International Journal of Engineering Education Vol. 36, No. 6, pp. 1760–1772, 2020
Printed in Great Britain
0949-149X/91 $3.00+0.00

Project and Practice Centered Learning: A Systematic Methodology and Strategy to Cultivate Future Full Stack Artificial Intelligence Engineers*

ZHEN GAO, TOM WANYAMA and ISHWAR SINGH
W Booth School of Engineering Practice and Technology, Faculty of Engineering, McMaster University, Hamilton, Ontario, Canada.
E-mail: gaozhen@mcmaster.ca, wanyama@mcmaster.ca, ishwar.singh@mohawkcollege.ca

Aiming at solving the current pain points of artificial intelligence (AI) education, a new AI course at W Booth School of Engineering Practice and Technology, McMaster University, was designed and delivered based on a paradigm called Project and Practice Centered Learning (PPCL). The overall teaching philosophy behind PPCL is: students should be systematically trained as future full stack artificial intelligence engineers who are capable to understand and implement feasible AI methods to solve real-world problems by building up systems which function completely to address practical issues in industry, business and daily life. Based on more interactive and practical training in hands-on activities, mini-projects, mid-term project, workshop, and capstone-like course final project, students learn to: (a) how to integrate AI sub topics to address issues raised from real-life, (b) how to create and analysis their own training and testing datasets, and (c) how to compare performance of different AI models, (d) inspire students' innovation ability, (e) cultivate their comprehensive ability to design and implement a sophisticated system individually, etc. Based on feedbacks from students and peers, the proposed PPCL based AI teaching and learning was effective. This pedagogy can also be applied to AI related courses and other technical engineering courses.

Keywords: project and practice centered learning; voice recognition; teaching strategy; AI education

1. Introduction

1.1 Emerging Issues of AI Education

Artificial Intelligence (AI), which is bringing a great impact to the society of humankind, has been reshaping many engineering and technology fields [1–8]. The national and international AI markets are continuously growing and it is expected that the prosperity of current third AI wave will continue for multiple years then settle down before the fourth wave becomes possible when fundamental breakthroughs are achieved in understanding intelligence itself [9–15].

With the integration of AI, emerging techniques are developed to improve teaching and learning efficiency in various course topics [16, 17]. These AI powered pedagogical methods include adaptive learning, customized online learning, test preparation, learning management, to name a few of them [18–20]. This research will focus on addressing the current common issues of AI teaching-learning itself since almost every institution realizes that present AI education is as essential as previous IT education for various majors.

The major challenging of AI teaching-learning includes: (a) This area includes too much subtopics with a few directions outdated and many directions open-ended; (b) Students face difficulty for preparing their own datasets and managing data; and (c), It requires sufficient practices to solve real-world problems from end to end.

Current major drawbacks of AI education can be outlined as: (1) Putting too much emphasis on theoretical details. (2) Only elaborating the big picture. (3) Disconnection between fundamentals and applications.

To solve the aforementioned issues, the detailed approaches will be explored in this pedagogical research to achieve the proposed paradigm called Project and Practice Centered Learning (PPCL). It is believed that students should be comprehensively trained to have both high level vision and ground-touch skills, such that they not only can see the entire system and but also build up a fully functional real-world targeted system piece by piece.

1.2 Project and Practice Centered AI Learning

Generally speaking, there are four major categories of AI in terms of its capabilities, including computational intelligence, perception intelligence, motion intelligence, and cognitive intelligence, as shown in Fig. 1. Based on this classification, applications of AI in areas of education, finance, manufacturing, healthcare, automotive, advisement, social media, gaming, and robotics can be the adaptation of one kind of capability or the integration of multiple kinds. The areas of AI actually are very diversified, including but apparently not limited to expert system, fuzzy logic, evolutionary algorithm, social intelligence, natural language understanding, knowledge engineering, machine learning, and artificial general intelligence. Those

* Accepted 20 March 2020.

areas are introduced to students with varied levels of depth; thus, students not only have entire picture but also obtain practical and in-depth skills through minds-on and hands-on learning strategy. It is noticeable that Deep Learning (DL) as the most dynamic and popular sub-area of machine learning has been massively applied in large scale image recognition, video analysis, speech recognition, automatic recommendation system, natural language understanding, etc. However, most education approaches of DL are about teaching students how to use libraries in frameworks such as Tensorflow, Pytorch, Keras, and Caffe. Only scratching the surface without solid foundations, students tends to be trained as technicians of AI hyperparameter tuning which is one of the lower levels in AI industry chain. PPCL is a paradigm to cultivate students to be an AI developer with open mind and creativity.

For related literatures, Experiential Learning (EL) was a popular pedagogy aiming at enhancing students' engagement and comprehension of content by integrating theory with real-world practices [21–23]. However, EL serves more as a high level concept while not a concrete approach, which means there is no unified reference system to follow. Besides, EL faces the challenges such as inadequate group skills, insufficient opportunities for reflection and so on. PPCL serves not only as a high level vision but also a concrete approach that peers can follow. The class participators gain the skills step by step with both breadth and width, and each student has sufficient chance for learning reflection.

Practice-based Learning (PBL) allowed the students to play an active role in classroom engagement to obtain better learning perception. However, it showed that there was a gap between traditional approach and PBL which caused difficulty in adapting [24]. The proposed PPCL provides a consistent learning environment for smooth transition from conventional mode to new style by seamlessly integrating various modules starting from lecturing to open ended project.

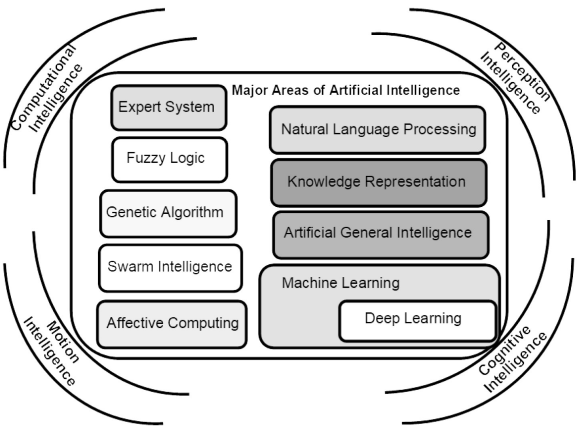


Fig. 1. Major categories of AI in terms of its capabilities.

Project-based Learning was positively affected and associated with teacher self-efficacy and student engagement [25]. Usually, projects can be divided as prescribed one and open ended one, both of which are difficult to monitor and assess accurately. With the idea of PPCL, the drawback of traditional Project-based Learning can be easily solved by requesting the students to build completed and robust system from scratch based on self-prepared and self-labeled datasets. The detailed break-down rubric guarantees the accuracy and fairness of assessment.

Conceive-Design-Implement-Operate (CDIO) as an innovative framework for engineering education was standardized and had its own trademark [26, 27]. Both CDIO and PPCL highlight the importance of active learning. However, CDIO's syllabus in four aspects is more suitable as guidance for curriculum re-design [28]. It can be applied to connect the knowledge blocks, transfer skills, and integrate learning outcomes in a series of courses. When applying CDIO in a specific course, it will be difficult to strictly follow its twelve standards [29].

New Engineering Education Transformation model (NEET) from MIT can be treated as an evolved and ambitious version of CDIO. NEET has been successfully implemented in many engineering departments at MIT [30]. NEET has attracted attention especially from internationally acclaimed research-intensive universities. Actually, the authors were inspired by NEET and developed Integrated Thinking (i-Think) model for multi-programs at McMaster University. However, the proposed PPCL is from the authors' own teaching experiences and practices. Overall, NEET is an innovative model for multidisciplinary programs, while PPCL is a novel paradigm for individual courses. They are on different layers so there is no competition. Actually, NEET or its variant such as i-Think can be integrated with PPCL.

Overall, the teaching strategy is formulated and visualized as the diagram in Fig. 2 to implement PPCL of AI. Each knowledge base is delivered and practiced based on the idea of 'divide and conquer' that utilizes 'minds-on and hands-on' loop to reinforce understanding and is further leveraged to higher learning levels such as application and synthesis. Interactive tutorial and live demo for dealing with real-world problem is arranged right after introducing background, principle and theory. The real-world problem-solving ability is transferable among relevant knowledge bases. Mini-project/hands-on activity is performed almost every week outside of classroom to enhance

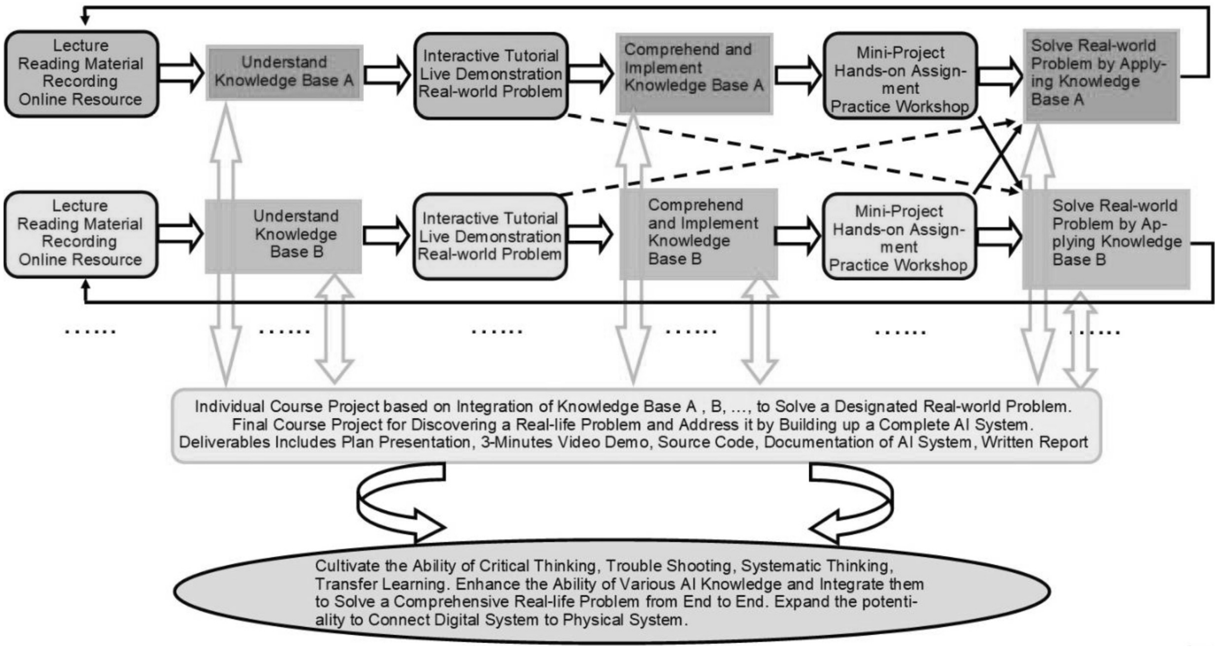


Fig. 2. Teaching strategy of PPCL of AI.

implementation ability and, in turn, to understand the knowledge base itself more deeply. The individual course project is arranged when the course is halfway done. A comprehensive project is designed that requires students to apply knowledge in sub topics to solve a designated real-world problem.

2. Course Design

2.1 Course Description

Course description of the proposed one is given as follows:

The ubiquitous nature of machine intelligence and its increasing impact on today's society, make the necessity to offer a practical AI course. This course covers the fundamentals and hands-on modules of classic and advanced AI techniques. The students will understand various AI models and tools such search and optimization, probabilistic methods, and pattern recognition techniques to solve problems including real world problems. The skill of management of training data will also be taught. Applications in areas such as manufacturing and automation, bio and healthcare, automotive, and energy, will be discussed. To establish a foundation for AI study, self-motivation and active practices are highly recommended.

2.2 Major Content

Major content of the proposed one is given as follows:

Overall, the course was offered online, with most of lectures delivered and recorded on Webex. Students' attendance was not counted for marks. Self-motivated was highly encouraged. The covered topics of AI methods and algorithms included but not limited to tree search methods, genetic algorithm, particle swarm optimization, Pareto-front based multi-objective optimization, shallow neural network, deep neural network, Hidden-Markov chain, and their applications in image recognition, speech recognition, and intelligent control. The detailed content was given in Table 1.

2.3 Learning Objectives

Learning objectives of the proposed one is given as follows in Table 2.

2.4 Course Assessment

The main modules for course assessment include three parts, i.e., weekly hands-on activities, mid-term project with 48-hour time window, final project with 3-week time window. Example of weekly hands-on activities is provided in Table 3.

2.5 Methodology Experience

To maintain a high quality, this AI course offered at W Booth School of Engineering Practice and Technology, McMaster University, had a small size class with 31 undergraduate students and 6 graduate students. They came from various programs. However, due to the high popularity and demand, the enrollment number was doubled in following academic year. Students were from different majors including Software Engineering Technology, Manufacturing Engineering, Power and Energy Engineering Technology, Civil Engineering Infra-

Table 1. Course main content

1. Introduction of AI topics, approaches and applications.	2. Tutorial of MATLAB programming of vectors and matrices. Assignment to check basic MATLAB. programming skill.
3. Tree search. Programming assignment for 8-puzzle problem.	4. Global search: Evolutionary computation. Programming assignment 1: Route optimization of traveling salesman problem based on genetic algorithm. Programming assignment 2: Use genetic algorithm to solve the global minimum of a self-defined function which has two variables. Programming assignment 3: Design optimization of vehicle suspension system based on genetic algorithm.
5. Swarm intelligence. Programming assignment 1: Use particle smarm algorithm to solve the global minimum of a self-defined function which has two variables. Programming assignment 2: Design optimization of vehicle suspension system based on particle smarm algorithm.	6. Multi-objective search/optimization. Programming assignment: Use multi-objective optimization method to minimize two functions with one variable.
7. Image fundamentals including segmentation, enhancement, filters, etc. Programming assignment for image fundamentals.	8. Pattern recognition: image recognition.
9. Midterm project for AI course: hand-written recognition. Students were asked to build up a functional and complete hand-written recognition system. They needed to create their own training and testing datasets. By doing this, every student's project is different from each other.	10. Intro of deep learning. Implementation of deep learning for Hand-Written Recognition and compared its performance with 'shallow' learning.
11. Speech recognition. Implementation of deep learning for speech recognition.	12. Hidden-Markov Model. Implementation of Hidden-Markov model for speech recognition.
13. Interactive workshop: Training the students to apply AI technique for a mechatronic system from scratch.	14. Final project: Design and implement an open project for any real-world problem that can be solved by AI techniques.

Table 2. Learning objectives

1.	Describe characteristics, classification, history and recent achievements of AI.
2.	Understand applications of AI based on various techniques and tools.
3.	Apply tree search and bio-inspired search methods for optimization problems.
4.	Solve classic pattern recognition problem in real world application.
5.	Understand the limits of artificial general intelligence.
6.	Design, evaluate and improve AI models for real-world problem solving.

Table 3. Hands-on activities

1.	Route optimization of traveling salesman problem based on genetic algorithm.
2.	Use genetic algorithm to solve the global minimum of a self-defined function which has 2 variables.
3.	Design optimization of vehicle suspension system based on genetic algorithm.
4.	Use particle smarm algorithm to solve the global minimum of a self-defined function which has 2 variables.
5.	Design optimization of vehicle suspension system based on particle smarm algorithm.
6.	Use multi-objective optimization method to minimize two self-defined functions with one variable.
7.	Remove the noise of a circuit board.
8.	Remove all watermark and shadow of a cat.
9.	Make very blurry image clear and visible.
10.	Hidden-Markov model and its application for speech recognition.

structure Technology, Biotechnology, Engineering Entrepreneurship and Innovation, Engineering Design, Technology Entrepreneurship and Innovation. Most students have working experience or they are currently employed, which means students are mature, and in many cases, self-motivated. For a small class there was only one professor who is dedicated to teaching. When the class size was doubled, a teaching assistant was required for grading. A few programs such as Manufacturing Engineering is listing this course as mandatory, which reflects the drastically increasing interest from academia and industry about AI. It indicates that today's artificial intelligence literacy and education is as important as yesterday's IT literacy and education.

3. Cases of Hands-on Activities

This section will explore more details of hands-on activities.

Hands-on Activities 1

Remove the noise of following image of a circuit board. Following image, as shown in Fig. 3, is very blurry. Students were asked to make it clear and visible. Students may attach the detailed process when trying to solve this problem.

Hands-on Activities 2

Taking Hidden Markov Model (HMM) as an

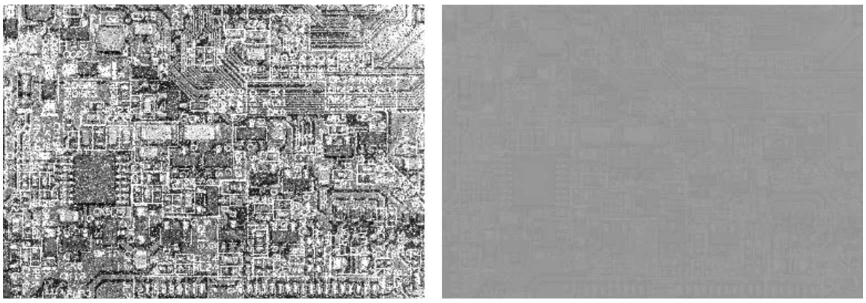


Fig. 3. Sample industrial images to be processed.

example to explain how to implement the proposed teaching strategy to achieve the learning objective. First of all, HMM as a fresh knowledge based was introduced at an early stage by lecturing and self-reading of relevant materials which are provided to students. In tutorial module, voice recognition based on deep learning was reviewed firstly, as shown in following figure (Fig. 4).

Furthermore, HMM was applied for the same voice recognition issue with GUI. Comparative analysis was performed between deep learning and HMM. A live demo was given to show the way to prepare HMM, re-train data and test performance. At a final stage, a workshop was arranged to guide students to integrate software with hardware to make a complete system that connects digital world to physical world. After that, students were expected to have sufficient confidence and enthusiasm to continue their AI journey in their current and future careers.

4. Midterm Project

The break-down of midterm project:

(A) Self-Prepared Training and Testing Images, 6%
(B) Functional Code: 7%
(C) Documentation of Project: 7%

Requirement of self-prepared training and testing images:
Student will prepare own handwritten images for training and testing. The handwritten images to be recognized can be anything including, but not limited to, digits, letters, symbols, non-English characters, and so on. Student can conduct handwriting on any media, such as hardcopy paper (need to use camera to take pictures) or any software such as 'paint' for handwriting. All images will be properly labelled so that other people can know what were written and prepared. Here is an

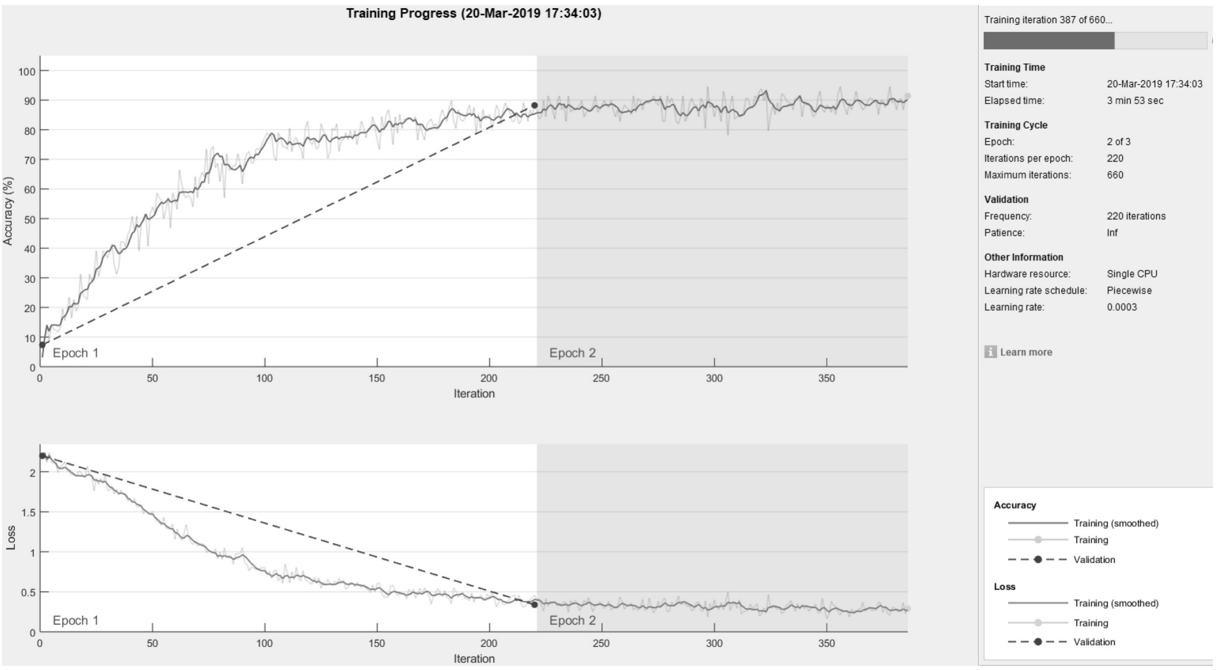


Fig. 4. Voice recognition based on deep learning.

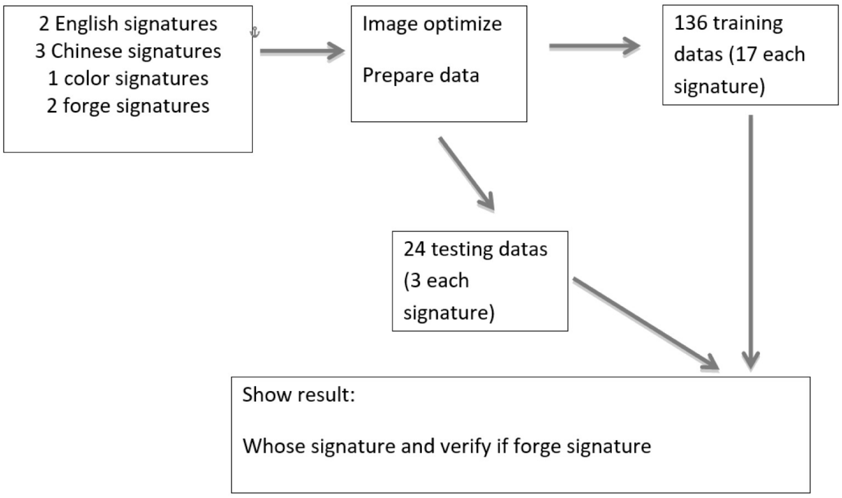


Fig. 5. Sample logic flow for hand-written training and testing.

example to answer what means 'properly labelled': a folder of 'myDigits' which contains all the labelled images. Instructor put all zeros in subfolder '0', all ones in subfolder '1', and so on. Based on this, if other people get the folder of 'myDigits', they will know what images are included in each subfolder. This is just an example of handwritten digits; students are encouraged to write something else. The real purpose of this project is to learn and enhance students' practical and applied skill sets. Pursuing high recognition accuracy is not the real purpose of this project. So students have high degree of freedom to handwrite anything and what needs is to label it properly. At least three classes should be created. Each class should have at least 20 sample images for training and 5 sample images for testing.

Requirement of functional code:
1. Code is fully commented.
2. Code can be easily executed by others.

Requirement for documentation of project:
1. In the word doc, it has a section about 'Project Implementation' to explicate how this project is performed. In the word doc, it has a section about 'Experiment Procedure' to explain step by step in details about how other people can run the code and check the result. In addition to plain words, diagrams, charts, photos and any other visualize items can be added in these two sections to help explain idea if any.
2. In the word doc, it has a section about 'Result Analysis' to analyze the test results and to visualize the test results with figures/tables. Students are expected to explain the test results and provide some suggestions about how the results can be improved.

Following flowchart (Fig. 5) shows one example of the procedure for letter/signature preparation, labeling, data categorization, and training/testing.

Before the students conducted this project, they were supposed to understand the history of artificial neural networks (ANN), which is briefly outlined in Table 4.

The training and testing process was performed based on a shallow feedforward neural network with one hidden layer. After evolution of 13 generations, the algorithm termination criteria were satisfied. To visualize the result, students were requested to display their original signature and indicate if the hand-written recognition result is 'Great!' or 'Opps!', which represented correct and incorrect respectively, as shown in Fig. 6.

Table 4. Brief history of ANN

Name of ANN variants or their key techniques	Major contributor(s)	Year
Perceptron	Frank Rosenblatt	1958
Automatic differentiation	Seppo Linnainmaa	1970
Backpropagation algorithm	Paul John Werbos	1975
Boltzmann machine	Geoffrey Hinton Terry Sejnowski	1985
Radial basis function	David Broomhead David Lowe	1988
Multi-level hierarchy of networks	Jürgen Schmidhuber	1992
Long short-term memory	Jürgen Schmidhuber	1997
Deep belief network	Geoffrey Hinton	2006
Deep learning	Geoffrey Hinton Yoshua Bengio Yann LeCun	2015

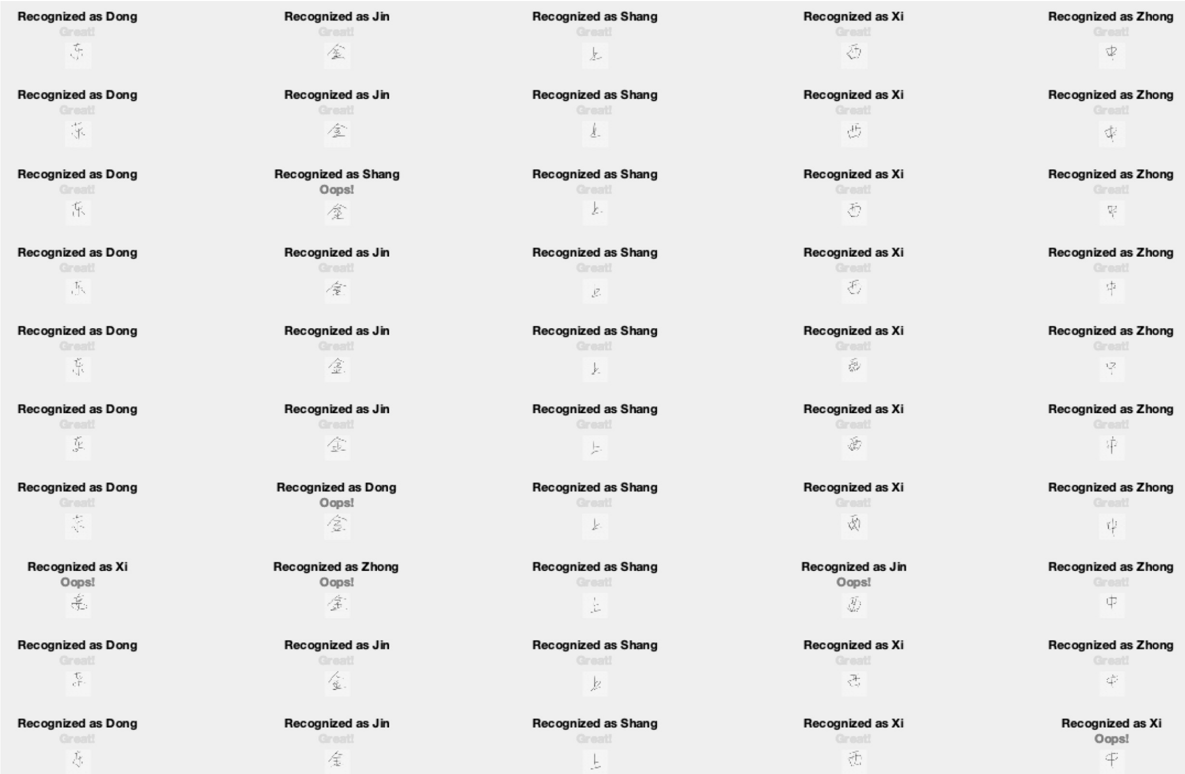


Fig. 6. Visualization of testing result for hand-written recognition.

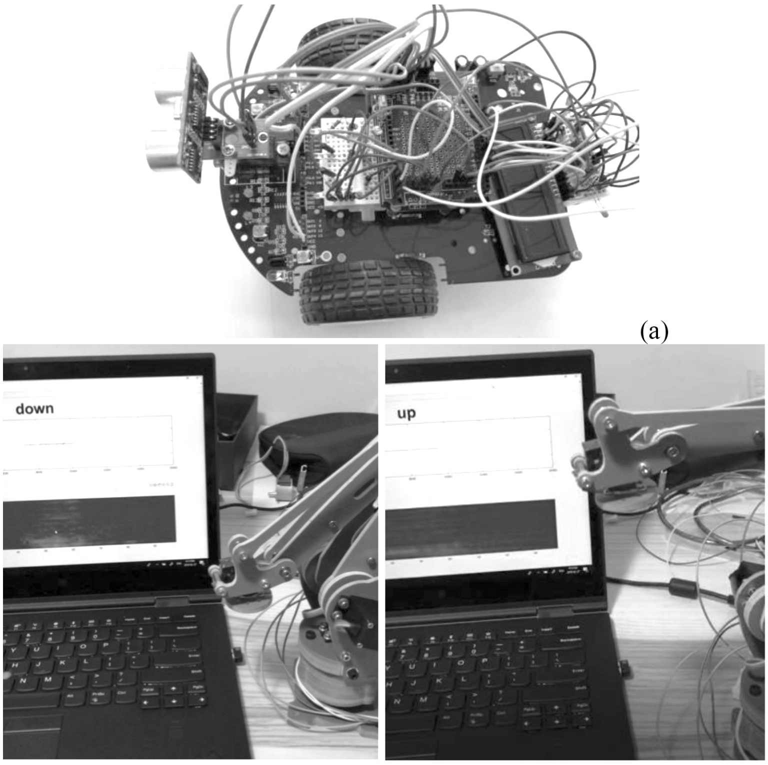
5. Workshops

5.1 Workshop 1: Intelligent Control of Mobile Robot

The pain point for practical AI course based on commercialized software was that it was not economical to purchase the site license and various toolboxes. This alternative workshop provided students a new perspective that a regular microcontroller was also capable to run modern AI algorithm to make decision and prediction based on the feedback of sensors. Actually, Microsoft Azure educational team also approached us to look for the potential collaboration for incorporating their educational platform to enhance students' practice based learning experience. In this alternative workshop, a feedforward neural network with one hidden layer was configured in a microcontroller for controlling a mobile robot as shown in Fig. 7(a). Input signals were from ultrasonic sensors, infrared sensors, light sensors, color sensors, push buttons, potentiometers, etc. Students decided the number of input neurons, hidden neurons, and output neurons. All input and output values were converted to acceptable ranges. Students were guided to design the feedforward neural network model modules by modules, i.e., initialize the connection weights between input layer and hidden layer, and between hidden layer and output layer, randomize the order of input-output training pairs from the dataset, set up hidden layer activation function and calculate the weighted summation, calculate the back-propagation errors in the hidden layer, set up output layer activation function and conduct the calculation of error in between actual output and predicted output, update the weights from input layer to hidden layer, and from hidden layer to output layer, determine the algorithm termination approach, determine what to be visualized based on a certain frequency.

5.2 Workshop 2: Robotic Arm Control Base on Deep Learning of Voice Recognition

Another hands-on workshop was arranged for this course. Since this AI course was offered online, an on-site workshop was helpful to gather students together and it provided a vehicle that students could build connection with each other to enhance experiential learning. This workshop took half a day, around 4 hours. Most students who registered this course were from computer science or software background, which meant they had no or little experience of software-hardware integration. Thus, this workshop also gave them a taste about how AI techniques that learnt in class could be applied to intelligently control a robot. Following four degree-of-freedom robotic arm was deployed in the workshop, as depicted in Fig. 7(b).



(a) (b)

Fig. 7. Workshop setup, (a) intelligent control of mobile robot, (b) robotic arm control base on deep learning of voice recognition.

Each group of two students were assigned a robot and its lab kit on a working station. Before applying any AI algorithm to control the provided robot, students were instructed to operate the servo motors based on PWM method. Sample code was given to students and specification of the motors were also given. Instructor would explain sample code, input/output of microcontroller, and wiring principle, so students could quickly comprehend a classic scenario for integrating hardware and software to implement an intelligent mechatronic system.

The overall objective of this workshop was to applying convolutional neural network to recognize vocal commands to control the mobility of the robotic arm. This work was treated as a mini-project that starts from scratch. Students were required to consider how to prepare their own utterance to control the motion of the given robot. Typically, they would like to consider to use words such as 'up', 'down', 'stop', 'start', 'left', 'right', 'forward', 'backward', etc., to fulfill controlling. Small scale datasets regarding the utterance were created by each student for training and testing. After that, vocal commands were trained based on convolutional neural network. Once the accuracy after training was high enough, it was ready to build up the connection between software and hardware of the mechatronic system. Serial communication was set up in order send/received the commands to/from the microcontroller. Some alternative solutions such as Bluetooth, Ethernet, Wi-Fi, radio frequency all could be considered if time allows. Eventually, the voice signal after successful recognition was written to the microcontroller to create respective motion of the robotic arm. The real-time performance of the proposed mini-project was ideal. Once students finished this mini project, they were encouraged to apply hidden Markov chain to conduct the similar application and then to compare the performance with convolutional neural network. By doing so, students' research ability could also be enhanced. Via well designed mini-project, it was observed that convolutional neural network exhibited better performance in terms of higher accuracy and responsive speed compared with hidden Markov chain.

6. Course Final Project

Basically, students were encouraged to find any real-world problem that could be solved by AI based on any programming language. The deliverables are indicated in Table 5.

Cases of course final projects:

1. Music genre classifier system.

This project was to explore the interdisciplinary comprehension of music information retrieval

Table 5. Components of final project

1.	(9%) Recorded video for project demo. About 3 minutes. Recommended format: MP4.
2.	(8%) All source code, well commented. Recommended format: put all source code into a .zip file.
3.	(8%) A detailed documentation for executing your project. Recommended format: WORD or PDF.
4.	(25%) Final written report. Recommend format: WORD or PDF.

through the application of two different machine learning approaches to identify the category of a song given an audio waveform file. The features of songs could be extracted for developing relative classifier to predict song genre. Student developed program to extract song features including zero crossing rate, spectral centroid, spectral bandwidth, spectral roll-off, chroma frequencies, root mean square. Two methods including k-nearest neighbors and feedforward neural network are implemented and their accuracy for music genre classification were compared. It concluded that feedforward neural network, which predicted songs' categories with up to 90% accuracy based on an average size of 50 songs, has significantly better performance compared with k-nearest neighbor algorithm. It was probably that the prediction accuracy of the genre of songs would be further improved based on adoption of deep neural network.

2. Game data extraction using trained neural network and optical character recognition.

This project was proposed and conducted by a graduate student who was enrolled in this course. Although the student did not have too much programming background, he successfully used LabView's trained neural network (TNN) and optical character recognition (OCR) to extract important driving simulator game data. These data were then interfaced to a hardware physical motion simulator as shown in Fig. 8. This project limited itself to (1) car speed, (2) gear setting to be recognized based on image processing. By using TNN and OCR, the console game's image data were visually recognized and converted to numbers. These numbers were fed to the mechanical motion simulator which through its own program determined how to move in order to replicate the accelerations which then the rider would perceive. The TNN had to be trained by the user to look at certain parts of the screen where the game data is being displayed. OCR with the trained character set would then be used while the game is being played. LabView has a very user-friendly interface for TNN which was appealing for most gamers who do not have programming experience. A video splitter fed display data to the gamer's screen and another to a laptop with video streaming and TNN/OCR program. In this project, a PC game had OCR performed on its screen to reduce project cost of having to purchase video feeding hardware. The output numbers were interfaced to a hardware motion simulator where car speed, gear setting will be tested to see if OCR is working. A most important issue to be addressed in this OCR program, is that OCR was noisy. A continuity test was used to detect when OCR has sporadically dropped digits or unable to recognize a certain number properly. This project was focused on making the proof of concept work and would not be concerned as much with the user interface.

7. Course Evaluation

The course evaluation system at McMaster University was based on three major parts, i.e., student evaluation, peer evaluation, and chair evaluation. Due to the lack of experience for students, sometimes their comments were not objective. However, student evaluation still had significant impact as an indicator of teaching effectiveness.

Table 6 shows the break-down marks in all assessment modules. All grading was conducted carefully by the course designer and instructor himself. The marks were fair and students had zero complaints regarding this.

Students' feedback about the value of this course were listed as follows:

> "The examples in lecture where helpful in completing the hands-on activities. The online format as extremely convenient."

> "The doctor is really nice. Every time I asked him questions he will always be willing to answer me. I like the hands-on activities its very useful."

Fig. 8. OCR recognition for a mechanical motion simulator.

Table 6. Student average marks in different assessments

	Hands-on Activity 1	Hands-on Activity 2	Hands-on Activity 3	Hands-on Activity 4	Hands-on Activity 5	Midterm	Project Presenta-tion	Video Demo	Code and Document	Report	Final Grade
Average	77.9 %	75.4 %	80.5 %	81.8 %	88.0 %	78.3 %	79.8 %	68.3 %	77.5 %	68.4 %	76.6 %
Standard deviation	10.8 %	12.8 %	5.6 %	6.8 %	10.1 %	16.1%	7.1 %	21.1 %	15.9 %	15.5 %	11.0 %

"Dr. Gao is patient and always willing to help students."

"Professor is really patient and course content is very interesting."

"Hands on activities were great, and the lap was amazing."

"The final project without the exam, and lab"

"The MATLAB code and examples in the lecture are really helpful."

"On site activity"

"I appreciate Professor Gao's approach to include many hands on activities in the course and to provide walk-throughs of course materials and code samples. This really helped in understanding how to use relevant software (MATLAB) which is very necessary in this field."

"I loved this course! We covered the popular AI topics and applied them in activities. My favorite part of this course was the Arduino workshop."

"Code examples and thorough explanation of how the code works is invaluable for learning this material. Thanks you."

"Use of MATLAB and Lab session."

"All the material we learned was very interesting!"

"MATLAB and even more home assignment with step by step example to solve assignment."

Students' comments and complaints about this course were listed as follows:

"Instructor was very focused on getting our hands dirty" excellent way to learn. But activities could be extended a little further."

"I spent my own money for MATLAB and required toolboxes. I wish McMaster could purchase the MATLAB license for students or have the software installed in computer lab. This is my only complaint."

"Please help students implement AI solutions rather than just use MATLAB libraries. It helps to understand what the algorithm does as opposed what the library does."

"Make it in class in computer lab setting instead of online focus more on in class step by step process to solve new programs. More software and machine (hardware integration) would like 50% course to be in lab with software hardware integration."

As can be observed from student feedbacks, most complaints from students are about utilizing paid software – MATLAB – for course study. This problem will be solving by replacing it with open source software and platform, e.g., Python and Tensorflow.

8. Future Development of On-Site AI Courses for Smart System Students in Undergrad and Grad Levels

W Booth School of Engineering Practice and Technology, McMaster University, recently created new stream of Smart System in both undergrad and grad levels. Smart systems integrates principal functions of sensing, actuation, communication, and operation to monitor and intervene in a situation, and deliver predictive decisions and intelligent actions based on collected data [31–33]. Smart systems, incorporated with concepts/techniques of Internet of Things, Cyber-Physical System, Cloud Computing etc., have massive potential applications in smart city, driverless vehicle, smart healthcare, smart factory and so on [34–40].

Students in smart system have more hands-on experience on software-hardware integration in automation industry. Thus, the emphasis of course design should be different with each other. T-shape would be considered for extending in both breadth and depth. In addition to cover the fundamental concepts and cutting-edge concepts including, but not limited to, supervised and unsupervised learning for regression, classification and clustering, neural networks (feedforward with backpropagation algorithm, recurrent neural network, convolution neural network), optimization, reinforcement learning, it will have a heavy focus on practical applications in following areas that will be aligned with stream vision and will also be relevant with other courses which is exclusively offered in smart system stream. These applications majorly include:

(a) Predictive monitoring of machine health.
(b) Artificial intelligence approaches for controlling system.
(c) Operation process automation based on natural human interaction.
(d) Machine learning approaches to monitor and model health-related information.
(e) Artificial intelligence applications in smart city/community for improving public safety and for optimizing public resources usage.

Many giant IT companies provide open platforms, e.g., TensorFlow, Keras, Watson, Azur-

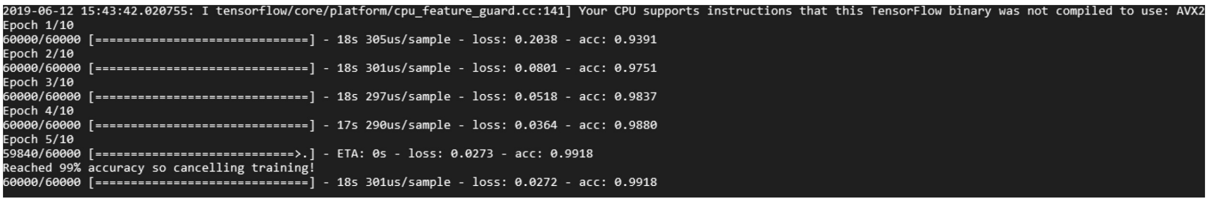


Fig. 9. Training process of traffic sign dataset with TensorFlow and Keras.

eML, Alexa, Inception, AWS-AI, to name a few of them, for building AI eco-system and running user-defined APIs based on open-source models of machine learning and deep learning to implement applications of image recognition, speech recognition, natural language processing, etc. TensorFlow as one of the most popular open platforms for AI/ML will definitely be adapted into this course [41–43]. Following image shows the training process of traffic sign recognition based on the combination of TensorFlow and Keras.

9. Conclusions

This work thoroughly introduces a newly designed and delivered AI course based on the pedagogy of Project and Practice Centered Learning aiming to cultivate students' practical abilities to build a complete artificial intelligence system from scratch. It is noticeable that PPCL does not mean to diminish the importance of theoretical knowledge learning. It is aimed to incorporate theoretical knowledge learning into practices. By doing this, students are capable to know what, why and how. With the well-designed hands-on activities, mid-term prescriptive project, practical workshop, and final open-ended project, students receive maximized opportunities to be fully exposed in the environment of PPCL.

The potential limitations of the proposed study are: (1) it is not feasible for engineering courses which put more emphasis on memorizing concepts in student assessment modules; (2) it is not appropriate to engineering courses which have no project modules.

For future consideration, (a) more course projects will directly come from the request of industry/community partners, (b) students will be encouraged to seek and solve real problems from industry when conducting course projects, (c) industrial speakers will be invited to share experience of AI/ML related projects. The proposed methods not only have impact of transformation of AI education, but also will bring more attention of improving engineering education with the assistance of artificial intelligence.

Finally, a list of a few best practices for future AI courses are recommended here:

(1) Developing and implementing ethical practice in AI course is necessary, since AI ethics including proper usage of huge amount of data is gradually becoming a main concern of modern society.
(2) Adapting the mainstream programming language such as Python and open-source frameworks such as Tensorflow or PyTorch.
(3) The course designer must be very diligent to better him/herself with start-of-the-art technology since AI area is extremely dynamic with new developing tools emerged frequently.
(4) Students should truly like this area while not being mandated to learn. Actually, AI will be as common as classic programming skill since both of them will be applied in many jobs especially when dealing with homogeneous and heterogeneous data analytics.
(5) Schools collaborate with local communities and impactful companies who can provide great coop opportunities or provide practical and realistic projects that students can work on as part of course modules.

Acknowledgements – The authors would like to thank the great support from colleagues and students who helped improve the quality of this course based on the idea of Project and Practice Centered Learning. The authors appreciate the valuable support from the administration and technical team of our department, including Dr. Mo Elbestawi, Dr. Dan Centea, Dr. Eugene Ng, Dr. Seshasai Srinivasan. The authors would like to thank the constructive suggestions from editors and anonymous reviewers.

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Zhen Gao is an assistant professor in the School of Engineering Practice and Technology (SEPT) at McMaster University which he joined in July 2014. He has published over 80 journal and conference papers, 1 book, and 4 book chapters in areas of robotics and control. Dr. Gao served as the Program Committee Member for World Congress on Intelligent Control and Automation, International Conference on Information and Automation, IEEE Conference on Robotics and Biomimetics, IEEE International Conference on Real-time Computing and Robotics, IEEE International Conference on Automation and Logistics, and International Conference on Intelligent Robotics and Applications, and IEEE Canadian Conference on Electrical and Computer Engineering. Recently, he was invited as a keynote speaker with the topic of 'Innovation of Education, Technology and Applications of Intelligent Machines and Robotics' in the International Conference of Robotics and Intelligent Equipment in 2017. He was also invited in the round table discussion about 'Frontier and Interdisciplinary Research with Machine Learning' in Global Machine Intelligence Summit in 2017. His current research interests include industrial controllers, advanced robotics and automation, artificial intelligence, neural network and pattern recognition. He serves as the Editor-in-Chief of International Journal of Intelligent Machines and Robotics; he is also the Editor-in-Chief of Journal of Robotic and Mechatronic Systems.

Tom Wanyama is an assistant professor in the School of Engineering Practice and Technology (SEPT) at McMaster University which he joined in May 2012. Wanyama has over 20 years of university teaching experience; teaching a wide range of undergraduate and post graduate courses, including: digital electronics and systems, electricity and magnetism, power electronics, power systems, electrical machines, microwave engineering, data communication and computer networks, software architecture, software design process and metrics, industrial networks and controllers, and software requirements and specification. Before joining SEPT, he led the team that developed, built and maintained packaging equipment for DuPont Canada at its Calgary distribution centre. At DuPont, he carried out simultaneous design of mechanical, electronic and software systems of packaging equipment (Nanomates, Fleximates, automated scales for the Form Fill and Seal (FFS) machines, and Tablemates). Moreover, he designed industrial Control Area Networks (CAN) based on TCP/IP, CsCAN, and Profinet. Wanyama has wide experience in the design and installation of electrical systems in commercial and industrial buildings, and he continues to consult in the area of packaging systems automation. His research work falls in three areas, namely: system composition and integration, use of artificial intelligence in systems control, monitoring and maintenance, and development computer based tools for personnel training.

Ishwar Singh is an adjunct professor in the School of Engineering Practice and Technology at McMaster University since 2010. Prior to that he was the founding Associate Director of the 4-year B.Tech programs, a joint venture between McMaster University & Mohawk College, programs and Chair of the process automation program within this stream. He coordinated the curriculum design, development and implementation of the process automation, automotive and vehicle technology program, and biotechnology programs in addition to his contribution for the establishment of the energy engineering technology degree completion B.Tech program. Prior to these roles he was the Chair of several programs at Mohawk College, where he taught for more than 35 years and held many other positions as well. He has many publications to his credit and has done basic and applied research in many fields such organic chemistry, X-ray crystallography, educational technology, software development, process and manufacturing automation.