

# Comparative Analysis of the Balance of Hardware and Software Academic Subjects: Two Study Programs in the Field of Computer Engineering

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**Abstract** – New trends in society lead to the need for changes in the academic curricula. The increased demand for software skills for Computer Engineering graduates has led to curriculum adjustments. This paper analyzes the relationship between hardware and software academic subjects in two higher education programs with a similar profile. The paper presents the results of a quantitative descriptive statistical study involving 59 students. The results of the study were used to modify the weight of hardware and software subjects. A questionnaire completed by students shows their opinion on some aspects of the academic subjects taken during their undergraduate studies.

**Keywords** – Engineering Education, computer curricula, student opinion

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DOI: 10.18421/TEM143-79

<https://doi.org/10.18421/TEM143-79>

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*Received:* 15 January 2025.

*Revised:* 13 July 2025.

*Accepted:* 30 July 2025.

*Published:* 27 August 2025.

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## 1. Introduction

At the Faculty of Electrical Engineering and Computer Science within the framework of Transilvania University of Brasov, Romania, there are two study programs which are close in scope. These programs are Computer Engineering and Electrical Engineering and Computers, for which the most balanced hardware and software training is required.

The combined hardware and software skills are looked for and appreciated by employers in the central area of Transylvania. The difference between the two study programs is given by a preponderance of software in Computer Engineering and preponderance of hardware in Electrical Engineering and Computers. Society undergoes rapid and important transformations so that the engineers' skill requirements from the field of electrical and computer engineering are also changing. In the first year of study, the fundamental academic subjects prevail, and in the following years of study the content of the specialized academic subjects is predominantly hardware or software. The content of each academic subject is established by the subject holder and is discussed in curriculum meetings. In these meetings, there are taken into consideration both the employers' opinions obtained from questionnaires completed by them and the opinions of the professors with expertise in the field.

The present paper analyzes these skills and outlines some of the challenges that educators must face [1]. One of these challenges is ensuring the competency-based education (CBE), with advantages mentioned in [2].

This requirement has been implemented within the framework of the Faculty of Electrical Engineering and Computer Science and all the subject worksheets must mention the skills developed by that particular academic subject, skills that are directly related to the national register of qualifications for the fields of the study programs, elaborated in cooperation with employers and in agreement with the European regulations. Ensuring the connection of higher education with the economic environment involves taking into consideration a project-based learning and blended methods for engineering education [3].

An achievement of one of the authors of the present paper showcases an original way of carrying out the Computer Engineering laboratory activity through project-based learning [4].

Several versions of curricula for Computer Science and Computer Engineering have been developed internationally; one of the studies was carried out in the USA and is presented in [5].

A detailed study of selecting the academic subjects in a Computer Science curriculum and tracking the effects of the changes over an 8-year period is given in [6]. In creating the curriculum at the Faculty of Electrical Engineering and Computer Science, not only the document entitled Computer Engineering, Guidelines for Undergraduate Degree Programs in Computer Engineering, 2016, Report in the Computing Curricula Series Joint Task Force on Computer Engineering Curricula Association for Computing Machinery (ACM) [7] and IEEE (Institute of Electrical and Electronics Engineering) Computer Society has been taken into consideration, but also the documents from the K-12 Computer Science Framework [8].

A curricular analysis team established through discussions with the subject holders the place of each academic subject in the curriculum. The necessary skills for understanding the academic subject and the skills developed by that particular subject were taken into account in order to determine the status or position of the academic subject. The content of the academic subjects was also analyzed and compared with similar academic subjects from other universities or based on information from specialized literature [9].

Regarding the Electrical Engineering and Computers study program, there is no correspondence worldwide, this program aims at combining knowledge from the field of computers in electrical engineering, skills highly valued by employers, the program being part of the field of electrical engineering. The study programs of Computer Engineering and Electrical Engineering and Computers have been accredited by EUR-ACE (EUROPEAN Accredited Engineer) according to EUR-ACE® Framework Standards and Guidelines [10].

Obtaining this accreditation meant that the curriculum was drawn up with the support of professional companies in the area close to the city of Brasov. An example of the conception of how to learn software engineering in cooperation with companies and aiming at the EUR-ACE accreditation is presented in [11]. In this project students work together with designers from companies in multidisciplinary teams to create a smartphone software application. The paper also presents the results of a survey about the students' satisfaction at the end.

Another aspect pursued in the creation of the curriculum was to ensure the compatibility with similar European study programs, following examples of good practices [12]. The curriculum analysis team studied the accreditation conditions of ABET (Accreditation Board for Engineering and Technology) and pursued the CDIO (Conceive – Design – Implement – Operate) principle as an educational goal. These principles are followed in many universities; one of the experiences of developing an educational plan at Computer Information Systems is presented in [13].

Special attention was paid to the national regulations of ARACIS (Romanian Agency for Quality Assurance in Higher Education). These regulations are minutely detailed; they establish a set of academic subjects that must be completed, the academic subjects being classified into fundamental, field and specialty subjects, the ratio between the fundamental, field and specialty subjects, the compulsory subjects and the optional ones, for each study program. The previously mentioned body strives to introduce subjects that are as current as possible, in relation to the demands of the labor market, and there are many changes that occur in a fairly short time, therefore the curriculum is a dynamic one. The initial curriculum of these study programs had to be modernized due to changes in society and the requirements of the economic environment.

The number of jobs in the software field has increased to the detriment of jobs in the hardware field, this modification justifying changes in the curriculum. According to the data provided by the datausa.io website, in 2023, there were 1.89 million jobs in the field of soft developers with an average income of 148 thousand dollars [14] whereas in the field of computer hardware there were only 62 million jobs with an average income of 141 thousand dollars [15], the number of hardware jobs in the USA increased in between 2014 and 2022 by 4.64% and the number of software jobs increased by 22.2%. The change that has already begun in the share of software jobs is interesting, when the place of basic and intermediate level programmers is increasingly taken by artificial intelligence. It is possible that the future will hold surprises that will lead to other changes.

An optimal balance between the software and hardware academic subjects is difficult to achieve, and curriculum changes have attempted to update and optimize this balance in line with the market demands.

A paper that provides an in-depth analysis of the current research in the field of software education in Romania is [16]. The paper is based on the proceedings of a Workshop in which the new challenges in the field of software education were discussed. Within the framework of the workshop, questions were addressed to the participants, approaching education from the perspectives of the student, professor and employer. The authors consider that the professor has the role of a facilitator between the students and the economic environment.

Currently, one of the major challenges in education has become artificial intelligence, whose emergence has brought numerous advantages and also risks.

A paper that analyses these aspects is [17]. The paper asks questions about the use of AI (Artificial Intelligence)-generated programs, analyzing the advantages and disadvantages which occur in the process of using them.

Universities are interested in aligning professional knowledge and skills with the demand in the economic environment. Thus, the paper [18] analyses the demand for knowledge in the software field in order to adapt the curricula. The paper presents a comprehensive study of the requirements of the economic environment and the supply of knowledge, but it does not contain the students' opinions. Good results in the students' education can be obtained through PBL (Project Based Learning). If both hardware and software work is effectively carried out in teams, students acquire complex knowledge.

The paper [19] presents a bibliographic study of this way of working. The advantage of combined hard and soft knowledge was also analyzed in the research presented in our article and there were identified the academic subjects in which this knowledge is formed and developed.

An article focused on students' perception of combined hard and soft training through PBL is [20]. The article shows the importance of combined hard and soft knowledge and confirms the conclusions reached in our article.

A recently published book [21] shows the need to rethink higher education in the context of the changing society.

This paper presents the current curricula of two study programs, Computer Engineering and Electrical Engineering and Computers and analyzes the results obtained in the teaching activities through the students' attitudes. The students showed their opinions by completing anonymous questionnaires at the end of the undergraduate cycle.

## 2. Methodology

The purpose of the study, which conclusions are presented in this paper, is to analyze the students' opinions about the content of the specialized academic subjects, so that the curricular decisions would be as correct as possible. From the discussions with the students, it could be noted that some prefer predominantly software academic subjects, the employers' demand being higher in this field.

The questionnaire completed by the students not only contained the identification of the degree concerning the acceptance and satisfaction for the hardware and software academic subjects, but also their preferences for certain contents and suggestions for improving the curriculum.

The questionnaire consisted of 11 questions about the software academic subjects, the same 11 questions for hardware academic subjects and one question about academic subjects that dealt with software interwoven with hardware. Three additional questions required a written answer.

The two current curricula contain academic subjects with a content discussed with the subject holders in the curriculum meetings, also chained so that the knowledge acquisition is done logically, being related to previous knowledge. The academic subjects considered fundamental mathematics, physics, etc, complementary subjects: communication, English, etc, optional and elective subjects do not appear in the diagrams. Only the field and specialty academic subjects were represented, these having a well-defined orientation towards hardware, software or hard- and software combined.

The diagrams of mainly hardware and mainly software academic subjects grouped by years of study are given in Figure 1 and Figure 2 for the Computer Engineering study program also in Figure 3 and Figure 4 for the Electrical Engineering and Computers study program. Of course, the connections between the academic subjects are complex.

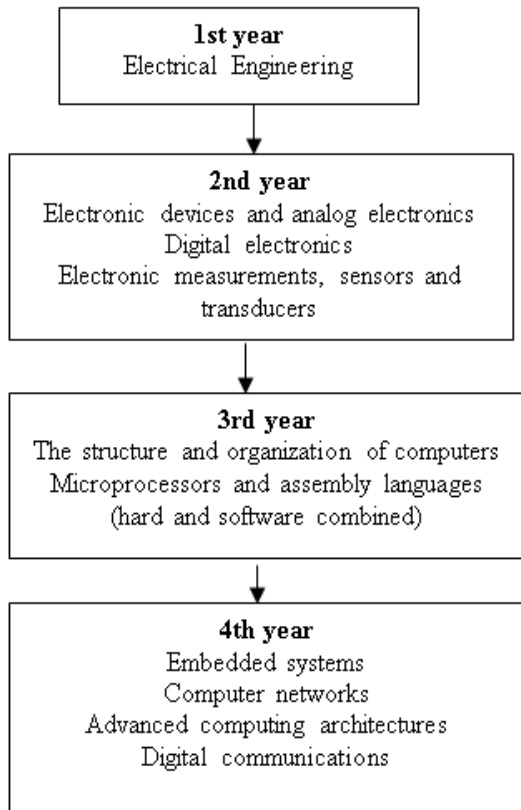


Figure 1. Mainly hardware academic subjects in the Computer Engineering study program

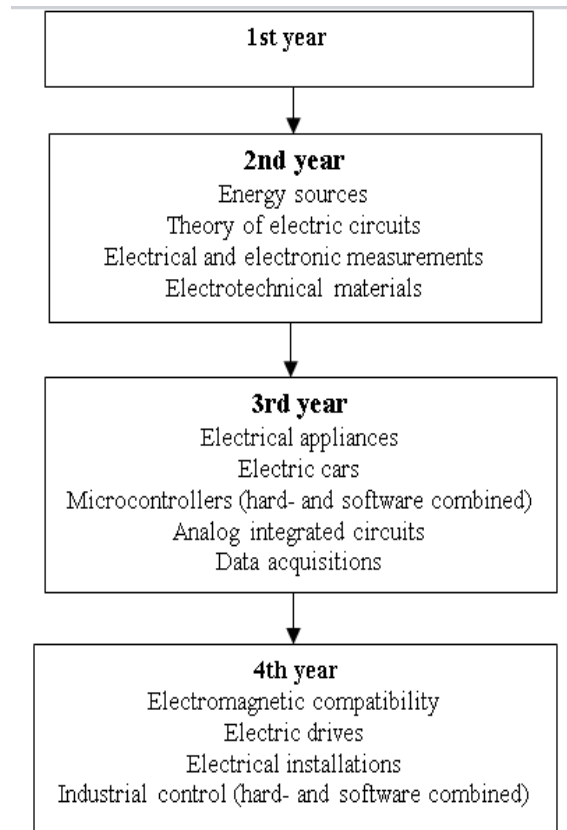


Figure 3. Mainly hardware academic subjects in the Electrical Engineering and Computers study program

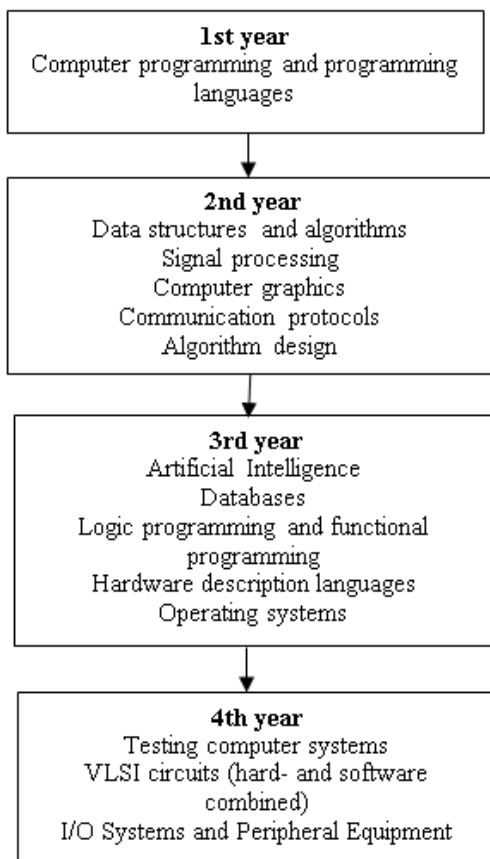


Figure 2. Mainly software academic subjects in the Computer Engineering study program

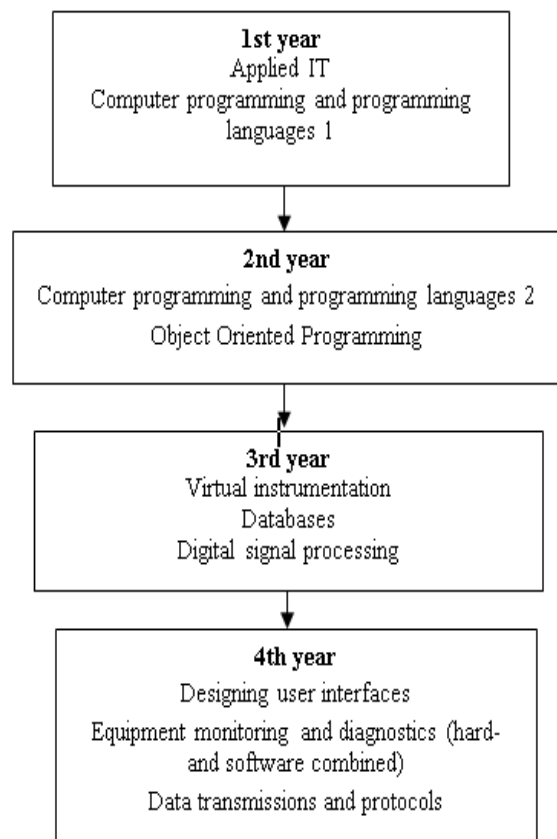


Figure 4. Mainly software academic subjects in the Electrical Engineering and Computers study program

The first difference is the number of hardware and software academic subjects, which shows a more highlighted orientation of the Computer Engineering study program (10 hardware and 14 software academic subjects) compared to the Electrical Engineering and Computers study program (13 hardware and 10 software academic subjects). Obviously, the academic subjects are different, in the Computer Engineering study program the hardware subjects are from the Electronics fields and in the Electrical Engineering and Computers study program the academic subjects are from the field of Electrical Engineering.

### 3. Results

The coordinators of the study programs as well as the teaching staff in charge of the academic subjects held discussions over time with the students to identify their opinions regarding the subjects with the objectives of ensuring software and hardware skills, respectively. The students' opinions were divided, so in the 2023/2024 academic year, students were asked to fill out a survey.

Completing the questionnaires was not mandatory; it was anonymous and met the conditions of academic ethics, including those of avoiding discrimination.

The students' answers can be used to adjust the syllabus, to respond to their requirements and according to the possibilities created by the legislative framework and ARACIS norms. The questionnaires were completed by the 4<sup>th</sup> year students who have a view of the whole study period. The questionnaire started with the important statement: *"The questionnaire is anonymous and its completion is not mandatory. If you have any doubt, you cannot fill it out. The answers do not influence the grades received in any academic subject, nor the attitude of the teaching staff towards you. The answers will be used to identify more effective ways of working to improve your training and integration into the workplace after graduation"*. The questionnaire had 12 questions (Table 1) used a 5-point Likert scale, where 5 meant strongly agree and 1 meant strongly disagree.

Table 1. Questions with ticked answers on a 5-point Likert scale

1.	I believe that software/ hardware subjects are necessary in the career I am targeting
2.	I liked the content of the software/ hardware subjects
3.	I learned and understood the software/ hardware part easily
4.	I believe that the material taught in the software/ hardware subjects is too complex
5.	The laboratory activity helped me to be able to understand soft concepts
6.	I got good results in the exams in the software/ hardware subjects
7.	I have chosen or intend to choose a software/ hardware achievement for the Bachelor of Science project
8.	I would like to work in software/ hardware in my future career
9.	I would like to have more software/ hardware academic subjects
10.	The pleasure of learning software/ hardware was due to the teaching staff's performance
11.	The exams in the software/ hardware subjects were easier
12.	There were academic subjects that dealt with the connection between hardware and software

Table 2. Detailed written answer questions

1.	Mention the most effective 2 academic subjects where you understood and learned the most soft/ hard
2.	Mention the 3 most important things learned in the mainly software/ hardware academic subjects
3.	Mention the 2 most effective academic subjects where you understood the connections between soft and hard

At the end of the questionnaire, there were three questions (Table 2) for which a written answer was requested. Students were then asked to mention whether they were employed and whether they worked in the soft or hard field.

23 questions were given, out of which 1-11 were about software, 12-22 were the same questions but about hardware, and additionally the 23rd question about hard and soft subjects.

Results obtained in Computer Engineering:

1. 51% of the students declared that they are employed in software fields, 5% in hardware fields, 2.5% in combined hard and soft, 2.5% employed in another specialty, 39% are not employed;
2. The preferred software academic subjects are: Artificial Intelligence and Computer Programming as well as Programming Languages. The preferred hardware academic subjects are: Digital Electronics and Hardware Description Languages.

The academic subjects that clarified the connection between hardware and software are: Digital Electronics as well as Input/ Output Systems and Peripheral Equipment.

Results obtained in Electrical Engineering and Computers:

1. 8% of the students declared that they are employed in software fields, 6% in hardware fields, 14% in combined hard and soft, 7% employed in another specialty, 65% are not employed;
2. The preferred software academic subject is Object Oriented Programming and the preferred hardware academic subject is Analog Integrated Circuits.

The average answers of *Computer Engineering* students to the questions about the software and hardware academic subjects are given in Table 3:

Table 3. *Computer Engineering* questions and average answers

Software question	Average	Hardware question	Average
1	4.79	1	3.15
2	4.17	2	3.20
3	3.82	3	2.38
4	2.66	4	3.30
5	3.94	5	3.79
6	4.02	6	3
7	4.46	7	2.20
8	4.41	8	2.48
9	4.17	9	2.43
10	3.07	10	2.69
11	3.35	11	2
<b>12 Hard/soft</b>			4.17

There can be noted the questions on which the students largely agreed, such as software is important in the career, the subjects had a suitable content, the results in the evaluation were good, they choose topics for a diploma project in the software field, software careers are aimed at, they are willing to take multiple academic subjects. Students have only partially agreed on the same hardware questions. The strongest disagreement occurs with the statement according to which the exams in the hardware subjects were easier.

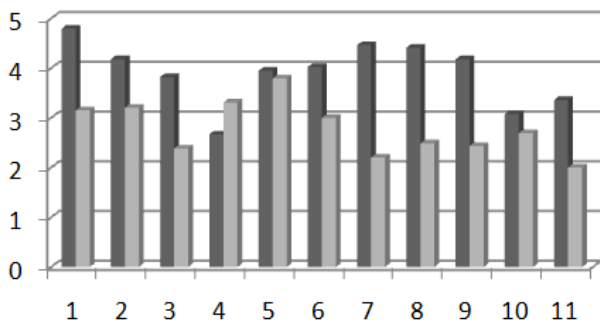


Figure 5. Average responses to questions 1-22, of *Computer Engineering* students

If the average answers to questions 1-22 are graphically represented (Figure 5), with black the attitude towards software academic subjects and with gray that for hardware academic subjects, the greater attraction towards software academic subjects is obvious. The overall average questions in software subjects is 3.90 compared to that of questions in hardware subjects of 2.56. The average answers of students from Electrical Engineering and Computers to the questions about the software and hardware academic subjects are given in Table 4:

Table 4. *Electrical Engineering and Computers* questions and average answers

Software question	Average	Hardware question	Average
1	4.10	1	3.68
2	3.63	2	3.63
3	3.61	3	3.52
4	2.21	4	2.89
5	2.84	5	3.89
6	3.42	6	3.47
7	3	7	3.78
8	3.84	8	3.42
9	3.73	9	3.05
10	2.36	10	3.10
11	2.94	11	2.47
<b>12 Hard/soft</b>			3.42

The degree of agreement of Electrical Engineering and Computers students on the statements about software is lower; there is only one average value above 4 on the statement that software is important in career. The average responses to the hardware statements are slightly higher than those of Computer Engineering students, which is justified because the study program is more hardware-oriented than Computer Engineering.

Students consider that the laboratory activity in hardware subjects helped them more than in software subjects, they want more to do hardware B. Sc. (Bachelor of Science) projects and that they were helped to a greater extent by the teaching staff to understand the hardware part.

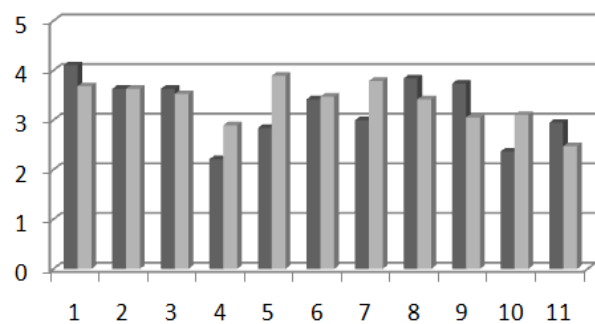


Figure 6. Average responses to questions 1-22 of *Electrical Engineering and Computers* students

If the average answers to questions 1-22 are graphically represented (Figure 6), with black the attitude towards the software subjects and with gray the one for the hardware academic subjects, a balanced attraction for the software and hardware subjects can be observed. The overall average for questions in software academic subjects is 3.24 compared to that of questions in hardware academic subjects of 3.08.

The answers to the 12<sup>th</sup> question exist in the table but were not represented graphically because this question was not addressed to all the series of students participating in the questionnaire and it is not very relevant for the comparison between software and hardware academic subjects. However, from the students' responses it was concluded that more academic subjects should deal with the connection between software and hardware, understanding this connection as being important for both study programs.

A free portion was reserved in the questionnaire and students were invited to express personal opinions. Only about 10% of the students expressed such views. An Artificial Intelligence course was requested in the Electrical Engineering and Computers program, and several reviews were positive about the balance between software and hardware. In the Computer Engineering program there was a critical opinion about a member of the teaching staff and some positive opinions about the teaching process. When analyzing personal opinions, the most pleasant surprise was a questionnaire that had a heart drawn on it.

#### 4. Conclusion

Curriculum changes were made gradually, based on market demands identified through discussions with employers. Each change was discussed with subject holders and the students' representatives in curricular meetings to check the appropriateness as well as the presence of possible overlaps. The risks of replacing some outdated subjects were taken into account, in order to keep the number of subjects taken by students constant.

The best evidence of the success of a degree program is the employment rate of graduates. In the period between 2018 and 2023, the data taken from the statistics produced by the university shows for the Computer Engineering study program that 75% of graduates are employed, 20.83% are not working and 4.17% have become entrepreneurs.

The situation in the Electrical Engineering and Computers study program shows that 65.91% of graduates are employed, 29.55% are not working and 4.55% have become entrepreneurs. The data were obtained immediately after graduation, but the number of employed graduates can be considered to increase over time.

Comparing the data declared by students through questionnaires with the data reported after graduation, can show that the absorption of graduates was fast, in Computer Engineering, the percentage of employment in the field of specialty increased in one year from 58.5% (4<sup>th</sup> year of studies) to 75% immediately after graduation. In Electrical Engineering and Computers, the percentage increased from 28% to 65.91%.

Regarding the future employment intention, in the Computer Engineering program 66.67% of the graduates declared that they wanted to work in Romania, 29.17% in an EU country and 4.17% outside the EU, and in Electrical Engineering and Computers study program 65.91% of graduates declared that they wanted to work in Romania, 22.73% in the EU and 11.36 outside the EU.

The results of the survey were used in discussions with teaching colleagues, and the subject holders appreciated by the students were asked to share their experience of teaching the course. The results were also used for the re-accreditation of the Computer Engineering study program, presenting the conclusions of the ARACIS commission, ARACIS standing for the Romanian Agency for Quality Assurance in Higher Education.

During the periodic meetings with the employers from the companies in the area, the results provided by the students through their answers were also discussed. Meetings with employers aim to modernize the content of the curriculum and of certain academic subjects to meet their requirements. Thus, the Artificial Intelligence academic subject was introduced at the request of the economic environment and in this survey it was highly appreciated by the students.

In the Computer Engineering and Electrical Engineering and Computers study programs, the students' opinion is aligned to the orientation of the programs, namely to apply software in engineering, that is, to combine the software and hardware parts. Graduation projects are mostly oriented in this direction, with Computer Engineering students in particular carrying out software projects with the inclusion of AI (Artificial Intelligence) and IoT (Internet of Things) applications for example in smart homes or robots, etc. Electrical Engineering and Computers students are more oriented towards remote software applications, monitoring and control interfaces in electrical engineering, motor control and sensor implementation, etc.

The aim of the present paper that of analyzing the balance between the number and quality of software as well as hardware subjects in the two specializations that train students in Computer Engineering, has been achieved. The gradual increase in previous years in the number of software subjects and the number of hours allotted to these academic subjects has had a beneficial effect on the education of students.

This increase in the weight of education in software fields followed the trend in society, a trend to which companies also aligned. There have also been extreme views, of significantly abandoning hardware knowledge, but rapid and unpredictable changes in society urge cautious patience. Education has always had a conservative dimension, useful in times of accelerated change.

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