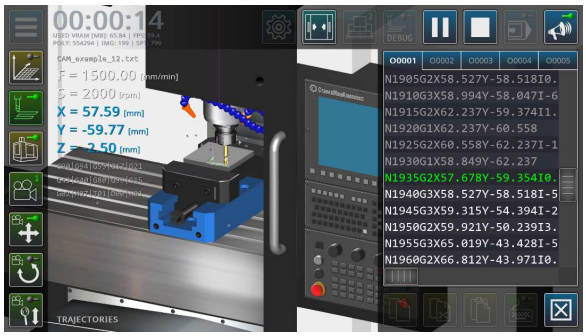


Fig. 9 Milling simulation environment for training [9]

Using a given virtual environment of CNC programming increases the flexibility and mobility of the educational process corresponding to the modern level of education informatisation.

In virtual programming, the student must have a basic understanding of logic and the proper skills in writing appropriate, functional and safe code in a given programming tool. Still, a thorough knowledge of the device and its functions, the operation of which is controlled, is required.

In programming computer-controlled machines, the problem to be solved is divided into sub-problems and algorithms are developed for these sub-problems. In the created program, cycles (repeated operations) are also used to make the product. This program is then tested on the computer using graphical simulation and put into operation on the CNC machine.

The programmer has to create a source code composed of commands that results in a program or software that solves the given problem in general. CNC machine programming uses a proprietary programming language only usable in software designed for that purpose.

It solves the specified problem at the hardware level, so it can only be used for a specific device to control a specific type of CNC machine [10].

7. ANALYSIS OF CNC TRAINING EXPERIENCE

The student is exposed to the production structure in CAD/CAM systems. He must acquire the skills and knowledge and learn the activities necessary for the ongoing processes to design the actual production of the component. At the beginning of the entire production process, drawings and the design and modelling of the part are drawn up in CAD software. CAD software models the part (e.g., SolidEdge, NX,...).

The following procedure is the programming and final simulation of the machining. For this, a CAM program is required. When verifying their skills, the student may encounter sub-problems (Fig. 10) [12].

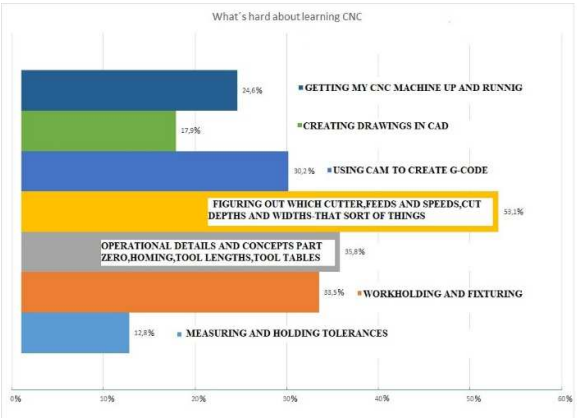


Fig. 10 Summary of critical points of students in CNC programming education [11]

Students need to gain experience in a variety of fields:

- adapting feed rate and speed to what the machine can handle;
- adapting cuts/views to suit the machine;
- analyzing how to go faster? Going slower? Getting a better finish? Longer tool life?;
- creating your database of materials used; Information how the material especially wood and plastics, behave during the process;

Getting a better finish? Longer tool life?;

- creating your database of materials used; Information how the material especially wood and plastics, behave during the process;
- acquiring practical tips that professionals take for granted, but beginners will only learn if they are lucky enough to be guided by professional CNC workers;
- experienced professionals can find ways to get feeds and speeds for unusual (weird) tools, but beginners need to get it from them practically or have it explained to them.

8. CONCLUSION

To ensure perfect precision machining on CNC machines, students must be educated in designing models, determining tooling and procedure of machining operations on CNC machines, program development and verification in available software where all physical processes and phenomena are verified. As part of the practical verification of skills on CNC machines, students or workers gain experience from more experienced workers or by practically solving problems that may arise. Workers acquire skills to avoid unnecessary excessive tool wear. How to select the correct size of tools and tool holders, and at the same time, choose the right speed concerning chip formation. Determining the correct toolpath type to avoid machine resonance and oscillation marks on the machined surface. Gain experience on how to select the tool diameter for machining corners. In the virtual simulation, students need to learn about the coolant nozzle alignment or the obstruction created in the flow, also causing the coolant to prevent the coolant from reaching the cutting surface. Selecting the correct coolant for the application and materials being addressed is important. If the coolant concentration is too low, it can have a negative effect on tool life and surface finish.

With years of experience with CAD/CAM software support and using a post-processor, any student can generate a program for a CNC machine. The method of debugging and simulating the program is acquired during the study, but the most relevant experience is gained by working directly with the CNC machine. In addition to analyzing the essential needs of an employee for work in industry, it is necessary to continuously support the development of pedagogical skills of university teachers who will be prepared to pass on the acquired knowledge to their students and constantly adapt to the needs of the market through their education in the field.

9. ACKNOWLEDGEMENT

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REVIZUIREA ANALIZEI COMPETENȚELOR CRITICE ÎN EDUCAȚIA DE PROGRAMARE NC

Rezumat: Noile tendințe și soluții în domeniul automatizării și robotizării, despre care o persoană neinițiată în domeniu nu are nicio idee, obligă la aprofundarea educației studenților pentru o mai bună pregătire pentru practică. Extinderea educației studenților trebuie să se concentreze pe activități practice reale, utilizând diverse proceduri tehnice, instrumente, ajutoare și dispozitive. Uneori, robotica sau automatizarea este adecvată pentru o activitate de producție sau un loc de muncă, alteori nu. Pentru ca elevul sau lucrătorul să poată utiliza cât mai eficient cunoștințele de bază de logică și competențele adecvate pentru a scrie coduri adecvate, funcționale și sigure într-un anumit instrument de programare, elevul trebuie să cunoască în profunzime echipamentul și funcțiile acestuia a căror funcționare este controlată. Pentru dezvoltarea adecvată a cunoștințelor tehnice, este necesară includerea în clasă a simulării programării CN, a simulării sistemului de fabricație.

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