A Hands-on University Short Course for Edge AI

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ABSTRACT

This paper aims to present a hands-on short course for Edge AI to university students of Computer Science and Engineering departments. Edge Computing is a modern, distributed computing architecture that brings data storage and computation closer to the source of data generation instead of being sent to the Cloud. This approach provides several benefits to a modern IoT network such as bandwidth savings and improved response time. We propose an Edge Computing short course that includes theoretical knowledge reinforced with hands-on laboratory exercises. Our course syllabus combines different cutting edge technologies like Embedded systems, Artificial Intelligence and Machine Learning. For the implementation of the Edge Computing laboratory exercises we selected the Raspberry Pi Single Board Computer (SBC) to inference ML workloads applying different configurations. The proposed short course provides students the opportunity to develop expertise in Edge Computing and enforce skill development to manage projects that may encounter in a professional carrier.

CCS CONCEPTS

• **Applied computing** → **Education**.

KEYWORDS

edge computing, education, hands-on, raspberry pi, edge AI

ACM Reference Format:
Ioannis Stoitsis, Petros Amanatidis, Thomas Lagkas, and Dimitris Karampatzakis. 2022. A Hands-on University Short Course for Edge AI. In *26th Pan-Hellenic Conference on Informatics (PCI 2022), November 25–27, 2022, Athens, Greece.* ACM, New York, NY, USA, Article 111, 7 pages. https://doi.org/10.1145/3575879.3575971

PCI 2022, November 25–27, 2022, Athens, Greece

ACM ISBN 978-1-4503-9854-1/22/11…$15.00
https://doi.org/10.1145/3575879.3575971

1 INTRODUCTION

Nowadays, Cloud Computing is one of the latest innovations in the field of information technology. The Cloud has been used not only by many large companies, but also by many individual users. It seems that it has started to present technological issues of the dissemination and development of new and demanding technologies on the edge of the network, such as the Internet of Things (IoT) [14]. Edge Computing (EC) is coming to fill this gap, with data generated by IoT devices being processed closer to where it is produced rather than being sent to the Cloud Computing infrastructures [10, 13]. In addition the great improvement of the computing resources which are available in our days is allowing the production of Artificial Intelligence application like Computer Vision, Natural Language Processing etc. at the edge of the network rather than sending these computational tasks to cloud, this technology is called Edge AI [3].

Moreover, as mentioned in [5], academics play an essential role in preparing students for the industry and it is important the modern courses to cover the current and future industrial needs by considering the trends in scientific research and emerging technologies such as Artificial Intelligence (AI), Internet of Things, and Edge Computing. Due to the above, this work aims to present the educational material needed for teaching Edge Computing to university students. The proposed short course consists of hands-on material for embedded systems (Software/Hardware), Python programming for Edge AI, lesson plans, worksheets, and course evaluation sheets.

In addition, the COVID-19 pandemic, has brought many rearrangements in the learning process, and many in person educational activities replaced by the so-called "digital classroom" [4]. Using a "digital classroom" students and teachers can connect and communicate instantly, collaborate and share digital files, exercises, assignments and resources in general. In our work we considered these new conditions in teaching and we prepared a hybrid short course supported by distance learning tools. More precisely, we used Moodle asynchronous learning platform and live video conferencing applications to support the learning procedure. The students utilized asynchronous and synchronous distance learning tools in order to have access to the digital course material while they communicate with each other, collaborate and receive feedback through the learning activities that assigned to them during the educational process.

The teaching techniques that have been applied during the educational process were intended to mobilize and maintain learning interest as they enable students to think, reflect, discuss and work individually or in groups [9]. The teaching techniques that have been applied for the implementation of the courses are "Presentation or Lecture", "Discussion", "Questions", "Brainstorming" using the Forum, and the "Flipped Classroom". Additionally, during the lessons, small "Working Groups" of two or three students were created in order to prepare exercises and activities and reach conclusions with the aim of cultivating cooperation skills.

We designed and prepared five (5) units which were delivered in five two-hour lessons during Spring semester 2022. The course syllabus includes: Introductory topics of Edge Computing, Embedded Systems using Raspberry Pi (Hardware – Software), Machine Learning (ML) using the Google Colab platform, machine learning models inferencing with various configurations (TensorFlow, ARMNN on CPU/GPU/TPU), and closing with Edge Computing challenges and opportunities. This course is based on previous research work [1].

Before the starting point of the course and at the end, the students filled an entry and an exit questionnaire respectively. The purpose of these questionnaires was to collect valuable data related to the students enrolled in the course and afterwards their opinion about course implementation. The completion of the questionnaire was anonymous so that the students can express themselves freely without restrictions in order to reduce the risk of altering the results [6]. All data from questionnaires processed and are presented in this paper.

The structure of this paper is organized as follows: In the next section, we present related works regarding other offered courses and related technologies and tools for Edge Computing. In Section 3, we present the Edge AI syllabus of the proposed short course. In Section 4, we focus on the courseware and the student participation. In Section 5, the course evaluation process is presented and our findings. Finally, we conclude this work by presenting our final remarks in the last section.

2 RELATED WORK

The research we have done with related works is divided into two subsections. In section 2.1 we deal with educational courses in Edge Computing and in the second section 2.2 we present ways to use the Raspberry Pi SBC in computer science and engineering.

2.1 Educational courses in Edge Computing

The authors in [5], point out in their conclusion remarks that in terms of hard skills, they identified that IoT and Edge Computing are covered with less emphasis than AI in university courses. We confirm these findings and our short survey results in the literature highlight the lack of related works.

The authors in [11], presents an introductory course on the design of IoT Edge Computing devices and results of their implementation during COVID-19 period. The authors prepared courseware based on Intel's DE2i-150 development system. They present results from two semesters (spring and fall 2020) and the courses were planned to be in-person, but due to COVID-19 restrictions, they forced to work remotely using RP SBC (spring) and their revamped remote platform with DE2i-150 in fall semester. The authors used hybrid teaching to deliver the courses and their findings are valuable for the preparation of an Edge Computing course.

2.2 The Raspberry Pi SBC

Our first consideration in choosing a hardware platform for the laboratory exercises was whether to use a micro-controller or a Single Board Computer. On one hand, Arduino is a micro-controller based development platform that has interfaces with sensors and actuators, however it can be programmed for advanced functionality. On the other hand, the RP SBC has an operating system with more advanced processes, it has the ability to install various programming languages, as well as frameworks and applications needed to teach an Edge AI course.

In articles [2, 7], the authors present several ways to use the RP SBC in secondary and higher education in order to improve students' knowledge of computer science and engineering. Using RP students learn to install Raspbian, a free operating system based on Debian Linux distribution, and install applications and programming languages like Python. They conclude that the RP SBC is a suitable platform for students to acquire new knowledge and skills in the field of computing and electronics.

A. Ravishankar Rao et al. in [12] highlight that due to the rapid changes in areas of Internet of Things, Cloud Computing and other modern technologies, the gap between traditional courses taught in universities with the technology used in industry expands. This influences students enrollment and participation, tend to discourage student effort, and leads them to drop out of STEM courses. So, in their work they proposed the use of RP for hands-on exercises in order to encourage students to get involved and deal with cyber-physical systems and to attract more students in STEM courses.

Based on our research and our experience, we recommend the Raspberry Pi 4 SBC (with memory greater than 4 GB for ML/AI applications) as the core platform for the proposed Edge AI course for the following reasons:

- It is supported by an international open community that shares experiences and knowledge.
- Supports programming languages like Scratch, Python, and frameworks like TensorFlow and ARMNN.
- Supports different operating systems GNU/Linux and Windows.
- RP Pi 4 has four cores with 64-bit ARM architecture, the same compact form factor board, has low power consumption, and a plethora of peripherals which makes it a good choice for IoT applications and Edge AI.
- Due to the low cost (before the global chip shortages), students can easily buy it to practice at home and to invest in this platform for future projects in various other courses and fast prototyping.

3 EDGE AI SYLLABUS

In this work, we present an hands-on short course for Edge AI. We delivered the course for undergraduate (U) and postgraduate (P) university students of a Computer Science department in Greece, during Spring semester 2022. The course was organized into five (5) Units and had a dedicated syllabus for Edge Computing, as follows:

- Unit 1. Introduction to Computing, Architecture and Applications of AI in Edge Computing.
- Unit 2. Embedded Systems - The case of Raspberry Pi (Software/Hardware).
- Unit 3. Machine Learning using the Teachable Machine Web platform.
- Unit 4. Training and Inference of ML workloads in Edge Computing Environments.
- Unit 5. Running ML Models with Various Configurations on a RP SBC - Challenges and Opportunities in Edge Computing.

Unit 1. This unit is intended to introduce students to Edge Computing technology but also to technologies related to it such as the Internet of Things, Cloud Computing, and Artificial Intelligence. In more detail, it offers introductory knowledge about why the need for computing at the edge of a network was created, the existing weaknesses, and the gap that it comes to fill. Also, in this unit we offer a description of the main components of an Edge Computing system, the architecture and the main operating layers that make it up, such as Perception layer, Networking layer, Edge Computing layer, and the Application layer. Finally, we focus on the main network challenges that Edge Computing aims to solve, such as latency, bandwidth and network congestion, while at the end of the section we present examples of Edge Computing applications in different sectors and industries.

Unit 2. The second unit aims to introduce students to embedded systems and the advantages they have, such as low energy consumption, small factor, and many interconnection possibilities. Students learn about Systems on a Chip (SoC) and their characteristics. During Unit 2, students use hands-on material to study hardware and software features of RP SBC, they conduct laboratory exercises such as the installation of the operating system (Raspbian) on the RP, basic command line commands (CLI), as well as the steps to install TensorFlow library for Machine Learning (ML) and Python Programming language.

Unit 3. In this unit, we introduce students to AI technology and ML models using the Teachable Machine platform. We present basic concepts about Machine Learning, training types such as Supervised Learning, Unsupervised Learning, Limited Supervised Learning and Reinforcement Learning as well as the most commonly used Machine Learning models such as Artificial Neural Networks, Trees Decision Making, Support Vector Machines, Regression Analysis, Bayesian Networks, and Genetic Algorithms. We present the methodology to prepare a ML model, the training phase of the model from a dataset and the inference phase of the model in order to make a decision. Finally, we encourage students to create small groups where they implement, using hands-on material, their own ML workload using the Teachable Machine (TM) platform.

Unit 4. This unit focuses more on the laboratory exercises where students deal with Google Colab Machine Learning platform. In the lab students perform all steps for training a ML model using GPUs on Google Colab. Additionally, they install the TensorFlow Lite library on RP as well as all necessary libraries using CLI commands. Also, they learn to run a model ML on RP. Finally, they gain experience how to enable and configure a camera attach to a RP and to run real-time object detection models.

Unit 5. The last unit in dedicated to present different configurations of execution of AI models/workloads at the edge of a network. The unit is supported with hands-on material to infer AI/ML workloads using different hardware and software configurations. Finally, we conclude this course with an open discussion about the evolution of Edge Computing technology, open challenges, and the great opportunities it offers for new advances in research and development.

The proposed course is supported by detailed and rich courseware for each unit. Each unit is followed by an interactive self-assessment questionnaire which is completed by the students, which contains multiple-choice questions, fill-in-the-blanks, word matches, and videos which has been posted on Moodle platform. The student monitors their learning progress through these questions while feedback is provided either live or via email or using Moodle forum to improve and engage them more deeply in the learning process. In addition, after the end of each unit, we assign a practical exercise to the students in order to work on a project and make a connection between theory and practice for a better understanding and solidification of Edge Computing technology. In detail, we present the courseware of each unit and the students participation as following:

3.1 Unit 1. Introduction Raspberry Pi

The laboratory part of Unit 1 is dedicated to introducing students to hardware and software of the RP SBC. Students should be able to use RP, learn to execute CLI commands using the terminal and be able to install and uninstall applications and libraries. After the first unit the students completed 10 multiple-choice self-assessment questions where the lowest score was (4.0), the highest was (10.0) and the mean score of all students was (8.14). Finally, we should note that a weekly feedback question was given to the students entitled "What Edge Computing technologies does a modern car have?" which was posted on the Moodle forum. The participation of the students was 44%.

3.2 Unit 2. Installing Raspbian OS on a Raspberry Pi

In the laboratory part of the second unit students install the Raspbian operating system on a RP using an SD memory card. They follow the instructions to download the operating system from the official Raspberry website and then install it on the RP. Additionally, they were asked to install Python programming language and install TensorFlow framework for ML using command line commands. In this unit, we observed an increase in the average score of the students. They completed 10 multiple-choice self-assessment questions in the university's Moodle where the lowest score was (7.0), the highest was (10.0) and the Mean score of all students (9.59). The feedback question assigned to the students in the forum for the second tutorial was "One of the uses of the RP is to use it as a desktop computer. Can you mention other uses – applications of (RP) specifically in Edge Computing?". Student participation increased to 69%.

3.3 Unit 3. ML Project using Teachable Machine

In Unit 3, the hands-on material introduces students to ML technology with exercises using the Teachable Machine online platform.

After the theoretical part of the course, the students prepared a model to recognize when a person is wearing a COVID-19 protective mask and extract from the TM their own trained model for the next units. In this unit students completed 10 multiple-choice self-assessment questions where the lowest score was (9.0), the highest was (10.0), and the mean score of all students was (9.93). The feedback question was posted on the forum and was directly related to the work implemented by the students on the Teachable Machine platform entitled "How reliable is the ML model we get from the Teachable Machine export? Are there ways to improve it? What uses would such a model have in Edge Computing?". Student participation reached 50%.

3.4 Unit 4. Machine learning using Google Colab

The laboratory exercise for Unit 4 deals with the Python programming language using the online Google Colab ML platform. Students trained to handle functions and methods of the Python programming language and be able to perform the steps for training an ML model on Google Colab. In this unit students completed 10 multiple-choice self-assessment questions where the lowest score was (9.0), the highest was (10.0), and the mean score of all students was (9.74). The feedback question was posted on the forum titled "Could we infer the machine learning model we created in the previous unit with the TM platform on the RP? And if so, what are the necessary actions we should take?". Student participation reached 56%.

3.5 Unit 5. Inference Machine Learning models

In final unit students study different hardware platforms on which the ML model can be executed (inference). Specifically, the students experiment and infer AI/ML workloads using various hardware resources, such as Central Processing Unit (CPU), Graphics Processing Unit (GPU) and Tensor Processing Unit (TPU). In parallel, students can test inference of AI workloads using libraries like Tensorflow and ARMNN on an RP SBC. Finally, they accelerate models using Coral USB Accelerator attached to a RP and compare them with CPU based results. In this unit students also completed 10 multiple-choice self-assessment questions where the lowest score was (9.0), the highest was (10.0), and the mean score of all students was (9.69). The feedback question assigned to the students in the forum was "After implementing the ML model in Google Colab which hardware platform (CPU, GPU or TPU) would you choose to run your model? Please, justify your answer." Student participation increased to 75%.

4 EVALUATION RESULTS

In total, sixteen students enrolled in this short course. Early in the course, five undergraduates aborted the course without any penalty as allowed in Greek Universities. The course enrollment targeted students who selected the elective course of Computer Architecture (undergraduate, 6th semester) or IoT technologies (postgraduate, 2nd semester). Nine (9) were undergraduate students and seven (7) students are graduates of computer science/engineering who are pursuing postgraduate studies. Before the start of the units, the students were given an entry questionnaire. After the last unit the students responded to an exit questionnaire. Google forms were used to collect data and students received the form via e-mail. The rating scale we used for the questionnaires is based on the 5-point Likert scale (1 "Not at all" to 5 "Excellent"). The questionnaires helped us to collect helpful data about the students attending the course. In addition, due to its anonymity the students expressed themselves freely, without restrictions, thus reducing the risk of altering the responses.

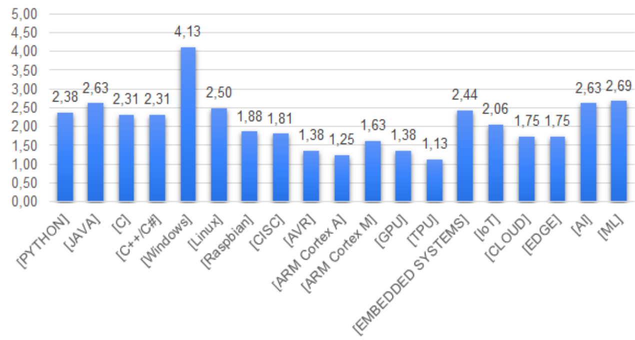

Figure 1: Average score of students per knowledge subject

4.1 Entry Questionnaire

The entry questionnaire consists of ten (10) questions and sixteen students participated. The first four questions collect demographic information such as gender, age, education level, and occupation. After processing of the responses, the course participants are 31.2% women while 68.8% are men. The age groups are: 15-25 (31.3%), 26-35 (12.5%), 36-45 (37.5%) and 45+ the (18.8%). The next six questions gathering information about their knowledge level for subjects related to the course. The responses related to how much students are familiar with software and hardware technologies, as presented in Figure 1, the largest percentage answered that they are familiar with Python and Java, not with C and C++/C#. When asked about operating systems, they answered positively for Windows, not familiar with Linux and Raspbian. To the question related to computer architectures they answered that they are not familiar with none of them. Following, they answered positively about their acknowledgement of Embedded Systems, but Internet of Things, Cloud Computing, and Edge Computing were topics new to them. Finally, in the questions about AI and ML, students declared that they are familiar with them.

4.2 Exit Questionnaire

At the end of the course, we delivered the exit questionnaire which consists of 49 questions that the eleven remaining students filled in immediately after the last unit using Google forms. By collecting the data, as presented in Figure 2, we analyzed the responses regarding their degree of satisfaction attending Edge Computing course, and in detail for the teaching material which includes: the quizzes, feedback questions in Moodle forum, and hands-on exercises assigned to them during the course. The questions are organized into five (5) groups with names (B1, B2, B3, B4, B5) and three (3) single questions (B6, B7, B8). The first named group of questions B1

Q.	U	U	U	U	P	P	P	P	P	P	P	AVERAGE
B1.1	4	3	4	5	5	5	4	5	4	4	5	4.36
B1.2	4	5	4	5	5	5	4	5	4	4	5	4.55
B1.3	2	3	3	5	5	3	5	4	5	4	5	4.00
B2.1	4	4	3	4	5	5	5	5	4	4	5	4.36
B2.2	4	3	3	4	5	5	5	5	5	4	5	4.36
B2.3	4	5	4	4	5	5	5	5	5	5	5	4.73
B2.4	4	5	4	4	5	5	5	5	4	4	5	4.55
B2.5	4	5	4	4	5	5	5	5	4	4	5	4.55
B2.6	4	5	4	4	5	5	5	5	4	4	5	4.55
B2.7	4	5	4	4	5	5	5	5	4	3	5	4.45
B2.8	4	5	4	4	5	5	5	5	4	3	5	4.45
B2.9	5	4	3	5	5	5	5	5	4	3	5	4.45
B2.10	4	3	3	5	5	4	5	5	4	4	5	4.27
B2.11	5	5	3	5	5	5	5	5	5	5	5	4.82
B2.12	3	3	3	4	4	5	4	4	3	5	5	3.91
B2.13	3	4	3	4	4	4	4	4	3	5	5	3.91
B2.14	4	3	3	3	5	5	4	5	4	4	3	3.91
B2.15	4	3	3	4	4	5	5	5	4	3	5	4.09
B3.1	4	3	3	3	5	4	4	4	5	3	4	3.82
B3.2	2	2	4	3	5	4	4	4	4	4	4	3.64
B3.3	2	2	3	3	5	5	5	5	5	4	5	4.00
B3.4	2	1	2	4	4	5	5	5	4	5	5	3.82
B3.5	3	5	4	2	4	5	5	5	4	4	5	4.18
B3.6	4	5	4	4	5	5	5	5	5	5	5	4.73
B3.7	3	5	4	5	5	5	5	5	3	4	5	4.45

Q.	U	U	U	U	P	P	P	P	P	P	P	AVERAGE
B4.1	4	5	4	5	4	5	5	5	4	4	5	4.55
B4.2	3	2	4	4	5	5	5	5	3	3	5	4.00
B4.3	4	4	4	5	4	4	5	5	4	4	5	4.36
B4.4	1	1	1	4	1	1	5	5	3	2	5	2.64
B4.5	2	1	3	4	2	3	5	3	3	3	1	2.73
B4.6	1	1	1	4	1	3	4	1	3	2	1	2.00
B4.7	1	4	2	4	4	2	4	1	3	3	4	2.91
B4.8	3	3	4	2	1	3	4	3	3	3	4	3.00
B4.9	2	1	2	2	1	3	4	1	3	4	4	2.45
B4.10	2	2	1	3	1	1	4	1	3	3	4	2.27
B4.11	1	3	3	4	1	3	3	3	2	3	4	2.73
B4.12	1	3	2	4	4	3	3	3	3	3	4	3.00
B5.1	2	2	2	3	2	3	5	2	4	4	5	3.09
B5.2	2	1	2	3	4	4	4	4	3	3	5	3.18
B5.3	1	1	3	3	3	4	4	4	4	4	5	3.27
B5.4	1	2	2	2	4	3	4	4	4	4	5	3.18
B5.5	3	2	2	4	3	3	4	4	3	4	5	3.36
B5.6	2	2	3	4	3	3	4	4	3	4	5	3.36
B5.7	2	2	2	4	3	3	4	4	3	5	5	3.36
B5.8	1	2	2	3	3	3	4	4	2	4	5	3.00
B5.9	1	2	3	3	4	3	4	4	3	3	5	3.18
B6	4	4	5	4	5	5	4	4	4	4	4	4.27
B7	3	3	4	5	5	5	5	5	4	4	5	4.36
B8	4	4	4	5	5	5	5	5	4	4	5	4.55

Figure 2: All student responses to the exit questionnaire

includes 3 sub-questions, B2 includes 15 sub-questions, B3 includes 7 sub-questions, B4 includes 12 sub-questions and the last group B5 includes 9 sub-questions. In Figure 2, student responses for all the questions and the average score for each question is presented.

The group B1 is entitled "Please rate the usefulness of the Edge AI course content..." and includes three questions (B1.1, B1.2, B1.3). Specifically, the first question titled "B1.1 For your cutting edge technology training needs" the students responded with 4.36. In the question "B1.2 For your fundamental knowledge" with 4.55, and in the third one "B1.3 About your professional subject that you already have or are you thinking of pursuing?" undergraduate students scored 3.25 and postgraduates higher to 4.43. The results show that all students believe that this course will help them in their studies, but postgraduates as expected are more mature professionally to apply new knowledge.

The second group B2 is entitled "Please evaluate the following parameters of the Edge AI course" and includes 15 questions (B2.1 to B2.15). The titled question "B2.1 The structure of the applied flipped classroom training program: asynchronous and synchronous teaching", the undergraduates scored 3.75 while postgraduates with 4.71. Next question "B2.2 Attending procedure of the course was clear from start" students replied 4.36. In the question entitled "B2.3 Access to asynchronous material" students responded with 4.73. The next group of questions (B2.4 to B2.8) students evaluated the quality of the asynchronous teaching material, specifically they asked about the "Quality of the asynchronous laboratory material for units 1, 2, 3, 4, 5". The score for the 1st, 2nd and 3rd laboratory exercises is 4.55, while for the 4th and 5th exercise it is 4.45.

The next question, how do you rate the "B2.9 Overall proficiency of Edge AI courseware" undergraduates responded 4.25 while postgraduates 4.57. In the question of whether "B2.10 Did the laboratories meet your expectations" undergraduates gave 3.75 while postgraduates 4.57. In the question about "B2.11 General climate and atmosphere during teleconferences / or in-person classes" students expressed with 4.82. In the question about "B2.12 Amount of knowledge/skills acquired" undergraduates gave 3.25 while postgraduates 4.29. In the question about "B2.13 Quality of knowledge/skills acquired" undergraduates scored 3.50 and postgraduates 4.14. In the question about "B2.14 Total duration of the training program" undergraduates expressed with 3.25 while postgraduates 4.29. In the question about "B2.15 Overall structure of the short course" undergraduate students scored 3.50 while postgraduates 4.43.

The third group B3 is entitled "To what extent do you feel that..." and includes seven questions (B3.1 to B3.7). In the question "B3.1 Edge AI course was time intensive" undergraduates gave 3.25 while postgraduates responded higher to 4.14. In the question of whether "B3.2 Edge AI course was demanding in terms of personal study" undergraduates scored 2.75 while postgraduates 4.14. In the question whether "B3.3 Was it necessary to systematically attend teleconferences or in-person classes to complete the course" undergraduates responded 2.50 while postgraduates went higher to 4.86. According to the question of whether "B3.4 Systematic study of asynchronous courseware was necessary to complete the course" undergraduates gave 2.25 while postgraduates 4.71. In the following question "B3.5 During the course, collaborative relationships among students were developed" undergraduates expressed with 3.50 while postgraduates 4.57. In the question whether "B3.6 The climate was friendly and encouraging in terms of sharing opinions, experiences and questions" undergraduates responded 4.25 while postgraduates 5.00. In the question about "B3.7 Asynchronous communication tools (e.g., Discussions) significantly facilitated the maintenance of a collaborative climate after the end of teleconferences or in-person classes" undergraduates responded 4.25 while postgraduates 4.57.

The fourth group B4 is entitled "To what extent did each of the following help you to better attend the Edge AI course" and includes twelve questions (B4.1 to B4.12). In the question about "B4.1 The interaction - discussing questions with instructors / assistants" students seem to be satisfied because they responded with 4.55. The question on "B4.2 Study of hands-on material" undergraduates gave 3.25 while postgraduates 4.43. The next question about "B4.3 The practical examples of using the tools" the undergraduates scored 4.25 while the postgraduates 5.0. In the next nine (9) questions

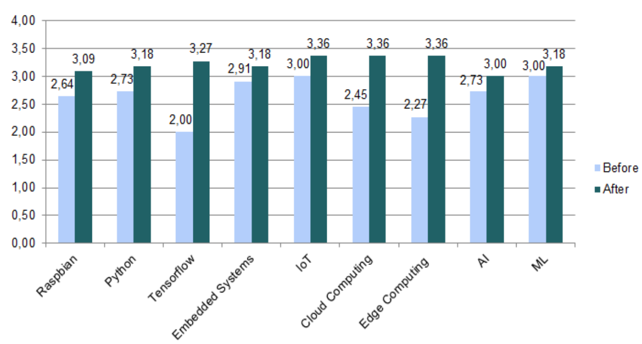

Figure 3: Average students' score per subject before and after course participation

(B4.4 to B4.12), we asked the students about the awareness they had before starting the course on specific IT and communications subjects such as Raspbian, Python, Tensorflow, Embedded Systems, IoT, Cloud Computing, Edge Computing, AI and ML. The scores for each answer are (2.64, 2.73, 2.00, 2.91, 3.00, 2.45, 2.27, 2.73, 3.00) respectively. The last group B5 is entitled "Do you believe that your enrollment in Edge Computing course improved your skills in the following" and includes ten questions (B5.1 to B5.10). We asked students to rate their awareness about the same subjects (Raspbian, Python, Tensorflow, Embedded Systems, IoT, Cloud Computing, Edge Computing, AI and ML) and after course finishing we gathered the following scores respectively (3.09, 3.18, 3.27, 3.18, 3.36, 3.36, 3.36, 3.00, 3.18), as can be observed in Figure 3.

In the single question "B6 To what extent do you think you have completed the Edge AI course?" undergraduate scored 4.25 while postgraduates 4.29. In the question "B7 To what extent would you recommend Edge AI course to your colleagues?" undergraduate students scored 3.75 while postgraduates higher to 4.71. Finally, on the last question "B8 Please rate the Edge AI course overall" all students expressed positively with an average score of 4.55.

4.3 Discussion and lessons learned

In our computer science department a low percentage of students (5-10%) follow disciplines like hardware and embedded systems, and the same pattern in presented also in [8]. In our case, the total number of 16 students (from two different programs) is not perfect to derive very reliable quantitative results, but it is sufficient to derive useful conclusions that will help in future optimal course design. With this work we would like to share with the scientific community our experiences and the lessons learned. In addition, due to the COVID-19 pandemic the course was designed using distance learning tools to enhance the total educational engagement. Based on the results of the evaluation procedure and our unit by unit experience with the students, we selected the following to discuss:

- The Raspberry Pi 4, proved that it is an optimal choice for teaching Edge AI concepts because it is a competitive low-cost, easy to access, and fully supported SBC. It has scalability and could be handled easily by novice users but also could be push to reach peak performance by advanced or expert users.
- As in [11], the authors mentioned that students struggle to use Linux and CLI, we confirm also this observation and we suggest to enhance hands-on tutorials with cheat sheets and examples, but it is crucial to discuss this issue with academics delivering courses related to operating systems. During the course the students reported an increase in familiarity with Raspbian from 2.38 to 3.18.
- The students started the course with 2.38 awareness of Python programming language. In our department we do not offer Python as a distinct course, but it is used as a development tool for project assignments. In combination with the TensorFlow framework, after the closing of the course, students reported that they enhanced their knowledge related to Python (3.18) and TensorFlow libraries (3.27).
- In the question B2.3 about asynchronous material which was distributed to the students during the courses, they seem to be particularly satisfied as the average was 4.6. Also in the question B4.3, all students responded an average of 4.5 which indicates that they utilized and experimented with the hand-on material.
- The students awareness of Embedded Systems, IoT, Cloud Computing and AI increased by 20%. Edge Computing technology had an average of 2.44 before the start of classes and reached 3.36. Finally, ML had a starting average score of 2.69 and 3.18 after the end of the course.
- In the question B2.11 students responded an average of 4.75 which shows that distance education prevailed the pedagogical climate which leads to the maximum degree of course engagement. In addition to the question B3.6 whether the climate was friendly and encouraging in terms of sharing opinions, experiences and questions, the students expressed with an average of 4.50 which also shows that the students are satisfied in total by the course.
- In the group of questions about whether Edge Computing would be a future career for a young scientist (B1.3), undergraduate students scored an average of 3.25 indicating that they do not know or are not sure if they will pursue a career in future with this particular technology, while postgraduate students gave an average of 4.43 score, meaning they believe that they will work professionally in the future on Edge Computing. In the question B8, the students shows that they were happy and satisfied with the delivered course overall (4.55). We believe that this excitement is related to the cutting edge topics they studied during the course which give them a new perspective in their professional carrier (especially for postgraduates). Finally, in question B6 "To what extent would you recommend Edge AI course to your colleagues?" students reported an average 4.71, which will act as a promo to younger students to pursue hardware/embedded systems majors and enroll in related courses.
- Lastly, we found that the course duration of five weeks (short) is insufficient to disseminate the subject to students, and in the next course offer, we will extend it to a full semester (10-12 weeks).

5 CONCLUSIONS

In this paper, we present a hands-on university-level short course for Edge AI consisting of five (5) Units. The main goal of this course is to transfer knowledge to university students for Embedded systems, Artificial Intelligence, Machine Learning and the convergence of these technologies to Edge Computing paradigm. All these topics are supported, during the units of the course, by detailed and rich courseware. We collected data for course evaluation, and after processing the results showed that most of the students improved their skills in Edge Computing and related technologies. Finally, we present our suggestions and lessons learned, to contribute in future course improvements for Edge AI.

ACKNOWLEDGMENTS

This work was supported by the MPhil program “Advanced Technologies in Informatics and Computers”, hosted by the Department of Computer Science, International Hellenic University, Greece.

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