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Operating Systems Course Modeling Through 12 Aspects and ISO/IEC Standardization

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Abstract: *The presented model of the accredited Operating Systems course syllabus (OSs, along with Moodle course), through 12 x n dimensions (12 aspects in n dimensions): 12 topics, 12 goals and 12 expected competencies (outcomes), is fully aligned with key principles and ACM/IEEE recommendations, seen through the prism of SRPS and ISO/IEC standardization. The verification of the compliance of the proposed Moodle course content model is conducted by a comparative analysis of the course content on an international level, as well as with other universities in the region and EU countries. The results obtained during the research indicate full coverage and flexibility towards novelties of 14 standardized aspects of Information technology through the OS hierarchical structure. These aspects can be easily reduced by with and depth to 12 aspects of Operating Systems. In addition to modeling and innovating the Operating Systems course content through 12 aspects, the paper analyzes the compliance of goals and students' competencies as well as regional and international content compliance. Examples of good practice are documented by effectiveness, which is confirmed by the achieved competencies and a wide range of (possible) knowledge, by applying the model in emergency conditions.*

Keywords: *Operating systems, content model, goals, competencies, standardization*

1. INTRODUCTION

Operating system (OS) as the most important system software on the computer is the core of the computer software system [1,2]. Therefore, it is necessary for every student attending software and computer engineering to have a basic knowledge of design principles and implementation of operating systems [1]. The Operating Systems (OSs) course belongs to the group of the most important professional and basic courses, realized as a compulsory part of the classic curriculum in undergraduate academic studies (OAS) in computer science, information technology, software and computer engineering. The course may be a compulsory subject at the entrance examination for some postgraduate studies [2,3,4]. At some universities, OSs course is an irreplaceable part of postgraduate curriculums. Some curriculums contain two types of OSs courses, one which is intended for system administrators and explores the characteristics of the OSs, basic settings and setting up the environment for all users, while others relate to the implementation of functions, solving problems that may arise during implementation and trade-offs to be considered [5].

The OSs course content in most cases includes the basic principles of OSs design [6]. Content has been iterated over a number of decades, and mainly contains topics such as task management, system calls, synchronization, scheduling, memory management, and file system structure [3]. On the other hand, the topics are often aligned with Tanenbaum's book's chapters [7]. The majority of traditional OSs courses contains basic topics such as: kernel, process and thread management, interrupts, scheduling, synchronization and deadlocks, file systems, memory management, interprocess communication and device management, where special emphasis is placed on the traditional view, from a computer science perspective [8,9]. Large number of the activities in teaching OSs involves programming in C/C++ languages, due the fact that these languages allow access to certain hardware resources, while some routines are to be programmed in assembler [3].

OSs as an important area of knowledge is included in the guidelines for the curricula development for Baccalaureate Degree Programs in Information Technology and for Undergraduate Degree Programs in Computer Science, recommended by Association for Computing Machinery (ACM) and

IEEE Computer Society (IEEE-CS) [10,11]. Therefore, it is necessary to model the course content in accordance with recommendations mentioned above, and to align it with 14 standardized Information Technology (IT) areas (14 ICS2 35 areas).

The compliance of the proposed contents with the courses' contents at the international and regional level is analyzed through a comparative analysis of the course contents studied in three-year undergraduate academic studies (180 ECTS credits) in the study programs of computer science, computer engineering and information technology in Italy, Slovenia and Montenegro.

It is shown that the presented contents, goals/sub-goals (shown at the 8th area as example) and competencies that students acquire at the end of the course provide coverage of all layers in the hierarchical structure of OSs. This is a unique way to enable application of all IT areas, compared to the analyzed content models and viewed through the prism of SRPS and ISO/IEC standardization. Model is successfully implemented at the IT study program in three and four-year undergraduate academic studies, as well as in Integrated Academic Studies (IAS) at the Faculty of Technical Sciences in Čačak.

The key details of the developed and implemented model with ensuring regional and international content compliance (required by accreditation standards) are presented. After the example of good practice, explicit conclusions follow (with possible implicit deductions), as well as confirmations of the possibility of achieving a wide range of competencies and knowledge, by applying the model in the new state of emergency and Online study.

2. DEVELOPMENT OF THE OPERATING SYSTEMS COURSE CONTENT MODEL

Modeling the OSs course content is guided by the 12 objectives that the course content should meet. Therefore, it is essential to consider the goals and specific abilities that students will have upon course completion. These 12 goals, together with their associated content and competencies, are used to determine whether the set goals, in the modeling process, are fully met. Otherwise, they cannot be the basis for creating OSs course content.

2.1. The basis of the Operating systems course content model through 12 aspects

IT as an academic discipline in its broadest sense encompasses all aspects of computer technology. According to ISO/IEC standardization and hierarchical classification, IT is classified into area 35 (ICS1 = 35) and further arranged into 14 standardized areas (ICS2). OSs is an integral, mandatory part of the innovated, accredited IT curriculums of the OAS and vocational studies in Serbia. OSs course belongs to the group of professional or professionally applied subjects and "spreads over" all 14 classes of the ICS2 level (earlier there were 12 standardized areas of IT, [12]). OS segments such as nucleus and shell are also located in the structure of the computer system, from hardware to user applications. The structure (architecture) of the computer system through IT aspects (2 - 12) is shown in Fig. 1. Aspect 1 is not presented at Fig. 1 because it encompasses terminology and introduce to all IT aspects.

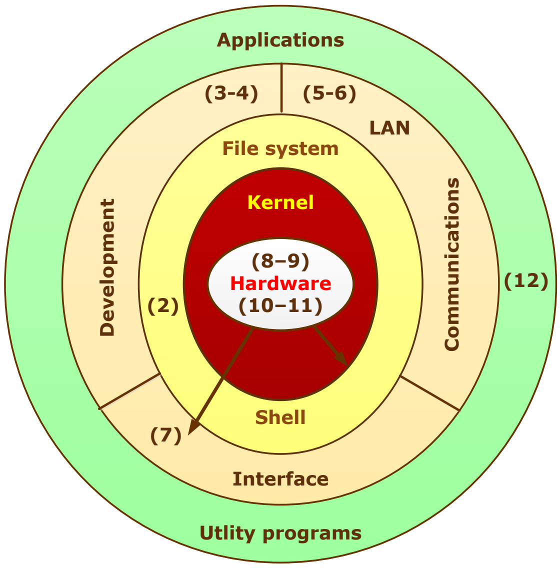

Figure 1. *The global system architecture example (OS - IT) [13]*

On the other hand, according to the ACM / IEEE recommendations for the IT curricula development, IT is classified into 5 essential domains, 5 essential + 5 supplemental domains and 4 support domains. Essential domains are: Information Management, Integrated Systems Technology, Platform Technologies, System Paradigms and User Experience Design. OSs are classified in Platform Technologies (ITE-PTF-02), and therefore require great engagement in learning process, which is closely linked to application and knowledge transfer to complex problems and situations (Level L3 in the Spiral model of the IT curriculum). For example, the L3 level requires three times more student's engagement compared to the L1 level, which is e.g. required to master the content of the Computer Architecture course [10].

According to the ACM / IEEE recommendations from 2016, OSs are studied in the curricula of the undergraduate studies in computer engineering through Systems Resource Management, which is one of the 12 knowledge areas in the Computer Engineering (CE) body of knowledge. The course contents are covered through 8 teaching topics (from CE-SRM-1 to CE-SRM-8), with a special emphasis on system resource management: History and overview of operating systems, Relevant tools, standards, and/or engineering constraints, Managing system resources, Real-time OSs design, OSs for mobile devices, Support for concurrent processing, System performance evaluation, Support for virtualization. The last two topics are elective [11].

Starting from the fact that students should acquire basic knowledge about the basics and principles of OSs, on the platform of IT standardization and according to standardized IT segments, taking into account the key recommendations of ACM / IEEE for IT curriculum development in order to achieve quality and meet the accreditation standards for the study programs (Standard 6.3), a "domestic" content model has been developed. At the axis of developed 3D model presented at Fig. 2 are: ICS1 = 35 = IT areas, ICS2 subareas (x), OS course topics (y), ACM / IEEE, CS - CE recommendations for IT curriculum development (z), for x = y = z =1, 2, 3, ...12), [12].

The OSs course contents are represented through 12 thematic topics which are directly related to ICS2 subareas:

(1) Introduction to OSs, applying and using OSs - ICS2 = 35.020;
(2) File system, data, information, protection and security management - ICS2 = 35.030, ICS2 = 35.040;
(3) Interrupt handling - ICS2 = 35.060;
(4) System development and documentation - ICS2 = 35.080;
(5) OSs and network management - ICS2 = 35.100, ICS2 = 35.210;
(6) OSs and support for global communications - ICS2 = 35.110;
(7) OSs and graphical interface (graphic environments) - ICS2 = 35.140;
(8) Process management, synchronization problems - ICS2 = 35.160;
(9) Input/Output (I/O) device management - ICS2 = 35.180;
(10) Computer system configuration - ICS2 = 35.200;
(11) Memory management and virtualization - ICS2 = 35.220;
(12) Application support - ICS2 = 35.240.

The key criteria, in accordance to European Foundation for Quality Management (EFQM) which aim toward excellence, are situated at the spatial diagonal of 3D model. Some examples are: leadership supported by standardized terminology (1.1.1), organization with the concept of knowledge transfer (2.2.2), team support (3.3.3), OSs development (4.4.4), standardization (5.5.5), etc.

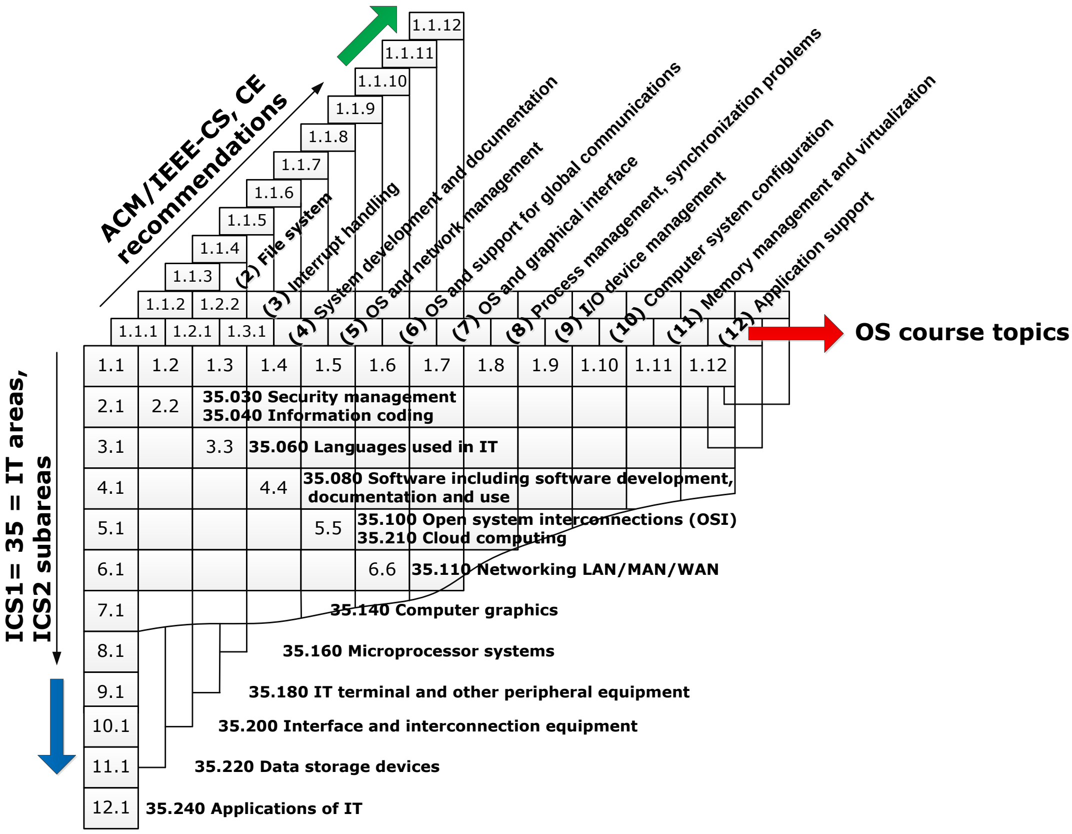

Figure 2. *Basic model of the OS course content (adapted from [12] and [14])*

2.2. Outcomes of the Operating systems course content model through 12 model aspects

The OSs course objectives (1 - 12), derived from the OSs course topics (1 - 12), cover the usage of the OSs (external objectives), as well as the design and implementation of the OSs (internal objectives). Course objectives must be defined in such a way that they are completely aligned with the objectives of the IT curriculum and could be used for measuring student's performances.

Objectivities defined in such way enable to students:
1) introduction to OS, with accompanying terminology and learning to work with different OSs;
2) data management (information and file management), including protection;
3) program execution control (language-independent programming) and interrupt handling;
4) view to the OSs from the aspects of IT and software development, and system documentation (OS documentation);
5) knowledge and skills to support global communications, including cloud computing;
6) knowledge of network OSs for network operations management in small, middle and large networks;
7) OSs from the aspect of computer graphics and elements of graphic communication,
8) resource allocation - jobs, processes and processors management;
9) peripheral management, I/O management;
10) configuring system and interface;
11) resource allocation and memory management;
12) effectiveness of knowledge and OSs application in different professional situations, especially in all standardized applications of IT.

Sub-objectives/outcomes are presented at the example of resource allocation 8), through the acquisition of theoretical and methodological bases for jobs, processors and processes management (8.x, x = 1 to 12):
8.1 define the role of the OS in system resources management;
8.2 describe the choices to be made in the file system designing and the way in which these choices affect the system resources management from the job/process aspect;
8.3 explain the basic types of interruptions and how to manage them;
8.4 give examples that illustrate why scheduling and dispatching are needed in system resources management;
8.5 explain concurrency is and why it must be supported in system resources management;
8.6 explain how simultaneous multithreading execution works and what kind of support is needed for multithreading;
8.7 define the role of key APIs at the example of WinAPI;
8.8 give the examples of runtime problems that may arise from concurrent operations, multiple tasks or system components, such as deadlock and race conditions;
8.9 list the key components of IEEE POSIX (Portable Operating System Interface) standard;
8.10 interfacing between hardware and software components, giving examples of basic concepts in concurrent processing (multiprocessor, multicore);
8.11 explain the memory hierarchy (cache through virtual memory), explain how to achieve trade-off between cost and performance, virtualization support knowledge;
8.12 evaluation of resources performances.

Objectives are accompanied by outcomes as mandatory accreditation element (also through 12 aspects), as well as competencies.

2.3. Student's competencies - through 12 aspects

By attending the OSs course, students get familiar with the purpose, characteristics and functions of the OSs and the basic principles of operation, design and implementation of the OSs, gain basic knowledge of concepts, algorithms, principles, problems and solutions related to the OSs, regardless of the type of OSs. Students should get to know and use existing systems, and eventually innovate existing systems. Depending from the input knowledge (from previous levels of education), as well as output (personal) goals, students could be able to design and implement independently their own specialized systems.

In accordance with the OSs course contents and the defined objectives and sub-objectives, appropriate competencies arise. These competencies are defined through 12 aspects:

1) professional competencies - students know how to choose the appropriate OS, describe the components operations and OSs functions, know how to install at least one OS and have academic skills to use, upgrade and maintain Windows, Linux and Unix-like systems;

2) skills for efficient file system management, development of personal functions in file subsystems, knowledge of security and safety aspects (as newly standardized IT sub-area) and successful management of threats and attacks towards the OS, through the application of various techniques for increasing security and system protection;

3) development of analytical and critical approach in research and solving problems that may occur, improvement of programming skills using scripts for OS tasks automation, efficiently managing interrupts and program execution control;

4) know the factors of OSs quality development, new OSs versions, define key criteria for OS design (e.g. efficiency, robustness, security), implement international and national standards in software engineering, such as, ISO/IEC TR 19759:2015 - Software Engineering Body of Knowledge (SWEBOK V3.0), ISO/IEC 25000, known as SPICE (Software Process Improvement and Capability Determination), SRPS ISO/IEC 12207 - IT - Software life cycle processes, and many IT novelties with over 750 new standardized sources of knowledge every year (SRPS and ISO/IEC);

5 - 6) skills for setting up connections to the local network and the Internet (in cloud - new standardized IT sub-area), skills for sharing resources with the network, manage users and groups, acquiring basic knowledge about network and distributed (clastered, cloud and grid) systems and types of migrations, distributed file systems, know the mechanisms for processes synchronization and performing transactions in distributed systems;

7) successfully use/ innovate/ compare and manage graphical environments in the OSs, appearance and personalization management, which provides creative development of innovative skills for the implementation of various procedures;

8) apply synchronization mechanisms, know interprocess communication routines in OS, know processor allocation algorithms, know how to use/innovate tools for monitoring log-based performance, as well as in real time;

9) know/ upgrade the hardware-software configurations necessary to communicate with I/O devices, know the organization, structure of I/O devices and services provided by the I/O core subsystem, have skills to manage I/O devices (peripherals), monitor I/O performances and manage errors (system calls);

10) select, install and configure systems, know the basic internal and external commands for working in the command interpreter, have the skills to set a standard set of functions (interface) for the interaction of applications and system configuration;

11) skills for memory management, such as paging, understand the importance of virtual memory, know basic and alternative techniques for loading pages and algorithms for replacing pages, manage secondary memories, know algorithms for disk schedule and criteria for selecting algorithms, apply virtualization;

12) upgrading the base for further education and training for the application of OSs and application support.

Specified 12 aspects enable the acquisition of fundamental and specific knowledge, expected student competencies (vertical - by depth or horizontal - by width), and open opportunities for subject correlations and competencies, and also for wider application in other OSs related subareas (such as competitive programming, design and application of algorithms, development and programming of embedded devices, system security and network management, etc.).

The latest provisions of the Law on higher education and the prevention of direct transition from vocational to academic studies have enabled additional "coloring" of degrees and types of studies in Serbia, with different requirements for the practice and operation of each course, including OSs.

3. INTERNATIONAL AND REGIONAL CONTENT COMPLIANCE - ACCREDITATION REQUIREMENT THROUGH 12 ASPECTS

Nowadays, OSs courses in Serbia are conducted on undergraduted academic and vocational studies in multiple accreditation areas: Computer science (Natural and Mathematical Sciences field - NM field), Computer engineering (Technical-Technological field - TT field) and Information technology (Interdisciplinary, Multidisciplinary and Transdisciplinary studies - IMT studies), through various topics, where in most cases there is no full coverage of all IT areas. The situation is similar in the EU countries, where, for example, at the Bachelor-level in Computer Engineering (BsC Corso di Laurea in Ingegneria informatica) studies at the University of Torino, the OSs course is evaluated with 6 ECTS credits and more than half of the planned topics are occupied by processes, threads and process synchronization (26 hours of a total of 45) [15]. On the other hand, in some study programs in Germany and in Scandinavian countries, OSs courses are not an integral part of the study programs in the undergraduate academic studies in computer science, computer engineering and information technology.

In order to verify the content of the OSs course, 3 three-year study programs in Computer science (NM field), Computer engineering (TT field) and Information technology (IMT studies), with 180 ECTS credits, were considered, where two of them are from the University of the European education area and one from our neighborhood (non EU). Contents of the OSs courses at the Università degli Studi dell'Aquila (Italy) for obtaining the title of BSC in Computer Science (Laurea in Ingegneria dell'Informazione) [16], from the Faculty of Electrical Engineering and Computer Science, University of Maribor (Slovenia), for acquiring the title BSc in Computer science and Information technology [17], and from the Faculty of Science and Mathematics at the University of Podgorica (Montenegro) for acquiring the title BSc in Computer Science [18], are compared with the course contents of the proposed model, performed at the Undergraduate academic studies of IT study program, at the Faculty of Technical Sciences in Čačak (Serbia) [14]. All mentioned courses are evaluated with 6 ECTS credits. The results of the analysis are presented in Table 1, through all segments of standardized IT areas (grouped in 12 aspects, 1 - 12).

Table 1. *Comparative analysis of OSs course content through 12 model aspects*

Area	Department of information engineering, computer science and mathematics, Università degli Studi dell'Aquila, Italia System services (1 - 12)	Faculty of Electrical Engineering and Computer Science, University of Maribor, Slovenia	Faculty of Science and Mathematics, Podgorica, Montenegro	Faculty of Technical Sciences, Čačak, Serbia
(1)	Introduction to modern OSs, definition, objectives and types of OSs	Role of OSs and their basic functionality	Introduction, the concept of OS, OS as an extended machine and resource manager	Introduction to OSs, applying and using OSs
(2)	File system management	File system management, implementation of file systems	Multimedia OS, security, file systems	File system, data, information, protection and security management
(3)	System programs	Interrupt handling		Interrupt handling
(4)	OS Design and Implementation		History of OSs, types of OSs, basic concepts of OSs	System development and documentation
(5)			Multiprocessing and distributed OSs	OSs and network management
(6)				OSs and support for global communications
(7)				OSs and graphical interface (graphic environments)
(8)	Processes and threads, CPU scheduling, process synchronization, deadlocks	Process scheduling, job and process management, process synchronization, classical problems of synchronization, threads	Processors, processes and threads, interprocess communication, process and thread planning, deadlocks	Process and job management, synchronization problems
(9)		Access to I/O devices	I/O devices, I/O management	I/O device management
(10)	System calls, OS Structure	Computer systems and OSs architectures	System calls, buses, OS structure	Computer system configuration
(11)	Main memory management, virtual machines	Memory management, virtual memory, disk scheduling	Memories, memory management	Memory management and virtualization
(12)				Application support

3.1 Content compliance analysis by all standardized IT segments

Compared to the OSs course contents at representative examples presented in Table 1 (thematic aspects in columns 2 - 4), the model with 12 aspects offers full coverage of 14 standardized IT areas, in contrast to the OSs course content at the Università degli Studi dell'Aquila and at the Faculty of Electrical Engineering and Computer Science University of Maribor, where there is obvious lack of content coverage in areas 4 - 7 and 12. At the Università degli Studi dell'Aquila, the coverage of these segments is partially done through System services, and the similar situation is in thematic aspects 9 and 12. In the neighboring country, which comes from a non-European educational area, at the Faculty of Science and Mathematics in Podgorica, as an example, there is lack of thematic aspects 3, 7 and 12.

On the other hand, there is almost complete alignment of all analyzed contents in areas 1 - 4 and 8 - 11 with the contents from the European educational space, as well as with the contents that are studied in our close environment (with the exception of the 3rd thematic aspect).

4. RESULTS OF MODEL APPLICATION IN STATE OF EMERGENCY - ONLINE NOVELITIES

The presented OSs content model is completely formally and structurally aligned with modern trends and novelties in the study of OSs, offering students the latest scientific and technical knowledge and skills, necessary for their further professional development and improvement in the IT area. The model is aligned with the courses contents of from EU and non-EU countries, ACM/IEEE recommendations and fully covers standardized IT areas. It has already been successfully implemented for two decades, at the OAS IT and Integrated Academic studies at Technics and Informatics (IAS TI) at the Technical Faculty in Čačak [13], now Faculty of Technical Sciences. The presented objectives, outcomes and competencies also cover the hierarchical structure of the OS (Figure 3).

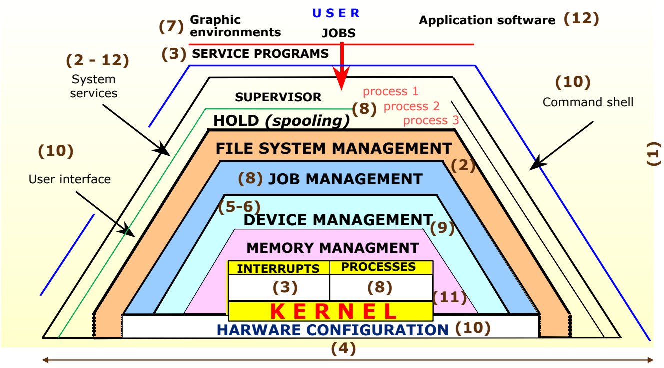

Figure 3. *A view at the basic content model through the hierarchical structure of the OS (adapted according to [13])*

In the state of emergency in Serbia, in combination with the Zoom application, the basic Moodle course for OSs at Web location of the faculty e-learning system is one example of good practice [19], with additional categories for 6 OS courses (Ubuntu, Android, Cent OS, Windows, Fedora Linux and Linux OS through 12 aspects), although the study programs OAS IT and IAS TI were not previously accredited for distance learning. Another example of good practice is the combination of basic OSs course, presented through 12 aspects at Moodle platform, and open source Web conferencing application BigBlueButton realized during the state of emergency at Academy of Professional Studies Šumadija in Trstenik (former College of Applied Mechanical Engineering Trstenik) [20]. This study program also was not previously accredited for distance learning.

Also, although the accreditation standard allows one teacher per maximum of 80 distance learning students - in all courses during one semester, this course at Faculty of Technical Sciences in Čačak has attended over 220 students. All students are allowed to choose a topic (installation of one of the OSs) and working principle of "week for week" - in all thematic aspects of the above model and concept -12.

This model and concept - 12 enabled 32 students to choose between 32 different topics (01_Android & CentOS; 02_Kali Linux ver. 2020.1; 03_Ubuntu ver. 19.10 Eoan Ermine; 04_Fedora Linux; 05_SuSe linux ver. 15.1; 06_Debian 10; 07_Mint 19.3; 08_CentOS 6.10 &-Android 10; 09_Win ser.2016; 10 FreeBSD 11: 11_Knoppix ver. 8.6.1; 12_Win ser.2019; 13_CP6 Linux; 14_Gentoo Linux 17; 15_Slackware 14.2; 16_Pappy Linux, 17_OpenMandriva LX 4.1; 18_Android 9_CentOS 7; 19_PCLinux OS 2020.1; 20_Solaris; 21_Android, CentOS & Windows; 22_Manjaro; 23_NetBSD; 24_iOS & Centos; 25_KaOS 2020.02 Linux; 26_Puppy Linux 8.0; 27_Lubuntu; 28_OpenBSD; 29_Arch Linux ver. 2020.03.01; 30_MacOS; 31_CentOS 6-iOS 12.4.5-Windows 10; 32_MX Linux 9.1), install/configure and study not only "their" OS installation, but at the same time, through the presentations of all other 30 OSs configurations, gain broader competencies. Thus, each student could compare "own" OS installation with about 30 other students, and all students had at least four OSs (1_Windows, 2_CentOS Linux, 3_OS OS on their mobile devices). Excellent performance was documented in the exam period in June 2020.

5. CONCLUSION

Based on all of the above it is obvious that the OSs course represents an essential part of the traditional curricula in three fields: Computer science (NM field), Software and computer engineering (TT field), and Information technologies (IMT studies).

Understanding major subjects (courses) in all mentioned fields, scientific areas and scientific/applied areas relies entirely on grasping the concepts and functionality of OSs. The developed "domestic" model in 12xn dimensions fully meets anticipated expectations. It is applicable to vocational studies and OAS, and is synchronized with European study programs in three different fields in Serbia, through scientific areas: computer science, computer engineering and information technology.

The OSs course content model, applied at the Faculty of Technical Sciences (previously Technical Faculty) in Čačak fully covers the structure of the OSs. It is open to innovations through 14 ISO/IEC standardized IT areas (grouped in 12 thematic aspects).

Objectives/sub-objectives and competencies arising from modeled contents and choosing "own" OS configuration enable students to get to know/ to know, to compare the basic characteristics of the most complex software products, to know functions and principles of OSs, to acquire basic and specific knowledge and skills for using existing OSs, as well as for designing, programming and implementing their own specialized and embedded systems and applications. Understanding algorithms, principles, problems and solutions related to the OSs represents the basis for expanding knowledge and applications of acquired knowledge in other IT areas that are closely related to the OSs in the future. In that manner, described by the given examples of online teaching in a state of emergency, students develop the habit of continuously expanding their knowledge, through experiences gained by using problem solving skills (for students, teachers and associates, in width and in depth - through 12 aspects).

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