An Undergraduate Curriculum for Deep Learning

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***Abstract*—Deep Learning (DL) is an interesting and rapidly developing field of research which has been currently utilized as a part of industry and in many disciplines to address a wide range of problems, from image classification, computer vision, video games, bioinformatics, and handwriting recognition to machine translation. The starting point of this study is the recognition of a big gap between the sector need of specialists in DL technology and the lack of sufficient education provided by the universities. Higher education institutions are the best environment to provide this expertise to the students. However, currently most universities do not provide specifically designed DL courses to their students. Thus, the main objective of this study is to design a novel curriculum including two courses to facilitate teaching and learning of DL topic. The proposed curriculum will enable students to solve real-world problems by applying DL approaches and gain necessary background to adapt their knowledge to more advanced, industry-specific fields.**

Keywords— Deep Learning, curriculum design, Machine Learning, Deep Neural Networks, Engineering Education

I. INTRODUCTION

Deep Learning (DL) studies began around 2000s, but it became a hot topic in 2008 and it is becoming more popular year by year as an artificial intelligence method for machines to perceive and solve the problems like human beings [1].

DL is a form of machine learning that enables computers to learn from experience and understand the world in terms of a hierarchy of concepts [2]. Recently, DL-based solutions have yielded extraordinary outcomes in various machine learning applications, including image processing such as face [3] and car plate recognition systems [4], fingerprint [5] and iris readers [6], computer vision [7,8,9], and natural language processing [10]. Thus, DL has a wide range of application areas. When the literature is examined, during the past decade the number of papers published yearly in

The number of papers annually published on DL topic according to indexes Web of Science (WoS), IEEE, Google Scholar and ACM, between the years 2008 and 2017 has been steadily increasing (see Table 1).

TABLE I. THE NUMBER OF PAPERS ANNUALLY PUBLISHED ON DL TOPIC ACCORDING TO INDEXES WOS, IEEE, GOOGLE SCHOLAR AND ACM

	WoS	IEEE		Google Scholar	ACM
		Conference	*Journal*		
2008	49	14	2	2740	3388
2009	33	9	2	3260	4434
2010	56	30	10	3980	4146
2011	81	25	8	4580	3860
2012	100	56	21	5660	3981
2013	178	100	20	6800	3711
2014	377	237	44	9350	4119
2015	1102	530	123	15000	4614
2016	2358	1235	234	25900	5475
2017	2504	2242	390	35500	6327

In addition, the number of open positions in the DL field seems to be high when looking at popular job posting sites such as Linkedin, Indeed and Monster (see Table 2)

TABLE II. OPEN POSITIONS RELATED WITH DL

Job Search Site	Number of Vacant Positions Advertised
Linkedin	16363
Indeed	21536
Monster	1000+

So it is obvious that there is a high motivation for the universities and institutions to teach DL in undergraduate or graduate level. To implement the DL approach successfully to any Machine Learning (ML) problem, some hardware and software infrastructure should exist. For example, a large amount of data is required for training, high performance computing resources are needed to train the deep neural network, etc. Further details on this topic are discussed in later sections.

After having these pre-conditions met, one would need adequate training to acquire necessary skills in ML and

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related software libraries and platforms. These subject matters. Thus, in Computer Engineering departments at universities, the design of new courses or updating the present courses is gaining importance to effectively teach DL techniques to the interested students.

In some universities around the world, "Deep Learning" or its implementation on a specific area is offered as a self-contained course. Some of these are as follows:

- Convolutional Neural Networks for Visual Recognition [11]
- Deep Learning for Natural Language Processing [11]
- Deep Learning in Computer Vision [12]

Similarly, some online education platforms such as Udacity, Udemy, Coursera, DataCamp, etc. offer various courses on "Deep Learning" [13-16]. In most of the universities, during a 4-year academic education at the undergraduate level, there are several courses, mostly technical electives, related to the emerging "Deep Learning" topic such as Artificial Intelligence, Machine Learning, Image Analysis, Neural Networks, Statistical Learning, Data Analytics, etc. However, there are a few universities provide a specifically- designed "Deep Learning" course or track.

For instance; when we investigate the universities in Turkey, out of the 193 universities, only 10 of them teach DL as a single course either in graduate or undergraduate levels. Those universities are Necmettin Erbakan University, Gebze Yüksek Teknoloji University, Boğaziçi University, METU, Bilkent University, Koç University, İzmir Economy University, TED University, Yıldız University, and Özyeğin University (see Table 3). Considering universities giving DL course in Turkey, it is seen that 8 out of 10 give the DL course at graduate level. Among them, only İzmir Economy University and Özyeğin University offer the DL course for undergraduate level. İzmir University of Economics offers elective courses to undergraduate students under the name of "Deep Neural Networks" while Özyeğin University offers more than one course alternatives related to DL in artificial intelligence track.

TABLE III. DEEP LEARNING COURSES IN TURKEY

University	Department	Course Name	Type
Necmettin Erbakan University	Industrial Engineering	Deep Learning	Graduate
Gebze Yüksek Teknoloji University	Computer Engineering	Deep Learning and Applications	Graduate
Boğaziçi University	Computer Engineering	Deep Learning	Graduate
METU	Computer Engineering	Deep Learning	Graduate
Bilkent University	Computer Engineering	Deep Learning	Graduate
Koç University	Computer Engineering	Deep Learning	Graduate
İzmir Ekonomi University	Software Engineering	Deep Neural Networks	Undergraduate
TED University	Computer Engineering	Machine Learning (Final week lecture is related with DL)	Graduate
Yıldız University	Computer Engineering	Deep Learning and Artificial Neural Networks	Graduate
Özyeğin University	Computer Engineering	Introduction to Deep Learning[1]	Undergraduate

[a.] DL courses are given as a track

When we look at Atılım University, "Applied Neural Computing", "Introduction to Artificial Intelligence", "Digital Image Processing" and "Pattern Recognition" courses which are related to machine learning are given as elective courses to undergraduate students of Computer Engineering Department. In Applied Neural Computing course; introduction to neural networks, perceptron learning rules, backpropagation algorithms, generalization and overtraining, adaptive linear filters, radial basis networks, self-organizing networks, learning vector quantization and recurrent networks are given in the content. In the other course named Introduction to Artificial Intelligence; Agent paradigm, problem solving by searching, informed and uninformed search methods, genetic algorithms, simulated annealing, constraint satisfaction problems, adversarial search, logical agents, knowledge engineering, expert systems, communication and AI applications are given. Similarly, in Digital Image Processing course; Introduction to signal and image processing, introduction to digital image processing, sampling, reconstruction, and quantization, digital image representation, image transforms, enhancement, restoration, segmentation and description contents are given. In another related course, Pattern Recognition; Bayes decision theory, classifiers, discriminant functions and decision surfaces, estimation of parameters, hidden Markov models, nearest neighbor methods; linear discriminant functions; neural networks; decision trees; hierarchical clustering; self-organizing feature maps are offered as content. However, when these courses are closely examined, it is observed that the current curriculum includes some fundamentals of DL area, but the curriculum does not cover the whole important components of DL applications and techniques. For this reason, a specific lesson should be designed so that a student who takes the DL course can have an adequate background in this subject. It is thought that the students who take this course will expertise in DL approach more easily and be more successful in related sector.

In line with the above-mentioned motivation and requirement, the aim of this study is to provide the option for the interested students in Atilim University Computer Engineering Department by which they are expected to achieve fundamental knowledge and skills in the field of DL.

To this end, we have developed a curriculum development project with two international partners, the Netherland Wageningen University and the University of Malta, and submitted to EU Erasmus + Strategic Partnership program [17]. At the present, the project is in the review phase. Anyhow, as Atilim University, we are committed to develop and integrate novel DL courses into our curriculum. In this study, we would like to share our experience which were gained in the preparation of above mentioned EU project with the academic and business community prior to their implementation. In brief, we have designed two novel courses; one for basic knowledge about DL and the other for developing DL application skills. In these courses, while theoretical background about DL is established in lecture hours, application development skills in DL will be practiced in laboratory hours. Details of the designed courses are explained in the following sections.

II. Underlying Skill Set and Knowledge Base to Learn DL

Machine Learning (ML) and Deep Learning (DL) disciplines are generating a huge amount of interest in the technology field, and data scientists who have the underlying skill set in ML and DL will be well positioned to solve real life problems in the upcoming years. Because of this need, we designed the courses such that they would provide the selected skills that a successful data scientist should have. In order to achieve the appropriate skills in DL, a relevant mathematical background is required about Linear Algebra, Calculus and Statistics and, also, a basic understanding in programming languages and ML is needed [18].

A. An Undergraduate DL Curriculum for Computer Engineering

In Atilim University, Computer Engineering curriculum cover Linear Algebra, Calculus, Statistics, C and C++ programming as must courses and Java as an elective course. As it is mentioned before, some of machine learning concepts are given in several different elective courses such as Applied Neural Computing, Introduction to Artificial Intelligence, Digital Image Processing and Pattern Recognition. In these courses, some critical Machine learning concepts such as; overfitting, underfitting, generalization, loss function and regularization techniques (evaluation techniques) are not completely covered in one course.

In the scope of this study, two courses were designed to facilitate DL. The curriculum designed according to the results of the analysis of the popular online and open course sites , popular books in DL field, and the curriculums of the universities that gives DL courses and DL experts' blog sites [11-16],[18-25]. The first course is *Fundamentals of Machine Learning* and the second course is *Applications of Deep Learning*. In the first of two proposed courses, topics which are not covered in the existing courses but which are essential for DL teaching will be given using Python programming language in the laboratory environment. The second course is designed to be given in laboratory and classroom environment. For both courses, while the theoretical background is given in classroom sessions, its adaptation to real life problems will be exercised in laboratory sessions. The second course includes 3 main topics; *Application to Neural Networks, Application to Deep Neural Networks and Application to Recurrent neural network* respectively. For each main topic, *data analysis, feature selection and feature engineering, design model, performance evaluation and visualization and parameter tuning* are given as sub-topics. So, in the designed curriculum, it is suggested that the student first take the *Fundamentals of Machine Learning* course and then take the *Applications of Deep Learning* course respectively.

B. DL Application Development Frameworks

It is important which framework you choose when starting the DL application. GPU acceleration, supported programming language/interface and supported platform (Operating System) features differ in each distinct framework. The most widely used frameworks are TensorFlow, Theano, Torch and Caffe. Within these frameworks, TensorFlow is an open source, self-renewing, and the most used environment. Python is the most widely used programming language for ML and DL, supported by the TensorFlow framework. For this reason, TensorFlow and Python are preferred in the laboratory environment of the designed courses. On the other hand, Keras library is used as it is a simple, neural networks library written in Python that works as a wrapper to Tensorflow.

C. Weekly Course Plan

The weekly course plan designed considering the selected framework and programming language is given in Table 4 and Table 5.

a) Fundamentals of Machine Learning Course

This course is designed to teach the Machine Learning (ML) related theories and practical background which are essential for understanding and applying DL approach. Shortly, this course covers Machine Learning basics, various Machine Learning Algorithms, data preparation, and performance evaluation methods. Students who pass the course successfully will be able to understand:

- ML basics and DL algorithms,
- how to use Python programming language to implement DL models,
- how to use DL libraries and toolkits to implement the designed models,
- when and why specific DL techniques work for specific problems

This course will help students to get familiar with the Python environment by using several important ML libraries as well. Thus, for the next course, Applications of Deep Learning, students will be able to concentrate on the topics rather than programming language or the required libraries.

TABLE IV. FUNDAMENTALS OF MACHINE LEARNING

Fundamentals of Machine Learning			
Lecture		***Lab***	
W		***W***	
1	Introduction to Machine Learning Probability and statistics review	1	Basics of Python Language
2	Probability and statistics review (cont'd)	2	Basics of Python Language (cont'd)
3	Machine Learning Basics -Learning Algorithms -Capacity, - Overfitting, -Underfitting -Hyperparameters -Validation sets	3	Installation and introduction of Anaconda /Kaggle/ Jupiter/Spyder
4	Supervised Learning -Linear Classifiers: -Logistic Regression, -Naive Bayes Classifier -Linear Regression	4	Introduction to Related Python toolkits/libraries (NumPy, SciPy, Pandas, SciKit-Learn, Seaborn, Matplotlib)
5	Supervised Learning (cont'd) -Support Vector Machines -Decision Trees -Boosted Trees	5	Linear Regression with Python SciKit-Learn Library Logistic Regression with Python SciKit-Learn Library,
6	Supervised Learning (cont'd) -Random Forest -Neural Networks -K-nearest Neighbor	6	Classification with Python SciKit-Learn Library
7	Unsupervised Learning -Clustering: K-means, - hierarchical clustering, - DBscan	7	Clustering with Python SciKit-Learn Library
8	Unsupervised Learning (cont'd) -PCA (Principal components analysis).	8	Principal components analysis with Python
9	Stochastic Gradient Descent	9	Stochastic Gradient Descent with Python
10	Reinforcement Learning -Markov Decision Process	10	Markov Decision Process with Python
11	Data Preparation Data discretization -Preprocess -Formatting, cleaning, sampling	11	Case study - Data preparation
12	Data Preparation (cont'd) -Transform -Scaling, decomposition, aggregation, reduction -Model selection and feature selection.	12	Case study : - Feature Engineering - Classification
13	Performance Evaluation Measures -Classification accuracy	13	Case Study : - Regression - Clustering
	-Logarithmic loss -Confusion matrix -Visualization		- Visualization
14	Performance Evaluation Measures (cont'd) -Area under curve -F1 score -Mean Absolute Error -Mean Squared Error -Cross-validation	14	Case Study : - Performance Evaluation - Performance Visualization

b) Applications of Deep Learning Course

This course is designed to teach the essential parts of the DL approach by covering theory and practical aspects of the subject. During the lab sessions, we plan to introduce the latest DL models with the common data sets so that students would be able to apply such DL models to various real life machine learning problems.

Students who complete the course successfully will be able:

- to understand the key concepts behind DL methods,
- to understand, implement, and train the latest DL models used in Deep Neural Networks, Convolutional Neural Networks, Recurrent Neural Networks,
- to implement, train, and validate their own neural network.

TABLE V. APPLICATIONS OF DEEP LEARNING

Applications of Deep Learning			
Course		***Lab***	
W		***W***	
1	Introduction to Artificial Neural Networks - Perceptrons - Neurons - Weights, bias	1	Introduction to TensorFlow, Keras, and Integrated Development environments (Anaconda /Kaggle/ Jupiter/Spyder)
2	Artificial Neural Networks - Activation Functions - Training vs. Testing	2	- Workflow in Keras - Build simple Artificial Neural Networks model in Keras for classification - Evaluate the model using Keras built-in methods
3	Artificial Neural Networks (cont'd) - Feed-forward - Back Propagation - Stochastic Gradient Descent - Error and Loss Functions	3	- Build simple Artificial Neural Networks model in Keras for regression - Evaluate the model using Keras built-in methods
4	Artificial Neural Networks (cont'd) - Regularization - Performance Evaluation Measures	4	- Managing Keras model parameters
5	Introduction to Deep Neural Networks - Network Layers - Feed-forward	5	Build Deep Neural Networks model in Keras for classification

	- Backpropagation - Learning rates		
6	Deep Neural Networks - Hyper parameters - Optimization - Regularization - Drop-out	6	Model Optimization with Keras
7	Convolutional neural network (CNN) - Image Processing Tasks - CNN Architecture - Filters - Feature Maps	7	Hyper Parameter tuning
8	Convolutional neural network (CNN) (cont'd) - CNN Layers - Convolutions - Subsampling - Backpropagation in CNN	8	Build CNN model in Keras for Image classification
9	Convolutional neural network (CNN) (cont'd) - Examining well-known CNN models - Sample CNN Applications	9	Build CNN model in Keras for Image detection and localization
10	Recurrent neural network (RNN) - Time series - RNN structure - Backpropagation in RNN - Training & Testing in RNN	10	Build simple RNN model in Keras for Time series
11	Recurrent neural network (RNN) (cont'd) - Examining well-known RNN models - LSTMs	11	Build RNN model in Keras for Generating Image Descriptions
12	Recurrent neural network (RNN) (cont'd) - Sample CNN Applications	12	Build simple LSTM model in Keras
13	Transfer Learning - Pretrained models - Modification of Pretrained models - Limitations	13	Transfer Learning - Image Classification using pre-trained models in Keras
14	Transfer Learning (cont'd) - Sample Applications of Transfer Learning - Language Modeling and Generating Text - Machine Translation - Speech Recognition	14	Transfer Learning - Image Detection and Localization using pre-trained models in Keras

III. RESULTS

In this pilot study, we designed a two-course curriculum of a specialization that will furnish students with the fundamentals of DL, provide grounds to develop and to excel their skills and to acquire experience on specific implementation fields in Engineering. Thus, the study which is also submitted as an Erasmus+ Strategic Partnership project aims to develop high-quality skills and competences required by the existing labor market [17]. As by the nature of the proposed study, designed curriculum will help to educate and train the students who are to face information processing sector challenges. Such that the graduates of the proposed specialization track will gain experiences on application of DL methods on real life problems and be more ready to labor in the DL projects and implementations.

As a further study, several surveys and interviews will be applied to academicians and fields experts to receive their feedbacks. According to the results of the surveys and interviews, the proposed curriculum will be improved.

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