Quantification of Competencies-based Curricula for Artificial Intelligence

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Quantification of Competencies-based Undergraduate Curricular for Artificial Intelligence Certificate

1. Objective and Motivation

Artificial intelligence (AI) as a national priority for future technologies in the United States, has demonstrated its potential as a lifestyle-changing technology in different electrical and computer engineering areas such as speech/image recognition, and autonomous vehicles [1-5]. AI applications are also heavily involved in most aspects of the economy, such as banking and finance, national security, health care, and transportation [6-11]. By 2030, AI is estimated to increase the global Gross Domestic Product (GDP) by 14% ($15.7 trillion) [12]. Because of this, the number of job openings in AI is increasing at an unprecedented rate. In the United States alone, private investment in AI more than doubled in 2021 over the previous year to $93.5 billion and AI-related job postings led all other sectors at 3.3% of all job postings [13]. In the year of 2022, there were 320,000 data scientist job openings on LinkedIn in the United States alone [14]. However, a Statistics Analysis Software (SAS) survey of businesses reported that 63% of respondents had a skills shortage in AI [15].

As the job market for AI grows rapidly, educational institutions are responding with commensurate growth in AI and data science programs. AI is now the most popular specialty among computer science (CS) Ph.D. degrees, with over one in five of all CS Ph.D. graduates specializing in AI in the 2020 [13]. Most outcomes on AI training were reported from a computer science perspective, partially due to the fact that the U.S. Department of Education lists AI as a computer science specialty. While computer science advances the state-of-the-art in AI computation, electrical and computer engineers create hardware-based AI applications and extend AI computation to microprocessor-based embedded designs. However, outcomes of training on AI from the Electrical and Computer Engineering (ECE) perspective were not well studied or reported.

Given the growth in AI specialization, quantitative evaluation of students' training outcomes is needed. Therefore, the goal of this study is to examine the AI-related curriculum in an ECE department hosted at the University of Texas at San Antonio, a Hispanic-Serving institute, evaluate the competencies of ECE undergraduates with AI certificates, and bridge the gap between desired educational outcomes and real job requirements identified in the global market.

2. Background

Future of Artificial Intelligence

Artificial Intelligence is an ever-evolving technology that has seen significant progress in recent years. Some possible future developments of AI include Enhanced Deep Learning Models, Explainable AI, AI-Powered Autonomous Systems, Quantum Computing, and Human-Machine Collaboration [16]. Deep learning models have already demonstrated advancements in machine learning and artificial intelligence. Enhanced deep learning models could bring about a significant change in the field and potentially improve the accuracy and speed of data analysis, leading to better performance in a wide range of applications. Explainable AI is the concept of developing AI systems that can explain their reasoning and decision-making processes to humans [17]. This would allow humans to better understand how these systems arrive at their conclusions and to detect any biases or errors. Explainable AI could be especially crucial in areas such as healthcare and finance, where decisions can have significant consequences. Autonomous systems powered by AI could become increasingly prevalent in industries such as transportation and logistics [18]. These systems would be able to make decisions and take actions based on real-time data, reducing the need for human intervention and potentially increasing efficiency. Another area of AI research is focused on improving collaboration between humans and machines [19]. This could involve developing systems that can assist humans in decision-making or automating certain tasks, allowing humans to focus on more complex and creative work. Human-machine collaboration may be especially applicable to medical diagnosis and screening [20]. The future of AI imposes educational challenges on training AI professionals with the necessary skills to meet industrial needs.

The core of Artificial Intelligence

AI, machine learning, and deep learning are commonly considered the same concept by the non-technical population. Deep learning is a sub-domain of machine learning, and machine learning is a sub-domain of AI. Machines or computers do not have the natural intelligence and cognitive abilities to learn. Machine learning is achieved by feeding an enormous amount of data into a machine (computer) so the machine can classify the data into patterns, and identify the patterns with new data inputs [21]. For example, to teach a machine to learn an image of "a dog", it must be fed with thousands of images of "dogs" of different kinds, from different angles, and told that "this is a dog." The machine remembers the features/pattern of a dog and identifies a dog if a picture of a dog is fed into it. With this in mind, AI engineers will work with enormous amounts of data on which they will apply mathematics to develop and implement algorithms by programming with computing languages. The results they obtained will be communicated using various graphs, reports, presentations, etc.

Industrial-Specific Skills Required for AI professionals

Several investigations and surveys have been reported recently on the in-demand requirements to build a career in AI [22, 23]. The requirements can be categorized as mathematical background, technical-based domain knowledge, programming skills, and non-technical related soft skills.

Because AI professionals develop and apply algorithms and interpret their results based on applied mathematics, mathematical skills like calculus, linear algebra, probability and statistics, and optimization techniques are highly desirable. Differential equations in Calculus provide foundations to build and interpret a model. Linear algebra forms the basis AI algorithms involving matrices, vectors, tensors, and others. Probability is an essential part of AI models including discriminative and generative models, and support vector machines. Statistics is a vital subject for data collection, analysis, and interpretation to understand the AI model.

Domain knowledge of AI includes machine learning algorithms such as classification, clustering, logistic regression, time series analysis, optimization of an objective function, neural networks, convolutional neural network (CNN), graphical convolutional neural network (GCNN), recursive neural network (RNN), generative adversarial network (GAN), Transformer, generative pre-trained transformer (GPT), supervised learning, non-supervised learning, and reinforcement learning.

Outside of specific domain knowledge, technical skills needed by engineers specializing in AI include programming languages, frameworks and libraries, and Linux operation system. To implement an AI algorithm, proficiency in programming languages such as R, Python, Java**, and** C++, is crucial for every AI professional. Efficient coding with a computer language requires a deep understanding of computer architecture, data structures, and optimization algorithms. To accelerate and enhance the development of quality code, open-source AI tools such as TensorFlow, Keras, PyTorch, Apache Spark, and the math library NumPy, have been developed [24-28]. Many tools work in the Linux ecosystem, leading to a requirement of being accustomed to Linux-based systems and UNIX tools such as cut, sort, ark, tr, grep, etc.

Due to the typical level of application complexity, an AI professional normally works in a team with multiple team members to debate, discuss, brainstorm, and communicate their thoughts and ideas through calls, meetings, presentations, and reviews. There will be a variety of meetings: scrum meetings, review meetings, and discussions on daily tasks, challenges, and progresses. Thus, emotional intelligence, reasoning, persuasion, and ideation are just as critical to success as technical skills. In addition, due to the huge amount of data, visualization or graph tools can enhance the understanding of data and facilitate the critical-think process to solve a problem.

Besides providing training on mathematical backgrounds, domain knowledge, technical skills, and soft skills, ECE programs can provide unique hands-on projects in their curriculum, and application platforms of AI such as autonomous driving and robotics which are not normally included in computer science curricula.

3. Methods

An AI certificate program was launched in 2019 at the Department of Electrical and Computer Engineering at the University of Texas at San Antonio. Currently, 605 undergraduate students are enrolled in the department with 45% first-generation college students, 18% female, and 59% underrepresented minority students.

The AI certificate program requires 1 course entitled "Probability and Stochastic Processes" and 4 elective courses from 8 undergraduate-level courses. Students can also choose 2 graduate-level courses once permitted by the instructor for the AI certificate. Domains of AI, courses offered for the AI certificates, and course descriptions are shown in Table 1. Once a student accomplishes 5 courses (must including Probability and Stochastic Processes) from the courses listed in Table 1, he/she can receive a certificate of Artificial Intelligence.

The department of ECE offers 5 mathematical courses including Calculus 1, Calculus II, Applied Engineering Analysis I & II, and Probability and Stochastic Processes, which are required courses for all undergraduate students seeking a BS degree in ECE. Since the Calculus and Applied Engineering Analysis courses are prerequisites for Probability and Stochastic Processes, we only listed Probability and Stochastic Processes as a required course for the AI certificate. Knowledge learned in these 5 courses will give students a solid mathematical foundation for AI.

Table 1. Domain, courses for the AI certificates, and industrial-specific technical skills identified.		
Domain	**Courses for AI certificate**	**Industrial-Specific Technical Skills** [22, 23]
Mathematics	Probability and Stochastic Processes (Required for AI certificate and for all ECE students)	Random process, random variable, Mean, median, mode, variance, covariance, regression
Programming Skills	Systems Programming for Engineers (Elective)	Linux, Python, C++
	C++ and Data Structures (Elective)	Data structure, programming basics
Domain Knowledge	Introduction to Machine Learning (Elective)	Clustering, classification, logistic regression, and support vector machines, classification, clustering, logistic regression, time series analysis, optimization of an objective function, neural networks, CNN, GCNN, RNN, GAN, transformer, GPT, supervised learning, non-supervised learning, and reinforcement learning
	Artificial Intelligence (Elective)	Informed search, logical and probabilistic inference, machine learning, planning, and natural language processing
Applications of AI	Introduction to Robotics (Elective)	Analytical techniques and fundamental principles of robotics; motion control, robot sensing, and robot intelligence.
	Intelligent Robotics (Elective)	Autonomous Driving with path planning, sensing (IoT), and study of artificial neural networks control, knowledge-based control, and fuzzy-logic control.
	Intelligent Control (Elective)	Neural networks and fuzzy logic basics, approximation properties, intelligent controller
	Internet of Things (IOT) (Elective)	IoT device programming (Arduino and Raspberry Pi), sensing and actuating technologies,
	Cyber-security (Elective)	Network/device security hygiene, search techniques, incident response, and risk assessment

Calculus I & II: The two-semester course covers an introduction to the concepts of limit, continuity and derivative, mean value theorem, and applications of derivatives such as velocity, acceleration, maximization, and curve sketching, and an introduction to the Riemann integral and the fundamental theorem of calculus. The 2nd semester covers methods of integration, applications of the integral, sequences, series, and Taylor expansions.

Applied Engineering Analysis I and II: The two-semester course covers mathematical modeling of engineering problems; separable ordinary differential equations (ODEs); first-, second-, and higher-order linear constant coefficient ODEs; characteristic equation of an ODE; non-homogeneous equations; Laplace transforms; shifting theorems; convolution; solution of an ODE via Laplace transform; matrix addition and multiplication; solution of a linear system of equations via Gauss elimination and Cramer's rule; rank, determinant, and inverse of a matrix; eigenvalues and eigenvectors; existence and uniqueness of solutions; solution to a system of ODE's by diagonalization. The second semester is focused on PDEs and solving the wave equation and the heat equation as well as complex numbers and developing parametric models to calculate curve length or positions on a surface.

Probability and Stochastic Processes: The course covers probability and random variables, conditional distribution, conditional density function, operations on random variables, Central Limit Theorem, random process, spectral analysis of random processes, and linear systems with random inputs (linear regression).

C++ and Data Structures: This course covers the review of C++ non-object-oriented programming (OOP) concepts, object-oriented programming, inheritance, virtual functions and polymorphism, and operator overloading. It also includes an in-depth study of data structures including stacks, queues, linked lists, trees, binary trees and its application to binary search trees and sorting.

Systems Programming for Engineers: The course focused on programming low-level interfaces of Linux using Python. Students will learn basics of Linux utilities and Python, interfacing to services in the underlying Linux kernel using Python's system programming tools, supporting for running programs covering threads, process forks, processing files and directories, and networking with pipes, socket, and queues in Python.

Introduction to Machine Learning: The course includes an introduction to concepts of inference and learning. It introduces concepts of clustering, classification, regression including linear and nonlinear regression, logistic regression, linear discriminant analysis, and support vector machines. It also covers an introduction to dimensionality reduction and artificial neural networks.

Artificial Intelligence: This course covers the construction of programs that use knowledge representation and reasoning to solve problems. Major topics include informed search, logical and probabilistic inference, machine learning, planning, and natural language processing.

Introduction to Robotics: The course covers coordinate transformations, forward and inverse kinematics, Jacobian and static forces, path planning techniques, dynamics, design, analysis and control of robots, sensing and intelligence.

Intelligent Robotics: The course focuses on the study of artificial neural networks control, knowledge-based control, and fuzzy-logic control. Analytical techniques and fundamental principles of robotics; dynamics of robot arms, motion control, robot sensing, and robot intelligence.

Intelligent Control: The course covers neural networks and fuzzy logic basics, approximation properties, conventional adaptive controller design and analysis, intelligent controller design and analysis techniques for nonlinear systems, and closed-loop stability.

Internet of Things: The course covers IoT device programming (Arduino and Raspberry Pi), sensing and actuating technologies, IoT protocol stacks (Zigbee, 5G, NFC, MQTT, etc.), networking backhaul design and security enforcement, data science for IoT, and cloud-based IoT platforms such as AWS IoT.

Fundamentals of Cyber Security: This course covers core cyber security terminology, concepts, and challenges faced by individuals, organizations, and nations through case studies and discussions. Applications will be emphasized with hands-on exercises in areas such as network/device security hygiene, search techniques, incident response, and risk assessment. The overall aim of the course is to familiarize students with security techniques and strategies needed across a broad range of industry sectors.

Graduate Course- Machine Learning: The course introduces concepts of training, testing, and cross-validation. It also coves 1) probability and statistical inference such as conditional probability and expectation, maximum likelihood estimation, and mapping and spatial analysis; 2) Linear and nonlinear supervised methods in regression and classification including linear discriminant analysis, logistic regression, support vector machines, ridge regression, LASSO, elastic net, and neural networks; 3) Unsupervised methods including clustering and dimensionality reduction; and 4) Mathematics of machine learning including vector spaces, linear algebra, convex optimization, and stochastic gradient descent.

Graduate course -Deep Learning: This course will introduce the basic concept of deep learning and cover the most important deep learning models including deep neural networks, CNN, and RNN. The course will also cover applications of deep learning in computer vision, natural language processing, computational biology, and other areas.

In summary, there is no extra course needed to obtain the AI certificate to fulfill the degree requirements of BS in ECE. However, students need to plan in advance to choose the proper electives to meet the requirements of an AI certificate.

Student Outcomes

We examined the courses taken by students gained the AI certificate, students' performance of the courses, and their research experiences during undergraduate studies. Students' competencies in AI were considered as the time period for job hunting, and placement post-graduation based on LinkedIn information. Data collected will be analyzed using descriptive and inferential statistics and presented in graph or tabular forms.

4. Results

Student outcomes

A total of 20 students gained AI certificates in the past three years with 3 students in 2020, 7 students in 2021, and 10 students in 2022. Among the 20 students, 2 students are female and 45% are underrepresented minority students. The Mean ± Standard deviation of the GPA of the 20 students is 3.55 ± 0.31.

We examined the post-graduate placements of these students using their LinkedIn profiles. Among the 20 students, 12 students chose an industrial career path, with 9 of them going to high-profile tech giants including IBM, Microsoft, and General Motors, and the other 3 going to small or startup companies. The other 8 students joined a graduate school for MS or Ph.D. degrees. Their career paths are either in AI, robotics, data science, or security.

A total of 18 out of 20 students launched their careers right after graduation or within 2 months post their graduation date. Only 2 of them started their first permanent job 4 months after graduation. Compared with the average 6-month job-hunting period in 2022, our students with AI certificates demonstrated a much shorter job-hunting period [29].

Curriculum for AI Certificate

We examined the topics covered by the AI certificate and the industrial-specific skills in demand presented in Table 1. Our data showed that all 20 students with AI certificates took machine learning or AI courses either at the undergraduate or graduate levels, suggesting our students gained some domain knowledge of AI before graduation. Most of the technical skills were included in the undergraduate courses. However, some AI algorithms such as CNN, RNN, GCNN, GAN, Transformer, GPT, and reinforcement learning, are only covered in graduate-level courses on AI and machine learning, suggesting improved undergraduate courses for training on domain knowledge of AI.

We also examined the courses taken by students who gained AI certificates as shown in Figure 1. Interestingly, it's observed that all students took probability and statistics, and C++ and Data Structure courses. About 50% of students took Systems Programming for Engineers, suggesting that 50% of students who gained AI certificates might not know Linux and Python programming, suggesting a strong need to address the training on Linux ad Python programming to improve the AI certificate program.

We also observed a significant trend of applying AI to robotics among this group of students. This may be partially caused by the ongoing NSF Research Experiences for Undergraduates (REU) program on AI and robotics and REU program sponsored by the student success center at the host institution. A total of 6 out of 20 students are REU trainees working on robotics. Their career choices demonstrated the continuity of their training in AI during the undergraduate program.

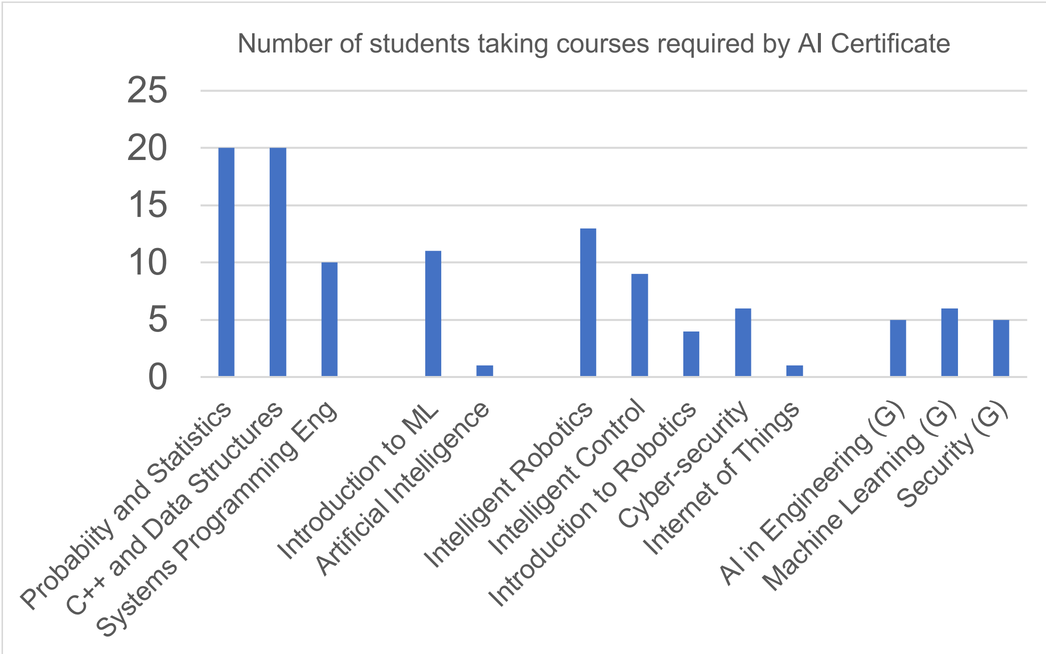

Figure 1. Number of students taking coursed required by AI. Graduate-level courses are denoted as G. All students gained AI certificate took probability and statistics, and C++ and Data Structure courses. All 20 students took at least one machine learning or AI course either at the undergraduate or graduate levels.

5. Conclusion

This is the first attempt to study the training on AI for undergraduate ECE students, and their capability to meet industrial-specific skills. The study specifically examined the training of AI professionals in a Hispanic Serving Institute. The curriculum selection for undergraduate AI certificates covers most industrial-demanded technical skills. Student outcomes in AI training programs demonstrated high competence in the job market evidenced by a relatively short job-hunting period and employment by high-profile tech companies. The number of students who obtained AI certificates increased every year since the program was launched.

Our study showed that the AI certificate curricula covered all technical skills required by the industrial-specific skills for AI professionals. However, there might be missing technical skills if a student takes biased subjects. For example, a student can take the core course, one programming course, then three courses in robotics to gain the certificate. However, this course setup may lead to a complete lack of domain knowledge in AI. Their competencies may be strong in robotics for a job-hunting but not well-trained in AI. This gives us an alarm to modify the requirement to cover at least one course in math, domain knowledge, programming skill, and applications of AI in the future.

We only evaluated the technical skills required by AI jobs. All non-technical soft skills cannot be performed in this study. The long-term effect of soft skills on their career development is an interesting topic to be conducted. Though 20 students obtained AI certificates from 2020-2022.

The low number of AI certificates might be caused by insufficient advertisement during the pandemic. In addition, the study was performed with institutional data and public data from LinkedIn. Qualitative interviews or questionnaires of the 20 students might help to gain meaningful insight from students' viewpoints to improve the AI certificate program. Finally, the low number of student samples and institutional and regional effects may also be considered for a complete study in the future.

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