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Enhancing engineering students' understanding and perception of compressed air system energy management in industrial manufacturing through the application of artificial intelligence

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ABSTRACT: Nowadays, using technology to manage energy in manufacturing is an important issue and is receiving increasing attention, especially energy savings in compressed air systems that use energy equivalent to 10% of the total electricity consumption in industrial plants. Therefore, the energy consumed in a compressed air system is expensive. Many studies have attempted to propose energy efficiency methods that can result in energy savings. However, the most advanced technology is difficult to teach, complex to transfer and disseminate knowledge, and it still requires engineering expertise. In addition, traditional teaching and training are limited and cannot reach the level of industrial practice and new manufacturing technology knowledge in realistic situations. Therefore, this study examined energy management with artificial intelligence in compressed air system training courses that use artificial neural networks to learn data about compressed air systems and predict energy use in various situations of pneumatic systems. The results showed that developing technological knowledge through collaboration between academics and industry partners helps to disseminate and distribute innovations that benefit other establishments.

Keywords: Energy management, AI education, learning factory, academia-industry collaboration

INTRODUCTION

In the modern industrial landscape, the importance of meeting sustainable targets, particularly in areas such as waste management and reducing excessive energy usage, is gaining significant recognition. Energy management is the key to saving energy, which is the process of monitoring, controlling and conserving energy in the industrial sector. Improving energy efficiency in industry is difficult due to the high complexity of industrial energy systems [1]. For example, energy savings in compressed air systems (CASs) can account for up to 10% of the total electricity consumption in industrial plants [2]. However, the journey toward energy efficiency has some challenges. One of the critical barriers is the need for energy efficiency promotion and, more importantly, staff training in energy management [3]. One reason for the critical barriers to staff training in energy management is the need for more awareness and understanding of energy efficiency practices and their benefits.

This underscores the need for action and involvement from all levels of stakeholders. Industries' electrical energy consumption is due to CASs. Effective energy-saving interventions for generating, distributing and transforming compressed air require proper energy information management [4]. CASs refer to air kept under more significant pressure than atmospheric pressure. They are an essential medium for the transfer of energy in industrial processes. CASs are primary energy consumers in the industrial sector, accounting for around 10% of the electricity consumed in the European Union and China. By contrast, the United States, Malaysia and South Africa account for 9% of the total energy consumption [5].

Many universities and industries have co-operated to provide students with opportunities to engage with new technology in industry practices and learn more about professional skills and competencies to be more effective in the classroom [6][7] and in the workforce. Energy efficiency in industries is essential for energy cost savings and sustainable competitiveness [8]. Thus, energy management is important for engineering students because they should learn how to use new engineering technology to optimise energy systems and reduce energy consumption, and they should understand the economic system to manage a budget and reduce operational costs [9].

In addition, proper energy management with new technology can help engineering students connect knowledge with practice in real life, thus reducing and preventing burnout in *abstract* learning. By learning how to manage their motivation and energy levels, students can cultivate problem-solving skills using technology that will benefit them in their future careers.

This study presents energy management (EM) with artificial intelligence (AI) in compressed air systems (EMAI-CAS) training courses that focus on applying AI to reduce energy consumption in compressors by considering real-time circumstances and predicted needs. The role of AI in these courses is to interpret the real-time performance information delivered by sensors in the trainer platform, and then act automatically to save energy in the pneumatic process in industrial manufacturing. To explore the effectiveness of this study, an experiment was conducted in a training course on collaboration between academics and industry partners to disseminate and distribute innovations that benefit other establishments, and to evaluate students' learning achievements and perceptions. The research questions are as follows:

RQ 1: Do the EMAI-CAS training courses enhance students' understanding of energy management in CASs?

RQ 2: How do students perceive EMAI-CAS training courses?

BACKGROUND

Artificial Intelligence Education

AI is a developed computer system or machine that can perform tasks that typically require human intelligence. It is a cognitive science technology related to image processing, natural language processing, robotics and machine learning [10]. Previous studies have confirmed that AI education is an essential concept and competency for new generation students in many fields and levels of education [11]. It is especially so in higher education that focuses on the curriculum inclusive of AI, and strives to create an AI-ready workforce with essential 21st-century competencies as identified by industry and government needs worldwide [12].

Some studies refer to course offerings based on challenge-based learning, physical and virtual practice laboratories, and mixed teaching methodologies to accommodate the digital transformation and demands of Industry 4.0, and to educate and prepare the new generation of students according to the labour market needs [13]. Other studies describe how to develop a conceptual understanding of AI through a literacy course at a university [14].

The true power of AI education lies in its connection with the industrial sector. This connection can facilitate fruitful collaboration and knowledge exchange between academia and industry, leading to valuable research partnerships, internship opportunities and industry-driven curriculum development. This symbiotic relationship ultimately benefits not just educational institutions but also the industrial sector, underscoring the crucial role of industry professionals in shaping the future of AI education [15].

Conversely, integrating AI technologies into industrial operations can help improve and streamline various industries' processes. Furthermore, AI teaching in the industrial sector can help employees adapt to and leverage AI technologies, ensuring a skilled workforce capable of utilising AI to its full potential. Companies can benefit from increased efficiency, reduced costs, predictive maintenance and enhanced safety [16]. AI can also facilitate the development of smart factories and automated systems, thereby improving productivity and competitiveness.

Academia-Industry Collaboration

Academia-industry collaboration (AIC) is essential in the education system because it allows for the exchange of knowledge and expertise between academic researchers and industry professionals, leading to innovations and advancements [17]. This collaboration also helps bridge the gap between theoretical research and practical applications, leading to real-world solutions to complex problems [18]. It provides valuable opportunities for students to gain practical experience and for industry professionals to stay updated on the latest research developments [19]. Overall, AIC fosters a mutually beneficial relationship that drives innovation and economic growth. In this study, the authors of this article designed a training course based on the AIC model (Figure 1), which focuses on providing students with an opportunity to connect with industry. Students can learn about the connection situation in the industrial sector, so that once they graduate, searching for a job becomes simpler. Using their established connections, graduating students easily find job opportunities.

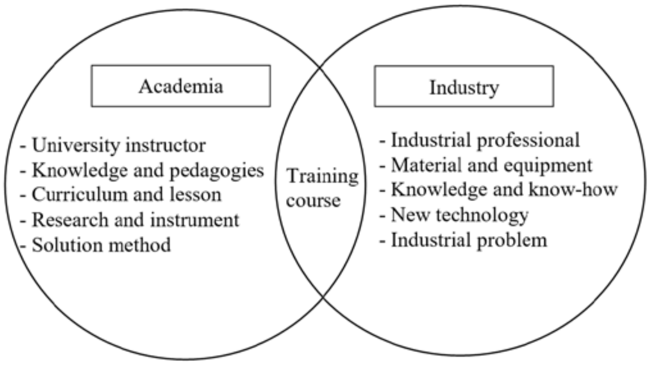


Figure 1: Training course based on the AIC model.

Application of AI in Industrial Manufacturing

The use of industrial AI in process optimisation in manufacturing is gaining rapid traction, enabling more innovative and more efficient data-driven decision-making by leveraging historical and real-time data. In developed countries, the power industry has started using AI technologies to connect with smart meters, smart grids and Internet of Things (IoT) devices to improve efficiency, energy management, transparency and the usage of renewable energies [20]. Thus, AI plays a crucial role in industrial manufacturing, as it can optimise production processes by analysing real-time data and identifying improvement areas. This increases efficiency and reduces operational costs.

This novel technology is transformed into advanced manufacturing by summarising the latest progress in critical enabling technologies (e.g. production processes) and transitioning toward digitalisation with the implementation of sensors that provide real-time data that can now be monitored remotely with IoT technology [21] and AI and IoT [22], which can monitor production processes and reduce high maintenance costs. AI also enables predictive maintenance and allows manufacturers to detect potential equipment failures before they occur, thus minimising disruptions to the production line. AI-powered robotics can handle repetitive tasks precisely and quickly, leading to higher productivity. Integrating AI into industrial manufacturing can lead to cost savings, improved quality control and enhanced overall performance.

Energy Management of Compressed Air Systems

As mentioned earlier, CASs refer to air kept under more significant pressure than atmospheric pressure in a pneumatic system. Pneumatics refers to how air pressure feeds and moves applications in industrial manufacturing. It puts compressed air into operation by moving applications, especially tools and machinery used in engineering. It is an essential medium for energy transfer in industrial processes, is an effective solution for balancing this mismatch, and is therefore suitable for future electrical systems to achieve a high penetration of renewable energy generation [23].

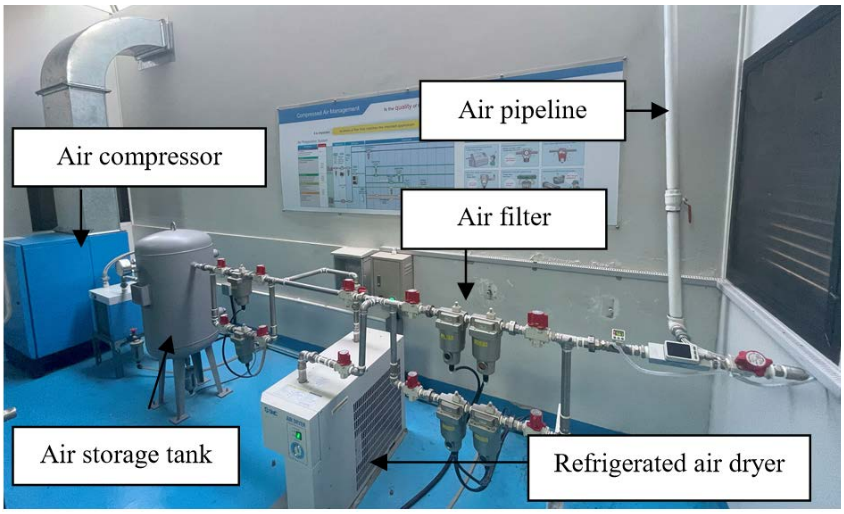


Figure 2: Compressed air system components.

Figure 2 shows the CAS components. They are prepared to use as a refrigeration dryer. There is usually a compressed air reservoir upstream or downstream of the refrigeration dryer. It is designed to compensate for fluctuations in consumption through tubes in the decentralised air preparation stage. This stage is the subject of this article, and it has the following functions: building pressure using an air compressor, transforming it into an air storage tank, filtering and oiling using an air filter, and regulating and drying with a refrigerated air dryer. The prepared compressed air is supplied to the machine to actuate the application through an air pipeline. Industrial manufacturers rely on compressed air, which comes with specific pressure, flow and purity requirements. With careful planning, these requirements can be met, offering significant cost-saving opportunities. Compressed air is a costly utility, but by implementing strategies to reduce air system operating costs, such as considering compressor controls, manufacturers can make substantial savings.

The ultimate goal of any compressor control system is to efficiently match the compressed air supply to demand, thereby optimising energy usage and reducing costs. Effectively managing energy in CASs can start by conducting regular audits to identify and address any leaks, inefficiencies or areas of improvement, and by considering investing in energy-efficient equipment. CASs in factories have more than one compressor, therefore, controlling multiple units in concert increases energy efficiency and pressure stability. Running multiple units independently often results in unstable pressure and wasted energy, such as running more machines than necessary or running compressors at higher pressures than needed.

Energy Management of a Compressed Air System Trainer Platform

The aim of this study was to teach students in practice situations from EMAI-CASs activities that create practice scenarios to: 1) understand energy in pneumatic systems; 2) understand energy efficiency and energy savings;

and 3) use AI for decision-making. Figure 3 shows the conceptual framework of the training course, which focuses on the activity of using a programmable logic controller (PLC) to control industrial equipment with an AI algorithm (i.e. an artificial neural network (ANN)) to manage energy in a CAS. At the same time, users can monitor visual information displayed on a dashboard through a monitor or mobile device.

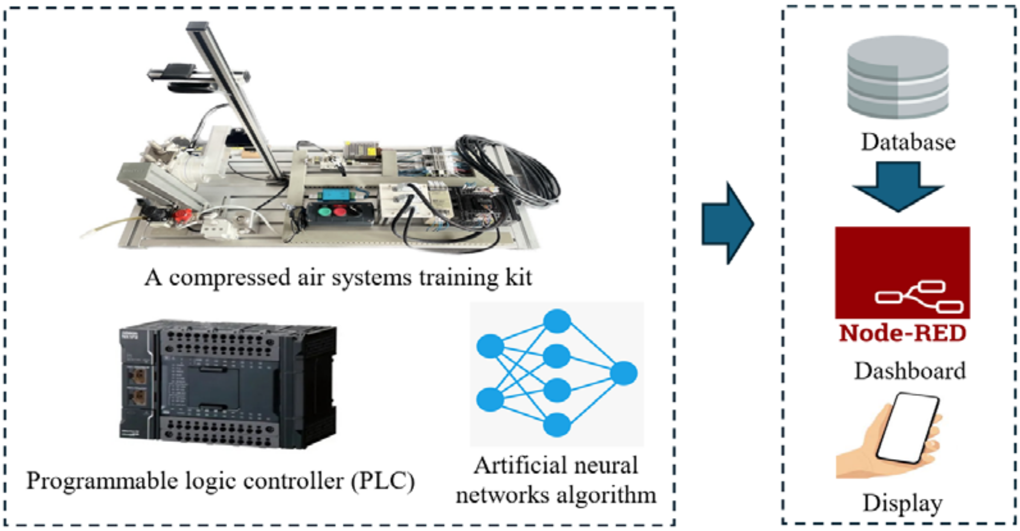


Figure 3: Compressed air system components.

This platform consisted of a CAS training kit based on three energy-saving scenarios: controlling the compressed air pressure fed to the air cylinder while being subjected to loads of different sizes; controlling the compressed air pressure supplied to the air cylinder while operating the air cylinder without load; and controlling the compressed air supplied to the machine, which is stopped.

METHODS

Participants

This study was conducted with the co-operation of an industrial enterprise and a university in Thailand. The university has instructors who are experts in applying AI concepts to industry. The enterprise supports industrial professionals with energy management expertise and industrial learning material from SMC Thailand Ltd. They have also conducted co-operative research on AI's contribution to energy efficiency in industrial manufacturing. This pilot study's target population was first-year engineering students interested in participating in training courses. There were 45 students, comprising 28 men and 17 women. Their age range was 19-21 years, and they majored in mechatronics and electrical engineering. Voluntary and informed consent from the participants was obtained before their involvement. They received information about the research purpose, procedures, risks, benefits, and their right to withdraw from the study at any time.

Instruments

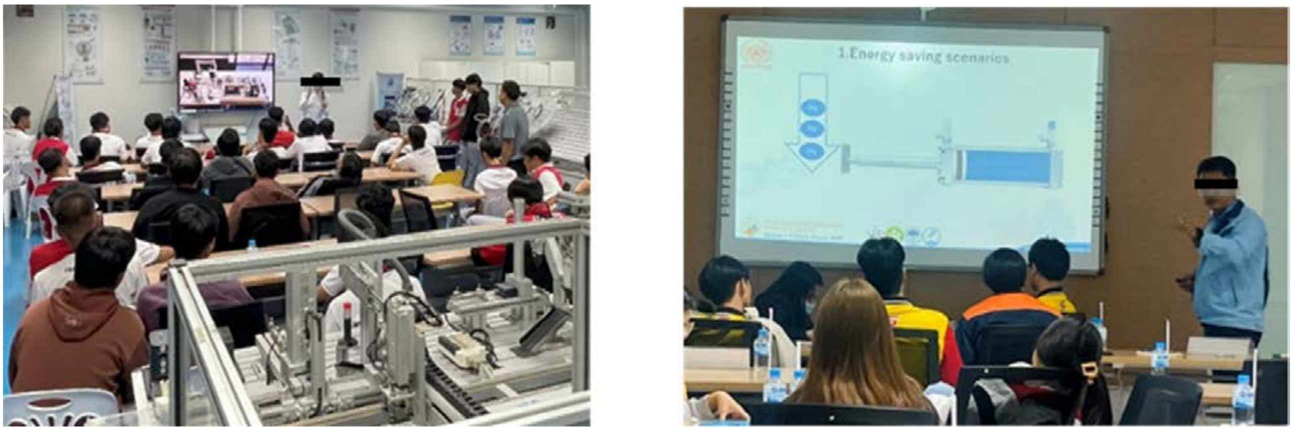
The assessment of learning achievements was designed by three experienced industrial sector experts and an instructor with more than ten years of experience in teaching-related fields. The test measured students' understanding of energy management using AI in CASs. It consisted of 30 multiple-choice questions in the pre- and post-tests, with items in the two tests being different. The test was evaluated and scored out of 30. The Cronbach's alpha of the EMAI-CAS tests was 0.75. The interviews were used to collect the students' perceptions after participating in the EMAI-CAS activity, including five semi-structured interviews that comprised open-ended questions.

Procedures

This study adopted a one-group pre- and post-test design to examine whether the participants' understanding levels were significant after participating in an EMAI-CAS training course. The students attended the training course, and the experiment took 12 hours to complete in two days. On the first day, the students were given an introduction and overview, and they took a pre-test to measure their prior knowledge, which was completed in 30 minutes.

Afterward, the instructor from the university presented and demonstrated the EMAI-CAS trainer platform. The students learned about the equipment in the pneumatic system and were introduced to the use of AI for making decisions (Figure 4a). On the second day, the EMAI-CAS activity was conducted, followed by a discussion of energy management expertise in the industrial sector (Figure 4b).

In the activity, the students were divided into eight groups, with each group comprising five-six members, through the EMAI-CAS trainer platform using three situations. The participants performed the learning activities based on scenario learning, which involved energy consumption problems in industrial manufacturing, the starting point for students to immerse themselves in real-world problems, and a subsequent solution-finding process to save energy. The students had to apply their knowledge and cognition to solve problems and conduct discussions during this process. After performing the training activities, the students in each group discussed the application of AI to manage energy in ten minutes. All the students took post-tests in 30 minutes. In addition, ten students were randomly chosen to participate in semi-structured focus group interviews for 20 minutes.



a) b)

Figure 4: Training activities conducted by a) a university instructor; and b) an industrial professional.

RESULTS

RQ 1: Do the EMAI-CAS training courses enhance students' understanding of energy management in CASs?

To answer the research question, the authors used the paired samples *t*-test to determine whether there was a significant difference in the students' understanding scores before and after the intervention (Table 1).

Table 1: Results of the means, standard deviations and paired samples *t*-tests.

Category	Pre-test	Post-test	*t*	*p*	Cohen's d
	M+SD	M+SD			
Understanding of energy in the pneumatic system	4.667 + 2.033	6.422 + 1.868	7.371***	0.000	0.313
Understanding of energy efficiency and savings	2.533 + 1.222	4.422 + 2.266	5.036***	0.000	0.555
Using AI for decision-making	5.356 + 1.864	6.378 + 1.305	3.499**	0.001	0.174
Overall	12.556 + 3.364	17.222 + 3.938	9.400***	0.000	0.310

N = 45, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

The overall pre-test and post-test mean scores were 12.556 (SD = 3.364) and 17.222 (SD = 3.938), respectively. It was confirmed that there was a significant difference between the mean pre- and post-test scores ($t = 9.400$, $p = 0.000$).

The students had an understanding of energy in the pneumatic system ($t = 7.371$, $p = 0.000$), with a pre-test score of 4.667 (SD = 2.033) and a mean post-test score of 6.422 (SD = 1.868); an understanding of energy efficiency and savings ($t = 5.036$, $p = 0.000$), with a mean pre-test score of 2.533 (SD = 1.222) and a post-test score of 4.422 (SD = 2.266); and an understanding of using AI for decision-making ($t = 3.499$, $p = 0.001$), with a mean pre-test score of 5.356 (SD = 1.864) and a mean post-test score of 6.378, SD = 1.305).

RQ 2: How do students perceive EMAI-CAS training courses?

Table 2 presents the results of the students' interviews about the EMAI-CAS training courses, including five questions. The summary of the group interviews showed that the students perceived the training courses as beneficial and responded positively to them. The training courses provided them with practical skills and knowledge directly applicable to their future careers. This hands-on experience could give them a competitive edge in the job market.

However, this course is too short to allow students to participate in the activities; they need more time to learn more about the complex concepts of AI. In addition, training courses often offer opportunities for networking and building connections within the industry, which can be invaluable for future job prospects. Moreover, completing these training courses can enhance students' portfolios and demonstrate their commitment to ongoing learning and professional development.

Table 2: Results of the students' interviews.

Interview questions	Students' responses
Q1: What did you learn and understand from this training course?	*I learned about Innovation 4.0 and AI systems, but some situations need clarification and understanding.* *I learned about using AI to save energy and practicing with industrial equipment, such as sensors, PLCs and pneumatic systems.*
Q2: How do you think this course can apply AI in energy management in industry?	*It is used to adjust the air pressure used to control the air cylinder in the factory to suit the load, and when the machine stops, it is ordered to close the air valve to reduce the air loss caused by air leakage in the machine.* *This course applies AI, which can be incredibly useful in energy management in industry. AI can help forecast energy demands more accurately, leading to better planning and cost savings.*
Q3: How can AI affect our lives in the future?	*I think that AI will continue to significantly affect our lives in the future… I can apply AI to my daily life, and it can make our lives easier… In the future, the impact of AI will depend on how we choose to use and regulate this rapid technology.*
Q4: If AI is integrated into our daily lives, how do you think will we adapt? If it does not, what do you think will happen to our lives?	*I need to learn how AI works…because I may be able to keep my job if I adapt… I mean, AI skills may be essential for industrial requirements.* *As AI becomes more integrated into our daily lives, we will need to adapt by learning new skills and to understand how to work alongside AI systems; otherwise, I may miss out on potential benefits from the application of AI in my work.*
Q5: Would you want this training course to be added with more content or activities?	*I suppose two days is too short a time to learn and understand the AI concept… It may take up to three days to learn and understand more.* *The timeline of this activity is slightly short, but I have a certificate to include in my portfolio. It can be useful in my job in the future.*

CONCLUSIONS

This study provides evidence to the power of collaboration between academics and industry establishments. The authors introduced the EMAI-CAS training courses, which leverage ANNs to learn data about CASs and predict energy use in various pneumatic system scenarios. This study is crucial because it provides a practical way to develop technological knowledge and disseminate innovations that can benefit a wide range of establishments.

The experiment demonstrated the immediate benefits of the EMAI-CAS training courses and highlighted areas for future improvement. Although the students' understanding increased and their perception of the course was positive, their feedback suggested potential enhancements in the design of the learning activities. This experiment opens up exciting avenues for future research in which additional factors and conditions for organising the learning environment can be explored, thus potentially revolutionising AI competency development in factory learning settings and engineering education.

AI education should be connected with the industrial sector to ensure that students are learning relevant skills that are in demand in the workforce. By aligning AI education with the industrial sector, students can gain practical experience and understanding of how AI technologies are applied in real-world settings. This connection can also bridge the gap between academia and industry, leading to better collaboration, innovation and job opportunities for graduates.

The authors plan to implement this course in the industrial sector with a knowledge transfer process in future studies. This process is not only beneficial for academia-industry co-operation. It is essential for industrial staff to ensure that valuable information, skills and best practices are passed on from experienced employees to new hires or existing team members to enhance operational efficiency, safety standards and overall productivity within the industrial setting.

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BIOGRAPHIES

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Sasithorn Chookaew, PhD, is an associate professor in the Division of Mechatronics and Robotics Engineering in the Department of Teacher Training in Mechanical Engineering in the Faculty of Technical Education at King Mongkut's University of Technology North Bangkok, Thailand. She is also the secretary of the Digital Education and Learning Engineering Association (DELE). She is interested in technology-enhanced learning, technology in engineering education, personalised learning, professional development and training, and educational robotics.