Volume 27, Number 1, 2025

Global Journal of Engineering Education

Electronic logic gates in the education of mechatronics students

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ABSTRACT: This article presents and justifies the placement of electronic circuits that perform logical functions in the education content for mechatronics students, as well as the need to design a workstation for studying basic circuits performing these functions - logic gates - that would account for both their technological and functional transformations. On the basis of the analysis of existing solutions, a designed and constructed stand for testing logical gates is described. The descriptive part of the article is supplemented by an empirical part containing an assessment of the usefulness of the stand by a group of 12 expert users, graduates of engineering studies, who have several years of experience working with electronic circuits. The experts highly rated the tested laboratory stand - with an average score of 4.33 points (on a scale from 1 to 5) and formulated a number of valuable comments on the design and use of the workstation.

Keywords: Teaching aids, electronics teaching, mechatronics field of study, logic gates

INTRODUCTION

The socioeconomic transformations of the modern world, such as: globalisation, digitalisation, and the integration of production and logistics processes (the emergence of intelligent factories) [1-3], have created the need for universities to introduce more engineering, multidisciplinary fields of study, of which mechatronics is a good example [4][5]. Since the end of the 20th century, studies in mechatronics have become increasingly popular [6][7], and this field is currently offered in Poland by 37 universities [8].

Electronics, in addition to mechanics and computer science (automatics), has a fundamental place in the mechatronics field of study [6][9]. On the one hand, the high position of electronics can enrich an academic teacher, but on the other hand, it requires him to optimise activities aimed at selecting the content of education from a very broad field of knowledge, including the selection of methods and means of education.

In Poland, the current legislative provisions regulating the content of education at higher education institutions refer to the superior document, which is the Higher Education Act [10], which obliges assigning a given field of study to a scientific discipline or several disciplines and linking the learning outcomes with the qualification framework [11]. A historical document, to which many designers of fields of study and study programmes currently refer, is the *Education standard for the field of study mechatronics* [12].

The electronics content in the mechatronics field of study shows strong connections with basic science subjects - mathematics and physics - as well as with technical subjects, such as: automation, robotics, engineering graphics, computer science, electrical engineering, machine construction, manufacturing, mechanics, metrology and materials science (Figure 1 next page).

According to the standards, the following provisions appear in the content of electronics education in first-cycle studies: semiconductor elements; methods for generating electrical vibrations, generators; rectifier and power supply circuits; two-state and digital circuits; electronic (analogue and digital) measuring and driving circuits; elements of microprocessor technology; microcomputer architecture; microcontrollers; modern techniques and technologies of electronic circuits. The learning outcomes include skills and competencies: the design and analysis of control systems for machines and mechatronic devices. In second-cycle studies, the scope of electronics content is extended to include the following issues: circuit theory; microelectronics and microdrives; identification and advanced control; optoelectronics and embedded systems [12].

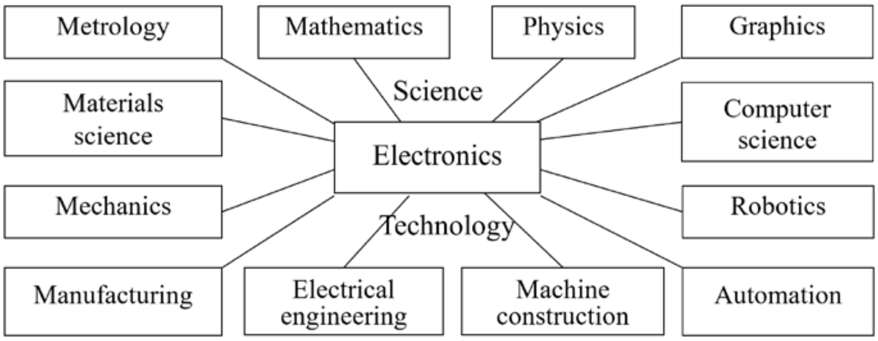

Figure 1: Interdisciplinary connections between electronic content in the mechatronics field of study.

Linking the abovementioned provisions with the levels of professional qualifications, a mechatronics engineer should supervise and organise the work of people with lower qualification levels: workers and technicians [13]. Therefore, the scope of qualifications can be specified by analysing the programme documentation (programme bases) for the profession of the mechatronics technician and mechatronics assembler. The qualifications of these professions include the assembly of electrical and electronic components and subassemblies (ELM.03.5.) and the following nine learning outcomes:

1. characterise the functions of electrical and electronic components and subassemblies;
2. explain the operation of electrical and electronic control circuits;
3. select electrical and electronic components and subassemblies for assembly in mechatronic devices and systems;
4. characterise the tools for the assembly and disassembly of electrical and electronic components and subassemblies;
5. use measuring instruments used during the assembly of electrical and electronic components and subassemblies;
6. assess the technical conditions of electrical and electronic components and subassemblies prepared for the assembly;
7. perform the assembly and disassembly of electrical and electronic components and subassemblies;
8. use methods for controlling the assembly of electrical and electronic components and subassemblies;
9. check the compliance of the assembly of electrical and electronic components and subassemblies with the technical documentation [14].

While installation work and minor repairs typical of maintenance require synthetic thinking with a two-state analysis of the system's operation, the design, construction and diagnostics of mechatronic systems should be based on a precise understanding and analysis of the phenomena occurring in electronic components and circuits.

As basic electronic components, logic gates, i.e. electronic circuits that perform logical functions, play a nodal role in the structure and operation of all electronic circuits [15-17].

The author's many years of observations and research clearly show that students using closed circuits in the form of a black box, including integrated circuits or computer simulations, are unable to connect the essence of the structure and functioning of logical circuits with other electronic circuits and the structure and functioning of analogue elements [18-22]. The occurrence of such a phenomenon has negative consequences for the teaching process and the implementation of professional tasks after graduation.

The abovementioned conditions resulted in the need to construct a stand for testing electronic logical functors at the Laboratory of Innovative Electronic Designs at the University of Rzeszów, Poland, taking into account both their technological and functional transformations.

THEORETICAL ASSUMPTIONS OF THE CONSTRUCTION AND FUNCTIONING OF LOGIC GATES

The difference in understanding digital electronics circuits from analogue circuits is determined by two regularities [16]:

1. Signals occurring in circuits can achieve a finite number of values (discrete signals). Most often, the number of values or so-called states (levels), is equal to two - high level and low level. In contrast, analogue signals can take on any value and change continuously.
2. Circuit elements, such as transistors and diodes operate in one of two extreme states: conduction (on, saturation) or nonconduction (off, cut-off).

In understanding electronic logic gates, the following issues also play an important role:

- showing the continuity of technological development - digital electronics circuits consisting of elements commonly used in analogue technology;

- learning the structure, operation and parameters of increasingly complex gate circuits - starting with switch circuits, then circuits using the following techniques: RDL (resistive-diode), RTL (resistive-transistor), TTL (transistor-transistor, bipolar), CMOS (complementary unipolar);
- showing the need to minimise the logical function before building the circuit;
- presentation of the possibilities of implementing various logical functions using full functors;
- wide application of logical functors in various digital circuits: switching circuits, code converters, arithmometers, counters, registers and memories;
- practical exercises with logical functors and functor circuits.

This research also revealed that the adoption of the symbolic convention (American), which is compliant with the ANSI/IEEE Std 91-1984 standard and its supplement ANSI/IEEE Std 91a-1991, which is based on traditional schemes developed in the 1950s and 1960s (MIL-STD-806), where the functions of the elements are defined by the different shapes of graphic symbols, is more important for the effectiveness of education than the (European) symbolism defined by the IEC 60617-12 standard, adopted in Europe as EN 617-12:1999, which is based on ANSI Y32.14 and other industrial standards, where the elements have a rectangular shape and the functions of the elements are marked with appropriate letter symbols placed inside the graphic symbols [22].

DESIGN ASSUMPTIONS FOR THE LOGIC GATE TESTING OF THE STAND

The search for a solution for a stand for testing logic gates began with an analysis of the subject literature. In parallel, an analysis of existing solutions was carried out on laboratory stands used in the educational process. In total, the structure and functioning of three stands were analysed - one in the form of a black box with inputs and outputs, the second one, in which the connections of the integrated circuit terminals with the connection sockets are realised on one mounting board, and the third one with a design similar to the second one, but extended with a transistor with biasing resistors. The abovementioned circuits are commonly used by students of vocational schools and university students in laboratory classes in electronics. Following the morphological method developed by Zwicki, the specificity of the structure and function of the abovementioned stands was translated into a circuit of solutions [23]. These activities allowed for the selection of the optimal solution in terms of the structure and implemented functions.

The comprehensive criteria for product evaluation proved useful during design and construction work. The criteria for assessing the set included general (universal) criteria [24-26]], criteria for assessing technical didactic aids [27][28] and detailed requirements related to the specifics of testing logic gates. The above criteria were assigned to two groups: design and utility.

The designed stand for testing electronic logic gates should meet the following design (design and construction) requirements:

- simplicity of construction - commonly used construction materials, electronic components and connectors - marked with K1;
- operational reliability (reliability, quality of permanent and detachable connections) - K2;
- ease of execution (in a university workshop) - K3;
- versatility - possibility of implementing gate circuits in various technologies - K4;
- availability of electronic components for disassembly and replacement - K5;
- durability - the stand’s housing should protect electronic components and connections against mechanical damage, and the station should operate without failure for a long time - K6;
- ergonomics - adapting the dimensions, shapes, colours of elements and their layout to human perceptual and manipulative capabilities - K7;
- originality - difference from other research sites - K8.

The tested stand should also meet the following operational requirements:

- visualisation - good visibility of elements, connections, connectors, symbols of elements and circuits - hereinafter designated - U1;
- accessibility - compliance of the location of elements with the schematic diagram of the circuit, gradation of the difficulty of the connected circuits - U2;
- ease of assembly and disassembly - U3;
- ease of connecting laboratory devices - U4;
- possibility and ease of measuring parameters, such as: propagation time, static power, maximum operating frequency, load capacity and taking transient, load and power - frequency characteristics - U5;
- expandable - U6;
- safety of use - electrical safety, protection against overvoltage, against polarity reversal - U7;
- multifaceted activation of those performing experiments - U8;
- possibility and ease of modelling the tested circuits - U9;
- completeness of instructions - names of tests, descriptions of exercises, diagrams of measurement circuits - U10;

- communicativeness of instructions - terminological clarity, stylistic correctness, coherence of drawings and text - U11;
- aesthetics of workmanship - precision of workmanship, harmony of shapes and colours - U12.

WORK DESCRIPTION

The stand for testing electronic logic gates was made via technology developed and improved by the author of the article. The front panel, made of acrylic glass (PMMA) contains a description and symbols of individual elements with connections. Switches and banana sockets are attached to the front panel, which allows for the assembly of circuits, connection of the power supply and connection of measuring devices. The switches and sockets on the front panel are connected by wires to discrete elements and integrated circuits are placed lower on the printed circuit board (Figure 2).

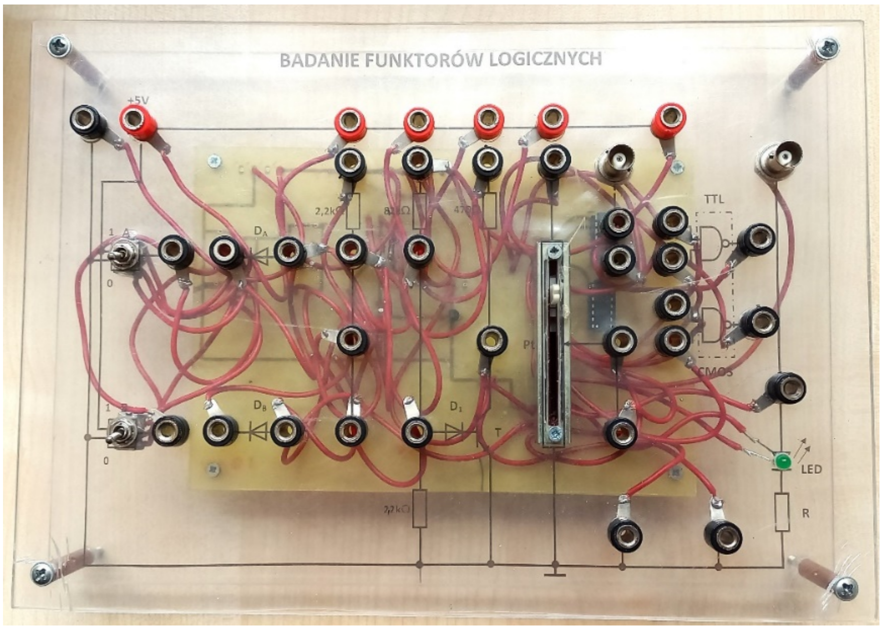

Figure 2: Logic gate testing stand.

The completed exercise set provides an opportunity to learn about the structure (elements, circuits are visible) and operation of logic gates made in various technologies: resistor-diode - RDL, diode-transistor - DTL, transistor-transistor - TTL and complementary-unipolar - CMOS. The stand also provides an opportunity for extensive modelling of measurement circuits and measurement of propagation time, static power, maximum operating frequency, load capacity, and removal of transient, load and power -frequency characteristics. A comparison of the measured parameters of logic gates made with various technologies will allow for learning the advantages and disadvantages of individual circuit solutions. Information obtained during lectures, deepened during laboratory classes, will allow for comparisons of the parameters and characteristics of specific systems with theory and the ability to draw appropriate conclusions.

ASSESSMENT OF THE STAND

The designed and constructed stand was evaluated by a group of twelve expert users. The evaluation team consisted of Master's degree students in the field of mechatronics, who were professionally active in the area of electronic mechatronics (minimum three years of work experience). They demonstrated strong knowledge of the theoretical and design issues of electronic circuits, as evidenced by high grades in electronic-related courses (average above 4.5) and an engineering thesis in electronics with a minimum grade of 4.5 (on a scale from 2 to 5).

At the beginning of the evaluation procedure, the students were acquainted with the purpose of the evaluation, and the subject of the evaluation, the structure of the evaluation sheet, the importance of individual criteria and the method of providing answers were discussed. Then, the students individually learned about the structure of the research station, performed the exercises included in the instructions, and expressed their opinions on the quality of the station by filling in the evaluation sheet. The evaluation sheet for the didactic tool included questions referring to the eight design and production criteria presented in the article and 12 utility criteria, which the students assessed on a five-point scale from 1 to 5 points (1 point - the lowest value, 5 points - the highest value). The validity of the research tool was ensured by the convergence of the questionnaire questions with the adopted criteria for assessing technical didactic tools. The reliability of the experts was assessed, via Krippendorff's alpha coefficient, which was to 0.83 [29].

The students highly rated the tested laboratory set (Figure 3, next page). The overall assessment score of the stand was 4.33 points. The design features of the set were rated at 4.42 points, whereas the functional features were rated at 4.26 points.

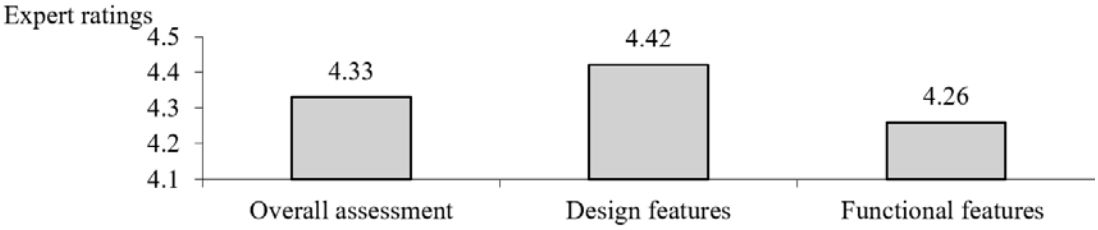

Figure 3: Expert ratings from a given category of evaluation criteria.

An analysis of the results for individual criteria (Figure 4), revealed that the highest score was given to simplicity of construction (4.75 points), followed by ease of construction and ease of connecting laboratory devices (4.67 points), operational reliability, versatility and ergonomics (4.58 points), and accessibility and safety of use (4.42 points).

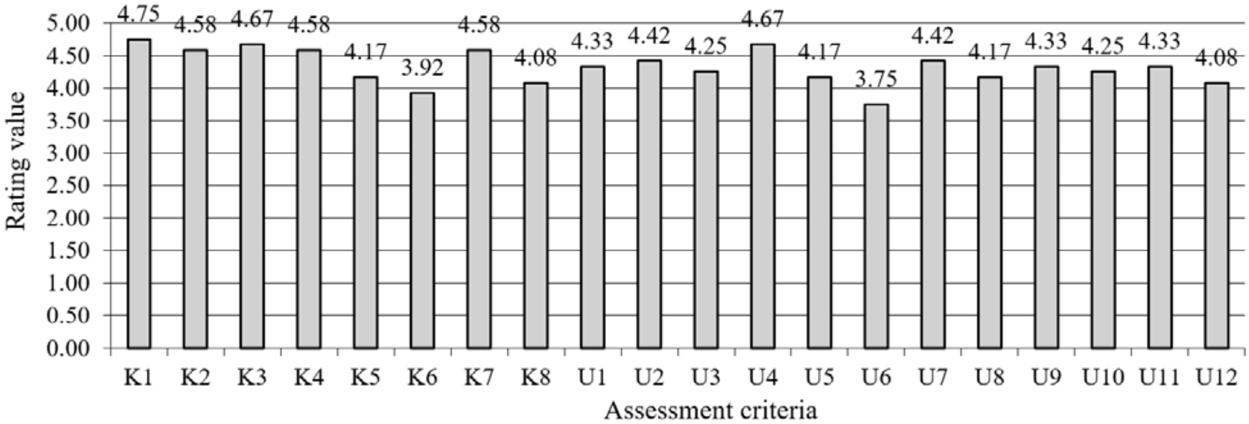

Figure 4: Assessment of the position on the basis of individual criteria.

Three features of the stand were also rated at a high level of 4.33 points: illustrativeness, possibility and ease of modelling the tested circuits and communicativeness of the instructions. Slightly below average were the following: ease of assembly and disassembly; completeness of the instructions (4.25 points); availability of electronic components for disassembly and replacement; possibility and ease of measuring parameters; multifaceted activation of those performing experiments (4.17); originality and aesthetics of workmanship (4.08 points). Below 4 points, the respondents rated two features: durability (3.92 points), and the possibility of expansion (3.75 points).

DISCUSSION AND CONCLUSIONS

The evaluation of the stand for testing electronic logic gates by mechatronics students with considerable professional experience confirmed the great usefulness of the circuit as a teaching aid. The construction values of the stand were very high at 4.42 points. The utility values were rated slightly lower - also high - 4.26 points. A characteristic feature of the tested stand is the high evaluation of parameters such as: ergonomics, ease of connecting laboratory devices, safety of use and operational reliability, which in the opinion of experts in the technical issues of teaching aids play a leading role [27].

A valuable tip for designers resulting from the low estimate of the circuit expansion (3.75 points) is to consider expanding the elements enabling an increase in the number of gate inputs and introducing, in addition to TTL and CMOS circuits, bipolar ECL (emitter coupled logic) and I^2L (integrated injection logic) circuits. To increase the durability of the circuit (3.92 points), replacing the sockets with more precise ones, increasing the thickness of the front panel and introducing plastic sleeves for the four screws fastening the end plates of the stand were suggested. Valuable comments also concerned increasing the distance between the printed circuit board and the connection board, using different colours of wires connecting the sockets with the elements and shortening their length.

The study of logic gates, as a basic exercise in digital electronics, involves a very large activating charge in the cognitive and operational layers. A well-made and aesthetically made research station also arouses interest and evokes a positive attitude in students.

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BIOGRAPHY

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