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Improvement of study programs for bachelor's and master's studies in Mechatronics in response to the requirements of Industry 4.0

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Abstract: *Development in information technology has resulted in revolutionizing all aspects of life and this revolution has been realized as Industry 4.0. A main approach that universities' educational systems may take towards Industry 4.0 is educating students who have the right skill set for reacting to the changes in their working environment, adapting their performance, and learning to cope with technological development. This paper presents the results of the project "Improvement of study programs for bachelor's and master's studies in Mechatronics in response to the requirements of Industry 4.0", which was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia as a part of program activity "Development of higher education" and performed in the 2020/21 academic year.*

Keywords: *curriculum redesign; university education; improving the student's skills; Mechatronics; Industry 4.0*

1. INTRODUCTION

The Mechatronics study program was founded at the Faculty of Technical Sciences in Čačak, as one of the first ones in Serbia, back in 1990. It has a tradition of 30 years, with permanent monitoring of modern trends in the industry, under which the study program was continuously innovated.

The purpose of such bachelor's and master's academic studies is the education of engineers who possess multidisciplinary knowledge in the field of mechanical, electrical and computer engineering, which are necessary for the successful implementation of academic and professional work in the field of mechatronic engineering and technologies, in accordance with trends and requirements imposed by modern industry 4.0 [1].

In consideration of the fact that the increase in interest in mechatronics engineers is conditioned by the accelerated technical and technological development and the increasing demand for that profession, the bachelor's and master's degree programmes in Mechatronics are aimed at the education of engineers for the design, development, reengineering and maintenance of mechatronic systems, in a way that they ensure the acquisition of competencies that are socially justifiable and useful [2].

These experts are necessary to work in the industry that will be applicable in the future period for many years and will maintain engineering knowledge in accordance with the needs of modern society.

By completing these study programs, students are qualified to be mechatronics engineers which are competent in both European and global frameworks [3].

The strategy and policy of industrial development of the Republic of Serbia envisage strengthening the educational capacities of technical faculties, with a focus on developing practical skills, creativity and leadership in all areas of engineering, in response to the requirements of modern Industry 4.0. According to this, the Faculty of Technical Sciences in Čačak developed a project "Improving the study programs of bachelor and master studies in Mechatronics", which is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through the fund for the support of projects for higher education development.

2. REDESIGNIG OF CURRICULUMS

The improvement of the students' skills was carried out due to the innovation of the educational content of courses in bachelor's and master's academic degree programmes in Mechatronics at the Faculty of Technical Sciences in Čačak. Improvements enable students to more easily integrate into the digital world of Industry 4.0 as future bachelor and master multidisciplinary engineers. The curriculum innovations in the selected courses enable future mechatronics engineers to understand modern trends in the field of information technologies and develop their awareness of the essential requirement for constant education and continuous upgrading of obtained theoretical knowledge [4].

The improvements include four courses in the bachelor's and master's degree programme in Mechatronics:

A. Bachelor degree courses

1. Hydraulics and thermotechnics, mandatory course, 4th semester
2. Process automation, obligatory course, 8th semester

B. Master degree courses

3. Robotics, the only mandatory course in 4th semester
4. Modeling and simulation of mechanical processes, obligatory course in 1st semester

2.1. Specific goals of improvement

Specific goals of curriculums improvement were:

1. Acquisition of new software tools (*MATLAB* with specialized follow-up modules: *Simulink*, *Robotics System Toolbox*, *Fuzzy logic toolbox*, *Deep Learning Toolbox*, *Simscape*, *Simscape Fluids toolbox)* which will provide students with quality professional education in the domain of application of information technologies essential for their training for the Industry 4.0 concept [5];
2. Purchase of equipment for creating new and improving existing laboratory exercises in laboratories for mechatronics, process engineering and mechanical testing;
3. Introduction of remote experiments in courses for access from distance locations;
4. Developing of four educational electronic publications to support the implementation of the courses;
5. Integrating the mentioned teaching elements into the distance learning system *Moodle*;
6. Building Faculty of Technical Sciences in Čačak - to - Industry partherships by signing agreements of cooperation, with a plan of activities that would be implemented at the Faculty and through professional visits to companies [6].
7. Establishing Faculty-to-Industry partnerships by establishing cooperation agreements, creating a schedule of activities to be carried out at the Faculty, and conducting professional visits to companies;
8. A special focus was aimed at the realization of a workshop on programming industrial robots in cooperation with the Science and Technology Park in Čačak, as support for improving the entrepreneurial skills among students.

2.2. Developing digital competences

One of the important goals of the project was the development of advanced and highly specialized competencies of students, i.e.:

1. Information literacy and understanding of data

The use of several types of specialized software for work simulation, design and programming of mechatronic systems are provided in classes. Innovating the content of the courses in bachelor's degree programme is the introduction of *MATLAB/Simscape*, *Simscape Fluids* software for simulating the operation of hydro-pneumatic components (course 1) and *MATLAB* software with following modules (*Fuzzy logic toolbox*, *Deep Learning Toolbox*) for the control and regulation of mechatronic systems (course 2).

Innovating the content of the courses in bachelor's degree programme is the introduction of *MATLAB*/*Robotics System Toolbox* software (course 3) and modern equipment and *ABB RobotStudio*'s software tools for robot programming (course 4) through which students will have the opportunity to be able to use the highly sophisticated equipment found in Industry 4.0 [7].

With the help of the above-mentioned software, students can realize simulation, management, control, measurement, and processing of the obtained results.

2. Communication and collaboration

The existing *Moodle* courses were improved for courses 1, 2, and 3, and a new one was developed for course 4. The course materials are published on the Faculty's e-learning system, which contains the content needed for teaching (presentations, animations, applets), as well as material for exam preparation (scripts, questions, solved examples). Students can use these materials on any available electronic device that has an internet connection (computer, tablet, or mobile phone).

The student acquires competences for communication and collaboration by selecting suitable digital services for communication.

3. Creation of digital content

By applying modern software tools *MATLAB* and *ABB RobotStudio* students can independently create, edit, and save digital materials within the laboratory exercises, based on the provided criteria. The software enables students to use ready-made elements of mechatronic systems and, based on the given criteria, realize their own system. Also, they can demonstrate competence in creating digital content through independent practical use of software tools for systems presented during lectures.

4. Safety

During the realization of laboratory exercises, students use components of mechatronic systems, a real industrial robot *ABB IRB* 120 as well as the most advanced collaborative industrial robot YuMi, they learn about the safe way of using the robots, and the proper connection and configuration of the system. During the implementation of exercises using software tools, students learn about the options of protecting digital content, in order to ensure the safe operation of industrial systems in real conditions.

5. Problem solving

The improved courses are designed so that students can independently solve specific real problems in exercises (calculation and laboratory). The practical functionality of the laboratory exercises that are realized using the software, students can also test in a laboratory environment. As part of the collaboration with the companies, students get to know how to solve problems that occur in real practice. Competence for solving problems is demonstrated through critical analysis and the selection of adequate software solutions for presentation, simulation, and management of mechatronic systems.

2.3. Development of entrepreneurial competences

The curriculums developed are primarily intended for students who plan their future professional engagement in the field of engineering. A wide range of knowledge and skills in the use of information technologies also enables them to work professionally (independently or collaboratively) in Industry 4.0 [8]. As part of the project, the following entrepreneurial competencies are developed among students:

1. Ideas and opportunities

Creativity - Advanced level: Students are able to transform ideas into solutions that create value for others. Through the lectures, the basic principles are explained to students, and they are introduced to a specific problem. Within a defined times frame during the semester, they have the task of realizing their ideas through a specific functional program. In order to realize the task, they combine theoretically acquired knowledge, IT and technical resources to achieve the best possible results.

Evaluation of ideas - Intermediate level: Students understand that ideas can have different values, which can be used in many ways. The concept of updated courses is that students can solve a specific practical problem independently or in teams. When programming, they independently design the algorithm and do the programming. Students present their projects in class and can compare solutions to problems, notice differences, advantages, and disadvantages, and improve their work if necessary.

2. Resources

Motivation and perseverance - Intermediate level: Students are ready to invest effort and resources to create value for others. By mastering the content of innovative courses, students increase their motivation and self-confidence to solve problems they may meet in the real industry environment. They develop competence for handling resources by using available technologies, equipment and software to solve given problems, thereby strengthening other competences needed for the idea realization.

3. Taking action

Taking initiative - Intermediate level: Students know how to initiate value creation activities. They are encouraged to independently recognize a relevant problem, define their project task, create an activity plan, face challenges and realize it by achieving the set goals.

Working with others - Basic level: Students know how to work in a team. Certain activities are realized as a team, where the final value relies on the successful performance of each individual. Most project assignments in updated subjects contain all or some of the following activities: understanding the problem, setting up the apparatus, setting the parameters, writing the program, testing the program, starting the application, checking for errors, recording the measurement results, writing the report, and presenting the work.

Learning through experience - Advanced level: Students can improve their ability to create value by learning from others, building on previous experiences, and interacting with others. By solving simplified programming tasks by applying the same learned programming principles, students can create new, significantly more complex programs based on the acquired experience (positive and negative). They are more willing to take on new challenges and gain confidence and readiness to solve more demanding tasks.

2.4. Human and technical capacities

Two accredited study programs relevant to the field of this project are realized at the Faculty of Technical Sciences in Čačak (Electrical and computer engineering and Mechatronics) at all levels of study, i.e., bachelor's, master and PhD. The Faculty is well equipped for the realization of these courses of these study programs and has appropriate IT resources.

For many years now, the Faculty has achieved intensive cooperation with companies with which it has signed contracts on business and technical collaboration, through the implementation of mutual projects, various types of training and research for the economy. Within this cooperation, the Faculty received modern industrial equipment, which is utilised through courses in the Mechatronics study program, where students can apply their theoretical knowledge to concrete applications found in the industry. The software was also acquired through the project which contributes to the innovation of the courses, together with the help of donated equipment, as well as equipment purchased from the Faculty's income. The faculty has a numerous number of signed agreements on the realization of students' professional practice with companies, mainly from western Serbia.

3. RESULTS OF IMPROVEMENTS

Through the realization of the project, all the planned goals were fully achieved, which are reflected in the following:

Course 1: ROBOTICS

Within the Science and Technology Park in Čačak, thanks to the funds provided by the Ministry of Education, Science and Technological Development of the Republic of Serbia, a new research laboratory in the field of robotics was created. Under the cooperation with the Science and Technology Park, the Faculty of Technical Sciences in Čačak was allowed to use a laboratory equipped with modern industrial robots for conducting practical laboratory exercises in the field of robotics.

Acquisition of new laboratory equipment and software tools: The course was innovated by expanding its content through the development of new laboratory exercises. In these exercises programming of industrial robots is studied using the *ABB RobotStudio* program, which represents software support for offline programming of *ABB* robots. For this purpose, the following parts were made: a gripper for the robot, aluminium supports and optical sensors with which a safety curtain was made between the two robots.

Preparation and implementation of new laboratory exercises: The innovative teaching content for cousre is very important for the future work of mechatronics engineers in the field of robot control and programming. As a part of the pre-examination activities, each student completed a project task using the ABB RobotStudio software. They modelled the robot system and the operating parameters of the system, such as: creating the robot's working environment, adding the necessary robot components, the workbench, the tool, and the object of processing. Then the characteristic points and paths of the robot's motion are defined. Path validation is performed by simulation, after which the code is transferred to the robot's physical controller. Once the code is loaded into the controller, the robot is fine-tuned and put into operation on a real robot system in the laboratory. In this way, students are fully familiarized with robotic systems, from theory to practice. This type of education allows students to develop an engineering way of thinking, connect theory and practice knowledge, and prepare them for work in the industry.

Faculty is increasingly emphasising and utilising close ties with industry and industry professionals to keep up with the changing role of Faculty in society, from centres of learning to centres training graduates to be job-ready. As a part of the course, an expert in this field Mr B. Mrgud from ABB Belgrade, gave the presentation "Management and programming of a collaborative industrial robot". (Fig. 1).

Figure 1. *Industry expert presentation for the students at the Science and Technology Park*

A robotics workshop was also held as part of activities outside of classes. (Fig. 2).

Figure 2. *Realization of a robotics workshop*

As a support for the implementation of laboratory exercises, a practicum in the form of electronic publication was issued: *OFF-LINE* programming of industrial robots - *ABB RobotStudio*, which is available to students on distance learning system *Moodle.*

Course 2: MODELING AND SIMULATION OF MECHANICAL PROCESSES

Acquisition of new laboratory equipment and software tools: Innovation through this course was carried out by expanding the content of the course through the introduction of new laboratory exercises based on the application of software tools for solving the mechanics of complex technical systems with multiple degrees of freedom. For this purpose, the *MATLAB* software package and its additional modules were acquired (*Simulink* and *Robotics System Toolbox*), as well as the corresponding literature, necessary for the proposed improvements.

Preparation and implementation of new laboratory exercises: New laboratory exercises have been introduced, with the implementation of computers in mechanical calculations. Each student completed a project using *MATLAB* software and its *Robotics toolbox* module as part of the pre-exam activities. He had the task of solving kinematics and dynamics, as well as simulating the movement of a complex mechanical system with multiple degrees of freedom, such as industrial robots. By modelling robotic systems using acquired software, the necessary parameters for sizing and selecting a robot for a specific application can be calculated. By simulating the operation of such systems, the possibilities of using robots for various purposes can be verified. In this way, students are introduced to the great importance of modelling and simulation of mechanical processes, from the standpoint of the fact that all mechanical systems can be modelled and tested in different conditions before final production, which can significantly reduce production costs.

As a support of the teaching classes (lectures and exercises), an electronic publication entitled: *Modeling and simulation of mechanical processes* was published and is available to students on the Moodle learning platform.

Remote access for performing laboratory exercises is provided for both courses of the master's degree programme (Robotics and *Modeling and simulation of mechanical processes*). Remote access is provided through a computer located in the Laboratory of Robotics at the Science and Technology Park in Čačak via the free application *AnyDesk* (with prior appointment via the *Microsoft Teams* platform).

Course 3: PROCESS AUTOMATION

Acquisition of new laboratory equipment and software tools: The proposed modifications and improvements of this subject, through project activities, are related to the introduction of new teaching content and introducing students to artificial intelligence techniques (neural networks, genetic algorithms, swarm intelligence, fuzzy logic, neuro-fuzzy systems) and their applications. For this purpose, the *MATLAB* software package and its additional modules (*Simulink*, *Deep Learning Toolbox*, *Fuzzy Logic Toolbox*) necessary for the proposed improvements of the teaching subject were acquired.

Preparation and implementation of new laboratory exercises: For this subject, 14 new exercises were created and implemented in *MATLAB*. All the exercises are related to the content (case studies) in the realized publication *Intelligent Modeling and Control - MATLAB Simulations*, which is required for the successful implementation of the exercises. The textbook is available to students at the electronic learning system of the Faculty of Technical Sciences in Čačak.

Subject 4: HYDRAULICS AND THERMOTECHNICS

Acquisition of new laboratory equipment and software tools: The innovation of the theoretical content of the course Hydraulics and thermotechnics was carried out following new literature sources, some of which were purchased from the funds specified in the project budget. The subject was innovated by expanding the content of the course through the introduction of new laboratory exercises based on the implementation of the *MATLAB/Simscape Fluids* software tool used for modelling and simulating fluid systems. For this purpose, the *Eplan* software package and *MATLAB* with its additional module (*Simscape Fluids toolbox*) needed for the proposed improvements of the teaching subject were acquired. In order to create new laboratory setups, pneumatic components such as cylinders, forks, hoses, mounting profiles, connections, cables and clamps were also acquired.

Preparation and implementation of new laboratory exercises: Students' practical and research work were improved using mentioned software through the lectures and independent work. As a part of the pre-examination activities, each student finished a mini-project using *MATLAB*, *Simulink* and the *Simscape Fluids toolbox*. They modelled the hydraulic system and determined the operation parameters of the system, such as flow rate, fluid flow speed through the pipeline and necessary pump power.

As part of the course, a lecture by a business expert, Mr M. Jović, from the *Alfaco Čačak* company was conducted. The topic of the presentation was "Designing hydraulic installations using modern application software", during which students learned about solving real hydraulics problems in practice. (Fig. 3).

Figure 3. *Lecture by an industry expert at the Faculty*

In support of the realization of the exercises, the electronic publication *Practicum for Modeling and Simulation of Fluid Systems* was published and is available to students on the Moodle learning platform.

Evaluation of the effects of the innovative content implementation on the course Hydraulics and thermotechnics was carried out at the end of the semester. (Fig. 4). On a scale from 1 to 4, students evaluated all questions with an average score between 3-4. The results of the evaluation showed that the innovations of the course were positively evaluated and that the teaching content is significant for their future engineering work in controlling the industrial hydro-pneumatic systems.

Evaluation of the application of SIMSCAPE FLUIDS software in the subject of Hydraulics and Thermotechnics. 17.6.2021

No.	Question	Average (1-4)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	The teaching material is well structured and presented in an understandable way.	3.6	4	4	4	4	4	3	3	4	3	4	3	3	3	4	4	4	4	3	4	3
2	Teaching content presented through practical examples contributes to an easier understanding of the material.	3.6	2	4	4	4	3	3	3	4	4	4	4	3	4	4	4	4	3	4	4	3
3	I was introduced to how to use the SIMSCAPE FLUIDS software.	3.25	3	3	3	3	3	3	4	4	3	4	3	2	3	1	4	4	4	4	3	4
4	Using software in classes to demonstrate practical examples contributes to greater satisfaction and motivation of students.	3.5	4	3	4	3	4	3	4	3	4	4	3	2	4	4	3	4	3	3	4	4
5	The subject course on the E-learning portal was useful for the realization of pre-exam obligations.	3.4	3	3	3	3	4	3	4	4	2	4	4	4	4	4	4	4	2	2	4	3
6	I consider the subject course on the E-learning platform necessary.	3.4	2	4	3	4	4	3	4	3	2	4	3	3	3	4	4	4	3	3	4	4
7	The practicum posted on the E-learning platform was helpful in doing the homework.	3.55	1	4	4	4	4	4	3	4	2	4	3	3	4	4	4	4	3	4	4	4
8	The application of the program enabled me to gain a better insight into the professional activities of engineers.	3.35	4	3	4	3	3	4	4	4	3	4	4	3	3	2	3	4	3	2	3	4

Figure 4. *Evaluation of innovative content on the course Hydraulics and thermotechnics*

The Faculty of Technical Sciences has performed cooperation with the following companies in the field of education and professional work with the aim of active participation of students in existing projects in order to gain practical knowledge and get familiarised with new technologies: Sloboda Cpmpany Čačak, Vorwerk Autotec Serbia, Knjaz Miloš Aranđelovac, Elsat Čačak, Wieland Production Čačak, and Cemprom Čačak.

4. CONCLUSION

The world of work is currently definitely changing because of the influence of digitalization. The industry is today facing a fourth industrial revolution, which has gradually spread throughout the world, directly influencing the activities of engineers and universities. Based on today's engineering education, the needs are shown that should be reflected not only in the improved curricula but also in a realignment of teaching and learning because this is based on the new working environments. In the process of education of appropriate engineers who will be able to meet all the requirements in Industry 4.0, both universities and companies are faced with enormous challenges that they will be able to successfully implement in cooperation with various stakeholders.

In this paper, project activities, which were performed at the Faculty of Technical Sciences in Čačak, focused on the improvement of Mechatronics engineering courses are shown. The obatined results of the project enabled the improvement of education content and the development of courses primarily intended for students who plan their future professional engagement in the field of engineering. An improved and spread range of knowledge and skills in using information technologies in different engineering disciplines allows students to work professionally (either independently or collaboratively) in Industry 4.0.

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