AI in Engineering and Computer Science Education in Preparation for the 4th Industrial Revolution: A South African Perspective

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***Abstract*—Artificial intelligence will play an imperative role in meeting the challenges posed by the fourth industrial revolution. This paper discusses how artificial intelligence can be incorporated into engineering and computer science education to prepare for the fourth industrial revolution in South Africa. The paper firstly examines how artificial intelligence can be incorporated into the engineering curriculum to equip engineers and computer scientists with the necessary skills to solve the complex problems that the fourth industrial revolution will bring. These range from online courses and short courses with certification that can be taken by practitioners, to degrees in artificial intelligence and data science. Artificial intelligence can also be used in the teaching and learning of engineering courses. The paper looks at the use of intelligent tutoring systems and teaching assistants to provide individualised tuition to students, artificial intelligence in blended learning and the use of artificial intelligence techniques for data analytics to identify learning difficulties. The paper also examines mechanisms and a case study for involving industry in engineering education. It provides an overview of initiatives at a South African university, namely, the establishment of research chairs, to promote collaboration with industry in education and industry projects at the undergraduate, Honours, Masters, and Phd levels. The paper examines the role that artificial intelligence can play in peace engineering education and concludes by identifying rubrics to assess the effectiveness of artificial intelligence in engineering education.**

I. Introduction

Artificial intelligence has contributed to various facets including manufacturing, finance, security and agriculture, amongst others. It is clear that artificial intelligence will play an eminent role in the fourth industrial revolution. While artificial intelligence has generally been perceived as a computer science discipline as we move into the fourth industrial revolution it is clear that it becoming interdisciplinary. This raises the question as to what implications this will have for education. The paper examines the role that artificial intelligence will play in engineering and computer science education in preparation for the the fourth industrial revolution. This is presented from a South African perspective. The paper also looks at how artificial intelligence can used to promote the awareness of peace engineering in these disciplines.

Section II provides an overview of how artificial intelligence can be incorporated into the engineering and computer science curriculum as well as mechanisms to promote artificial intelligence literacy in the community. The contribution that artificial intelligence can make in the teaching of engineering and computer science is highlighted in section III. Section IV examines collaboration between industry and academia in order to prepare our graduates to face the challenges posed by the fourth industrial revolution. Section V describes the role that artificial intelligence can play in promoting the awareness of peace engineering in tertiary education. Suggested rubrics for assessing the impact of artificial intelligence are presented in section VI. The paper concludes with a summary discussion in section VII.

II. Artificial Intelligence Education and Literacy

South African undergraduate computer engineering degrees usually span four years and computer science degrees three years. At the University of Pretoria artificial intelligence is included in the undergraduate curriculum for these degrees in the final year of the degree. These courses range from general courses on artificial intelligence to courses on specific areas such as neural networks and evolutionary algorithms. After completing an undergraduate degree majoring in computer science, students can register for an Honours degree in computer science. This degree focuses on specialisations in computer science and some curricula include one or more modules on artificial intelligence such as deep learning and machine learning. Students are required to complete projects in the final year of the undergraduate degree and in the Honours degrees, these project options also include artificial

intelligence options in both engineering and computer science. However, as we move into the fourth industrial revolution is this sufficient to prepare our engineers and computer scientists as they enter the workforce. We need to look at whether it will be necessary to offer an undergraduate degree with majors in artificial intelligence or machine learning. This will be done with input from industry to determine whether the artificial intelligence skills that our graduates possess are sufficient to meet industry needs. Based on input from industry the Department of Computer Science is currently offering two bachelors degrees with streams in data science and a Masters in Technology (MIT) degree in Big Data Science. The MIT in Big Data Science is a multidisciplinary degree including artificial intelligence, engineering, mathematics and statistics, and is generally taken by practitioners from industry.

In the case of computer engineering and computer science, artificial intelligence is included as one or more modules in the curriculum as described above. However, as we move into the fourth industrial revolution it is necessary for graduates in other areas of engineering such us mechanical, chemical and industrial engineering to also have the ability to apply artificial intelligence to these domains. One option will be to include a general artificial intelligence module in the curriculum of all engineering degrees. Alternatively, an online module on artificial intelligence can be made available to all engineering students which they can complete in their own time and space. Another option that we are considering is including an artificial intelligence module in the work readiness program offered by the University of Pretoria.

There is also a need to bridge the gap in the case of engineers and computer scientists already employed in industry that need to develop or upgrade their artificial intelligence skills. This again will be based on input from industry indicating the need of certain artificial intelligence skills. At the University of Pretoria such short courses are offered by the enterprises unit and the students completing the module receive certification in the particular area.

III. Artificial Intelligence for Teaching

Artificial intelligence has played a significant role in teaching and learning since its inception. One such area that is continuing to grow is that of intelligent tutoring systems. Intelligent tutoring systems (ITSs) use artificial intelligence techniques to provide individualised tuition to learners based on their current state of knowledge and skills [1], [2]. Given limited funding at South African universities such individualised tuition is not always possible and hence intelligent tutoring systems can play a crucial role in assisting engineering and computer science students overcome individual learning difficulties. Nedic et al. [3] explain the necessity of intelligent tutoring systems, especially for first year engineering courses where students usually struggle to bridge the gap between secondary and tertiary education and given the diversity of student backgrounds and hence knowledge, individualised tuition is necessary.

Intelligent tutoring systems have successfully been applied in the teaching of engineering and related foundational topics. In the study conducted by Dzikovska et al. [4] an intelligent tutoring system, namely, BEETLE II, has been employed to tutor students on electronics and electricity. Mostafavi and Barnes have developed the ITS DeepThought to tutor deductive logic [5]. Nedic et al. [3] have created a prototype of an intelligent tutoring system for first year electrical engineering courses. STATFAG [6] is an intelligent tutoring system for mechanical engineering that focusses on the design and manufacturing of gears and gearing. It is evident from [7] and [8] that intelligent tutoring systems have proven to be effective in teaching computer programming to novice programmers at tertiary level.

Computer science and engineering students at the University of Pretoria usually experience learning difficulties with first year computer programming modules. These students come from a variety of backgrounds and hence individualised tutoring is needed. From 2018 bootcamps for assisting these learners have proven to be effective, however due to budgetary constraints we are now looking at automating this process using intelligent tutoring systems. The use of intelligent tutoring systems in other computer science and engineering modules where students experience learning difficulties resulting in low throughput will also be investigated.

Yigit et al. [9] have successfully incorporated artificial intelligence in a blended learning program for computer engineering. More recently artificial intelligence has contributed to the development of automated teaching assistants. The first artificial intelligent teaching assistant, Jill Watson, was successfully deployed in 2016 [10]. Jill Watson was used to answer student queries in forums for an online module on artificial intelligence and achieved this with a 97% accuracy.

Educational data mining and learning analytics and knowledge aims at improving teaching and learning by analysing educational data [11]. While educational data mining focusses on using artificial intelligence techniques to automate these processes, learning analytics and knowledge using artificial intelligence to perform analyses that are still interpreted by the human researcher. These techniques have been successfully employed to determine learning difficulties experienced by students, predict failure and pass rates, identify success/failure indicators and identify entrance requirements for programmes. As we move into the fourth industrial revolution data mining and learning analytics and knowledge will play a larger role in improving teaching and learning as the associated problems become big data problems.

IV. Industry Collaboration to Develop Artificial Intelligence Skills

In order for engineering and computer science graduates to develop the necessary skills to face the challenges posed by the fourth industrial revolution in the workplace, it is essential to include industry collaboration in engineering education to provide students with the experience of solving real-world problems. The Faculty of Engineering, Built Environment

and Information Technology at the University of Pretoria has established research chairs in collaboration with industry to facilitate this.

One such initiative is the Multichoice machine learning research chair which is sponsored by Multichoice, a broadcasting company in South Africa. This is a joint chair including the Department of Electrical, Electronic and Computer Engineering and the Department of Computer Science. The co-chairs from both departments supervise computer engineering and computer science students in applying machine learning techniques to solve problems in the broadcasting industry posed by Multichoice. The projects require the use of machine learning in order to solve the problem at hand. Depending on the complexity of the problems these range from final year engineering projects, Honours projects, Masters projects to Phd projects. The projects are assessed using the standard assessment criteria for the particular degree. For example, for a Phd project the thesis is assessed by three external examiners whereas an Honours level project is marked by two external examiners and moderated by an external examiner.

Such collaborations provide the ideal platform to promote peace engineering in the application of artificial intelligence to solve real-world problems. Research chairs in collaboration with industry partners can make students aware of and ensure peace engineering principles are supported in providing artificial intelligence solutions to industry problems.

V. Artificial Intelligence and Peace Engineering

This section looks at the role artificial intelligence can play in promoting peace engineering. Online courses incorporating the use of intelligent tutoring systems for peace awareness, e.g the ITS could present engineering scenarios where students have to make decisions that support peace engineering and provide feedback on this, and automated teaching assistants to facilitate discussion forums on peace engineering will be effective at promoting peace engineering.

Artificial intelligence, namely a neural network system, has proven to be effective in detecting corruption in government in Spain [12]. Similar artificial intelligence systems could be put in place to detect potential violations of peace engineering and rectify these.

Intelligent decision support systems [13], which use artificial intelligence techniques to make decisions traditionally made by humans, have proven to be effective in engineering. For example, Hung et al. [14] have employed a decision support system to make decisions on engineering design. Similarly, in the study conducted by Good [15] a decision support system employing a genetic algorithm is developed to assist project managers make decisions regarding water supply systems projects and their feasibility. Intelligent decision support systems can be used to promote peace engineering. This can be achieved by using these systems to make decisions or providing a second opinion in cases of potential conflict or bias in the engineering decision making process.

The development of these systems as well as artificial intelligence systems to predict potential peace engineering violations can be included as project options for final year undergraduate, Honours, Masters and Phd projects and research.

One of the aims of peace engineering is social equality [16]. This can be achieved by understanding each others cultures and differences. Students in the Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria are required to complete a programme on Diversity and Transformation. This programme requires two students of different cultures in the same module to interact with each other and complete a writeup on each other. The students then assess each other's writeup. The aim is to get the students to understand each other's cultures and differences. This idea can be extended further by using artificial intelligence to emulate students of different cultures which a student can interact with online, thus providing a diverse range of students from different cultures instead of just one other student.

VI. Assessing the Impact of Artificial Intelligence on Engineering Education

This paper has looked at the use of artificial intelligence in engineering and computer science education in preparation for the fourth industrial revolution. This has been examined in terms of :

- Artificial intelligence education and literacy
- Artificial intelligence for teaching
- Collaboration with industry
- Artificial intelligence for peace engineering

How do we know if artificial intelligence has achieved what we have anticipated it would in engineering education? This section suggests rubrics for assessing this.

A. Artificial intelligence education and literacy

The aim here is twofold. Firstly, we need to ensure that artificial intelligence has been sufficiently incorporated into the engineering and computer science curriculum so that our graduates have the necessary knowledge and skills to solve problems in industry as we move into the fourth industrial revolution. Secondly, it is necessary to promote artificial intelligence literacy in the computer science and engineering industry to enable the existing workforce to develop or upgrade their artificial intelligence skills. Section II describes degrees, majors, online courses and short courses as possibilities to achieve this overall aim. In order to determine whether these degrees and courses are sufficient it is imperative to obtain input from industry.

The engineering and computer science departments in the Faculty of Engineering, Built-Environment and Information Technology have established advisory boards to liaise with industry. Members of these boards are representatives from various industries, a number of which employ our graduates. These advisory boards will be used as a forum via which to get input regarding whether our degrees and courses are adequately preparing our graduates in terms of artificial intelligence for the fourth industrial revolution as well as to determine the need and impact of courses to develop and

upgrade the skills of the existing engineering and computer science workforce.

B. Artificial intelligence for teaching

Three main areas of artificial intelligence for teaching have been highlighted in section III, namely, intelligent tutoring systems, automated teaching assistants and educational data mining and learning analytics. In this instance the impact of artificial intelligence can be assessed in terms of the number of successful intelligent tutoring systems and automated agents employed in the teaching of engineering and computer science courses and the number successful educational data mining and learning analytics studies.

One of the challenges facing the widespread use of intelligent tutoring systems and automated teaching assistants is the time it takes to develop these systems. A solution to this problem is the development of authoring tools that will speed up the development of these systems and require little or no artificial intelligence and computer science knowledge of the developer. For example, Nkambou et al. [17] describe different authoring tools that can be used for the development of intelligent tutoring systems. Similar tools need to be made available for the creation of automated teaching assistants. Educational data mining and learning analytics have been research-based and in this area as well there is a need for tools that educationalists can use to perform the necessary analysis and/or interpretation without knowledge of the underlying artificial intelligence techniques.

C. Collaboration with industry

The aim here is to enable students to develop the skills necessary to apply artificial intelligence techniques to solve real-world problems from industry posed by the fourth industrial revolution. As discussed in section IV research chairs have been established to facilitate this. The projects and research completed by the student will be assessed using the standard criteria for the particular degree. In addition to this the project/research conducted must have provided a solution that is usable by the industry posing the problem. In projects where relevant, how the principles of peace engineering were adhered to must be documented and reported.

D. Artificial intelligence for peace engineering

Section V highlights the potential of artificial intelligence in promoting peace engineering, namely, intelligent tutoring systems and automated teaching assistants, artificial intelligence systems to detect potential violations of peace engineering, intelligent decision support systems to make a decision or provide a second opinion in cases of decisions involving conflict and/or bias and online systems to promote social equality. The impact of artificial intelligence in these areas can be ascertained through the widespread successful use of these systems for peace engineering. To support this it will be necessary to put in place working groups, comprised of engineers, computer scientists and educationalists, to drive the development and implementation of these systems. In order to prevent replication of the work and reusability by different engineering and computer science departments it will be necessary to establish some standardisation for development and implementation.

VII. Conclusion

Artificial intelligence will play a crucial role in the fourth industrial revolution. This paper examines the implications of this for engineering and computer science education. The paper firstly looks at the incorporation of artificial intelligence into the engineering and computer science curriculum to adequately prepare our graduates for the fourth industrial revolution. The paper also looks at mechanisms for general artificial intelligence literacy in industry and mechanisms to enable the existing workforce to develop or upgrade their artificial intelligence skills. The role that artificial intelligence can play in the teaching of engineering and computer science is highlighted in terms of intelligent tutoring systems, automated teaching assists and educational data mining and data analytics. In order to develop the skills of our graduates to deal with the challenges posed by the fourth industrial revolution it is essential for collaboration with industry in engineering education. The paper describes research chairs as an option for achieving this. The paper also examines the role that artificial intelligence can play in promoting the awareness of peace engineering. Four areas, namely, intelligent tutoring systems and automated teaching assistants, artificial intelligence systems to predict violations of peace engineering, intelligent decision support systems and online chatbots for cultural literacy have been identified. The paper concludes by suggesting rubrics to assess the impact of artificial intelligence in engineering education as we move into the fourth industrial revolution.

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