Renewable Energy, Environment, and Power Quality Journal (REE&PQJ)
ISSN:3020-531X
Volume 26, July 2026

AI Poses New Challenges in Energy Education: On the Example of Robotics

V. Vodovozov, Z. Raud

Department of Electrical Power Engineering and Mechatronics
Tallinn University of Technology
Ehitajate tee 5, 19086, Tallinn (Estonia)
Phone number: +372 53235223, e-mail: valery.vodovozov@gmail.com

Abstract. The arrival of artificial intelligence (AI) rapidly transforms technological, economic and social life, leading to a rethinking of the role of an engineer and changing requirements for engineering education. This paper presents some results obtained at Tallinn University of Technology in the field of energy education using AI. The research is based on explicit data collection from staff experiences, student communications and feedback, as well as descriptive statistics of learning management systems while the participants studied energy features of robots in two disciplines, namely "Robotics" at the Bachelor's level and "Advanced Robotics" at the Master's level. Students united in a single cohort differed from one another in terms of academic levels, professional prerequisites (mechanical, electrical, and information technology), knowledge backgrounds, and forms and duration of training. At the moment, such distinctions meet the needs of the modern community, in which multidisciplinary professional teams jointly solve complex industrial and societal tasks. At that, robotics disciplines have become a crossroads where three types of AI converge: narrow AI responsible for the robots' "thinking", conversational AI interfaces such as ChatGPT, Copilot, or Gemini used to answer numerous educational questions, and generative AI capable of making design and control decisions. Several stages of AI implementation are considered that have yielded the most significant outcomes in students' knowledge and skills acquisition.

Key words. artificial intelligence, energy education, robotics, active learning.

1. Introduction

The advent of artificial intelligence (AI) is rapidly transforming technological, economic, and social life, leading to a rethinking of the role of an engineer and changing requirements for engineering education. This is especially important when it comes to robotics widely used in various branches of industry across the globe [1-3]. Since the energy consumed by robots depends on their architectures, kinematic, static, and dynamic properties, the AI potential plays a key role in enabling new learning technologies in higher education, where the acquisition and appropriation of core competences and skills require engaging learning experiences and value-adding interactive resources.

As educators face new challenges and difficulties in developing and implementing AI tools, it is essential to support them, considering both their pedagogical and technological aspects. The time has come when such concepts as active learning, blended learning, and mobile learning are no longer the prerogative of exceptional, talented, or individual students but are becoming a mandatory educational platform.

The goal of this study is to introduce some new AI-reinforced learning scenarios and resources to strengthen the skills required by community in the scope of digital literacy challenges. Some ongoing results on supporting engineering education with an orientation towards energy-efficient thinking and AI agents are presented. The focus is on the robotics disciplines that have become a suitable crossroads where three types of AI converge: narrow AI, designed for specific tasks; conversational AI, which is a technological concept where machines perform many intellectual problems that a human can do; and generative AI, capable of creating content and making design and control decisions [4].

2. Related Study

In recent years, a significant surge in academic publications on the use of AI in education appears that reflect a growing interest and rapid adoption of different AI tools. Multiple systematic reviews analyse a variety of research on AI in education, the number of which has increased dramatically since 2022. Most of them cover different educational levels, regions, and stakeholders. A separate overview group focuses on research directly related to implementation of AI in higher engineering institutions, highlighting their innovations, opportunities, and challenges. Geographically, most studies are originated from China and the U.S., but other international contributions are growing as well. At that, the U.S. and China lead with near-total adoption, India and UK show strong growth in higher education, Germany focuses on vocational applications, Indonesia and Nigeria are emerging markets using AI to improve access and teacher support. The most diverse topics relate to intelligent tutoring systems, adaptive learning, ethics, teacher training, and student engagement. Large-scale research studies the opinions of students and teachers about AI technologies and their use in education. The authors provide answers to questions such as how familiar students are with AI technologies; what is the prevalence and purpose of AI application; what are the potential pros and cons associated with the use of AI in education; how ethical principles change when using AI; how educators assess the potential of AI to improve teaching and learning; how open faculty members are for the implementation of AI technologies; and many others.

According to these publications, AI offers many teaching and learning benefits [5, 6]. Along with that, AI brings new challenges and concerns to the field of education.

In [7], the AI-related problems are divided as individual (personal traits, motivation, self-efficacy, personal choices), pedagogical (lack of theoretical coursework, insufficient hands-on digital tool training), and environmental (poor resource availability, weak institutional advocacy/support, etc.).

In [8, 9], such problems are identified as the need for knowledge sharing and policy development regarding AI, the necessity to support students in ethics of using AI, the role of humans in AI-assisted learning, the need to align AI systems with educational goals, as well as assessing the degree of AI credibility and security.

The author of [10] highlights a major gap in structured frameworks, fragmented and uneven AI adoption, leadership challenges in balancing objectives, and lack of common language and shared understanding.

The issues listed in such comprehensive reviews as [11-13], signal that, though AI offers great transformative opportunities, it must be implemented with close attention to pedagogy and institutional responsibility.

As energy-efficient manufacturing becomes an increasingly important part of sustainable development, energy consumption of various groups of robotic stations is attracting the attention of technological universities. According to [14], electrical energy consumed by robots in the production of vehicles is about 8% of total energy consumption in the vehicle lifecycle. In industrial [15], aerial [16], floating [17], mobile [18] and professional [19] robotics, electricity consumption grows due to such factors as increase of power equipment of robots, introducing robots in tasks previously performed by humans, growing productivity of applications, and involvement robotics in more and more spheres.

In service robotics, the reduction of energy losses is crucial for their practical application, further development, and deployment that are often constrained due to their high energy demand. The role these restrictions play for the battery-supplied wheeling and, especially, legged robots is significantly more important than that of stationary robots of the equivalent size and capacity.

Collaborative robots have at least three advantages over the specialized robots in terms of energy efficiency. First, they are convenient for designing optimal motion trajectories. Second, they allow to customize their configuration depending on the task being solved. And third, the same robot can perform different services [20-23].

One of the design features that directly affects energy demands is related to optimizing the robot joint configuration, that is, an arrangement of robot joints needed to locate the tool in the desired pose. The paper [24] could be noted as an early work on searching for the best configurations in view of the lowest power requirements. In [25], the same problem was solved for a pick-and-place operation. In [26], power consumption is minimized while robots hold processed objects in assembling, welding and packaging, quality control, loading and wrapping stations. Some other studies also concentrate on decreasing the energy consumed by robots during their motion along predefined trajectories [27-29]. Unlike traditional models, AI-driven solvers are increasingly being introduced nowadays thanks to their ability of making predictions, solutions, and insights. One of the first AI-driven models fitting the energy-efficient configuration of linear Delta robots was published by the authors in [30].

Despite the variety of scientific studies, the authors failed in finding any special studies in the field of the AI influence on energy education.

3. The Method

The method was tested during eight semesters while the participants studied two disciplines, namely “Robotics” at the Bachelor's level and “Advanced Robotics” at the Master's level at Tallinn University of Technology (TalTech).

Three categories of students who participated jointly in the common stream are shown in Fig. 1. They are the ordinary full-time home university students for whom these courses were mandatory, the Erasmus+ learners who chose robotics courses as electives for one or two semesters of their stay at TalTech, and the EuroTeQ applicants who decided to learn optionally in the frame of the blended format. As opposed to TalTech, EuroTeQ Engineering University is not a traditional university, but rather a joint initiative of several leading universities of technology that offers students a unique opportunity to take optional courses at partner universities in hybrid and blended formats [31].

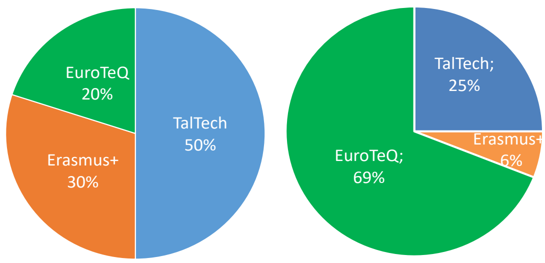

Fig. 1. Averaged charts of the educational situation in the robotics disciplines over the studied period: enrolment fractions of the full enrolment rate (left) and dropout fractions of the full dropout rate (right).

These diagrams represent the educational situation in two robotics disciplines over the studied period. The students, united in a single cohort, differed from each other in terms of academic levels, professional prerequisites (mechanical, electrical, information technology), knowledge backgrounds, forms and duration of training. Such distinctions meet the needs of the modern community, in which multidisciplinary professional teams are invited to jointly solve complex industrial and societal tasks.

Blended learning [32] was chosen as a mode of knowledge delivery combining in-person or online classes along with mandatory in-person labs practice, with formative assessments, allowing for flexibility, self-paced learning, and personalisation. As the prerequisite for final grading, students had to complete at least three personalized computer tasks and three labs. In contrast to the traditional studies, the described assessment system is based on the scores accumulated during the semester for answering quiz questions and participating in optional activities. The rounded-up amount of these scores served as an examination grade.

The discussed research focuses on the AI-caused problems faced by faculty and students on their way to academic success, gaining energy-related cognition. At that, various progressive AI-driven solutions were studied in lectures, computer exercises, laboratory classes, and numerous additional robotics-related educational forms.

Lectures were broadcast via MS Teams, while lecture recordings were also available there, along with lecture slides published in the learning management system (LMS). To track the study progress, quizzes were open from the lecture day until the deadline and closed automatically. The student's future grade has increased with each correct answer, decreased with incorrect answers, and stayed unchanged if a question or a full quiz was skipped. Once the quiz closes, all answers were immediately published for learners' acknowledgement, and the next quiz open, and so on, each lecture week throughout the semester.

As for the computer exercises, every student had an individual task related to the robots available at the department. Following the "Manual on Exercises," learners independently worked in MATLAB, uploaded reports, received the teacher's feedback, and corrected them until completion. In addition to the mandatory exercises, there were some advanced energy-focused optional ones that could increase the learner's grade. They concern energy-saving measures such as improved braking, the use of high-efficiency motors, gearless design, and new lightweight materials. Participants might follow online exercise classes via MS Teams, and class recordings were also available.

Laboratory experiments are always a necessary, integrated and most valuable part of engineering education. Industrial and collaborative robots of serial and parallel topologies manufactured by ABB, Festo, Siemens, Kuka, UFACTORY, and Universal Robots, were proposed for study. Similarly to computer exercises, a part of labs were mandatory, whereas some works were the advanced options that, however, could help to increase the grade. Energy-efficient robot management and trajectory planning were most often considered as optional laboratory topics.

To elevate the final grades, students were also invited to give presentations on the advanced energy-efficient solutions at the International IEEE Student Workshop "Amazing Robotics".

4. Results and Discussion

The obtained results are discussed based on explicit data collection from faculty experiences, learners' communications and feedback, as well as the descriptive LMS statistics. They demonstrate how such concepts as active learning, blended learning, and mobile learning are merging in a natural platform for higher engineering education. In Fig. 2, an averaged allocation of students participated in different study forms is shown.

Since artificial intelligence-based learning opens up many different ways of learning leading to the completion of the course, such a multitude initially puzzled students who, due to their youth and incompetence, tried several of them at once. Gradually, everyone turned onto the road that best fits his/her interests and capabilities. The diagram shows that some students preferred lectures and on-lecture polls, post-lecture quizzes, or presentations while others focused on solving optional exercises, and the third group enjoyed additional labs, etc.

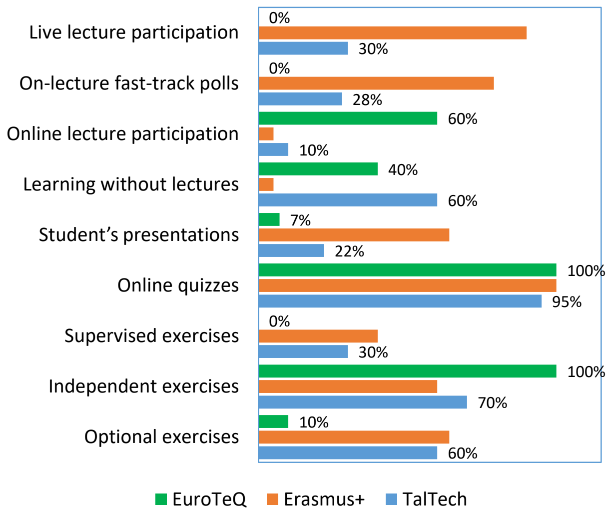

Fig. 2. Allocation of students among study forms.

Figure 3 represents the lecture-related dynamics.

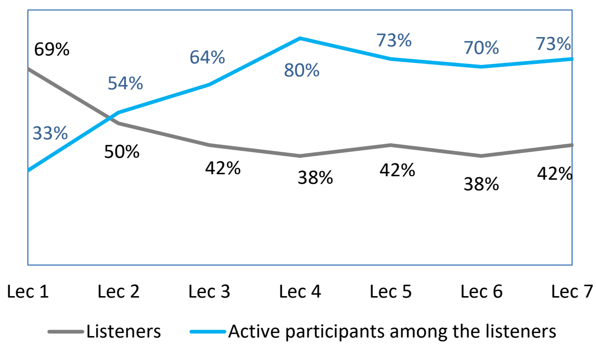

Fig. 3. Lecture-related dynamics of theoretical study forms.

Traditionally, attending lectures in person was not very popular among the audience. Over time, as students mastered the skills of working with AI, they became more interested in lecture slides and recorded videos rather than attending lectures and following the lecturer. They also prefer online textbooks to paper books, primarily because of the ease of finding the requested information and checking its relevance. However, the most active learners attend lectures in order to take part in on-lecture polls and increase their grades through the personal communication with a lecturer and fellow students.

According to Fig.2, the main fraction of the final grade is received from the post-lecture online quizzes. Figure 4 demonstrates four stages of the quizzing process change during the years.

Until about 2024, students hardly used AI-enabled tools, in particulardue to their lack of energy awareness ("Best results before the AI era"). To successfully respond to quizzes, they had to attend lectures and study lecture notes, slides and recordings. As follows from our previous researches, during 2022-2023, the number of participants involved in active learning with quiz-based assessment gradually reached 90% [33, 34]. In these studies, the average time taken to answer a 10-question test was almost 37 minutes, and the average test score was about 74% of the maximum level.

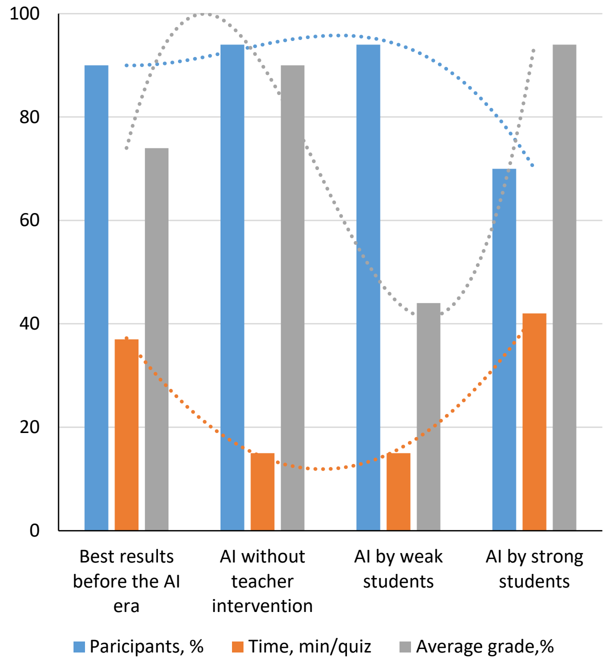

Fig. 4. Averaged clustered diagrams of AI implementation to quizzing in robotics during the explored period.

Conversational AI interfaces, such as ChatGPT, Copilot, or Gemini, have quickly captured the attention of students since their introduction. Figure 4 shows a significant growth of student participation in quizzes and their grades, despite a reduction in time spent on them ("AI without teacher intervention"). However, exams and tests revealed a lack of growth in the cognitive abilities of "successful" students, along with a low level of appreciation of the principles and algorithms for the actions performed and the programs generated.

Realising that the level of knowledge had not increased in proportion to the grades received, the teachers responded by improving the quizzing system. Once educators introduced graphics, videos, and ambiguous options with tricks into their questions, the average grade has decreased. As a result, many weak students have lost interest in quizzing ("AI by weak students" in Fig. 4), whereas the strong ones began to spend more time searching for answers in favour of improving their grades ("AI by strong students" in Fig. 4). Regarding the observed disengagement of lower-performing students, the tutors were critically expanded on the pedagogical validity and ethical implications of their attempts to deter AI reliance. To this aim, novel assessment resources were searched, which insights would strengthen teaching by enhancing understanding, giving students real opportunities to learn from their mistakes and engage with the course material in exciting ways. An important advantage of this stage for both students and faculty was the tendency to transition from conversational to the generative AI assistance capable of making decisions.

The main features of contemporary students are most strongly manifested in exercises and labs, where practical skills are obtained. Therefore, the mandatory group of labs and computer exercises have become a fertile ground for getting to know multiple narrow AI systems responsible for the "thinking" of robots. On the other side, optional labs and exercises contributed to the study of generative AI. The change of exercise-related activities is shown in Fig. 5

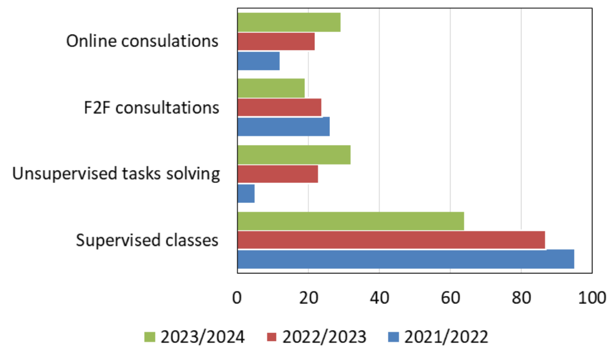

Fig. 5. Exercise-related dynamics of students' involvement.

According to this diagram, with the development of licensed software, the need to follow the teacher during exercise classes gradually drops and the volume of the face-to-face (F2F) consultations decreases. Instead, the role of online consultations is growing. Thanks to the AI help, there is also an increased interest in solving additional optional tasks in order to raise the appropriate component of the final grade. The same can be said about student presentations.

5. Conclusion

The emergence of AI demonstrates a rapid transformation of the engineering educational technology. Thanks to AI, such concepts as active learning, blended learning, and mobile learning are becoming a natural platform for higher education.

The presented results offer the faculty and students a unique opportunity to gain experience in AI through mandatory and optional forms of study in hybrid and blended formats. Several stages of AI introduction show that robotics disciplines have become a suitable crossroads where three types of AI converge: narrow AI responsible for the "thinking" of robots, conversational AI interfaces such as ChatGPT, Copilot, or Gemini, and generative AI capable of making decisions.

Qualitative outcomes of this research show an importance of the development of the AI-assisted education as an evolutionary stage and useful tool.

Such an approach, on the one hand, promises to expand the possibilities of implementing AI in energy-related education. At the same time, new constraints are being discovered that are not inherent in artificial systems, such as an unpredictably changing targets, student-oriented environment, and reward functions. Now, the authors are critically expanded on the pedagogical validity and ethical implications of their attempts to deter negative AI reliance, particularly regarding the observed disengagement of lower-performing students. Therefore, novel AI-resistant assessment resources are to be searched, which would provide insights to strengthen teaching and enhance understanding, giving students real opportunities to learn from their mistakes and engage with the course material in exciting ways.

The results demonstrate the prospects of the proposed approach for the development of educational AI. However, two disciplines are not enough to assess the impact of AI on the overall energy education level. Therefore, it seems advisable to continue these investigations in a broader field.

References

[1] C. Müller, World Robotics 2023 – Industrial Robots, IFR Statistical Department, VDMA Services GmbH, Frankfurt am Main, Germany (2023). Available: https://ifr.org/img/worldrobotics/Executive_Summary_WR_Industrial_Robots_2023.pdf.

[2] R. A. Kampa, What is a Serial Robot? (2024). Available: https://www.easytechjunkie.com/what-is-a-serial-robot.htm.

[3] Web Parallel Robots: The High-Speed Robotics Platform (2021). Available: https://howtorobot.com/expert-insight/parallel-robots.

[4] Robotics and Smart Autonomous Systems Technology and Applications (2025). Priyadarshini, R., Mehra, R.M., Sehgal, A. and Singh, P.J. (Eds.), CRC Press, 289 p. Available: https://doi.org/10.1201/9781003537083.

[5] Artificial Intelligence and the Future of Teaching and Learning (2023). Cardona, M.A. (Ed.), Washington DC, 71 p. Available: https://www.ed.gov/sites/ed/files/documents/ai-report/ai-report.pdf.

[6] Artificial Intelligence Based Smart and Secured Applications. Third International Conference proceedings. Revised Selected Papers, Part IV (2024). Rajagopal, S., Popat, K., Meva, D., Bajeja S. and Mudholkar, P. (Eds.), ASCIS Rajkot, India, , Springer, 471 p. Available: https://doi.org/10.1007/978-3-031-86299-1.

[7] Intelligent Technology for Educational Applications: Proceedings of the First International Conference (2024), Lee, K.W. and Wong, L.L. (Eds). ITEA, Kuala Lumpur, Malaysia, Springer, 160 p. Available: https://doi.org/10.1007/978-981-96-4090-4.

[8] B. Han, S. Nawaz, G. Buchanan and D. McKay, "Students' perceptions: Exploring the interplay of ethical and pedagogical impacts for adopting AI in higher education," International Journal of Artificial Intelligence in Education (2025), Springer. pp. 1–26. Available: https://doi.org/10.1007/s40593-024-00456-4.

[9] N. K. Viet, "The use of generative AI tools in higher education: Ethical and pedagogical principles," Journal of Academic Ethics (2025), 23:1435–1455. Available: https://doi.org/10.1007/s10805-025-09607-1.

[10] M. Sposato, "Artificial intelligence in educational leadership: A comprehensive taxonomy and future directions," International Journal of Educational Technology in Higher Education (2025), Springer, 18 p. Available: https://doi.org/10.1186/s41239-025-00517-1.

[11] A. K. Singh, M. K. Kiriti, H. Singh and A. Shrivastava, "Education AI: Exploring the impact of artificial intelligence on education in the digital age," Int J Syst Assur Eng Manag (2025), 16 (4), Springer, pp. 1424–1437. Available: https://doi.org/10.1007/s13198-025-02755-y.

[12] M. Airaj, "Ethical artificial intelligence for teaching-learning in higher education," Education and Information Technologies (2024), 29, Springer, pp. 17145–17167. Available: https://doi.org/10.1007/s10639-024-12545-x.

[13] Innovative Technologies and Learning, Proceedings of 8th ICITL International Conference, Part I (2025), W.-S. Wang, F. E. Sandnes, C.-F. Lai, T. A. Sandtrø and Y.-M. Huang (Eds.), Springer, Oslo, Norway, 398 p. Available: https://doi.org/10.1007/978-3-031-98185-2.

[14] 3 Trends in Robotics Energy Consumption (2021). Available: https://www.roboticstomorrow.com/story/2021/03/3-trends-in-robotics-energy-consumption/16385/#.

[15] D. H. Canchanya, R. A. B. Alva, V. E. P. Villa and J. H. Pariona, "Features of Implementing Tensegrity Robots: A Detailed and Innovative Review," CMAAE International Conference on Mechanical, Aerospace and Automotive Engineering (2021), pp. 126-131. Available: https://dl.acm.org/doi/10.1145/3518781.3519194

[16] Springer Handbook of Robotics (2016), Siciliano, B. and Khatib, O. (Eds.) Springer, 2228 p. Available: https://dblp.org/db/reference/robo/robo2016.html

[17] V. Vodovozov, V. Mjadzel, and L. Rassudov, Robots in Shipbuilding Manufactures (1986), St. Petersburg: Shipbuilding, 248 p.

[18] V. Vodovozov, Z. Raud, and E. Petlenkov, "Review on braking energy management in electric vehicles," Energies (2021), 14(15), 4477. Available: https://www.mdpi.com/1996-1073/14/15/4477.

[19] S. Hosseini and I. Hahn, "On experimental energy consumption estimation of a 6-DoF industrial UR3e robot arm manipulator in trajectory planning," 33rd IEEE International Conference on Robot and Human Interactive Communication (2024), Pasadena, CA, USA, pp. 1430-1435. Available: https://doi.org/10.1109/RO-MAN60168.2024.10731263.

[20] I. Voysey, T. G. Thuruthel and F. Iida, "Autonomous dishwasher loading from cluttered trays using pre-trained deep neural networks," Engineering Reports (2021), v. 3, no. 5: e12321. Available: https://doi.org/10.1002/eng2.12321.

[21] A. Zahavi, S. N. Haeri, D. C. Liyanage and M. Tamre, “A dual-arm robot for collaborative vision-based object classification,” 17th Biennial Baltic Electronics Conference (2020), Tallinn, Estonia, pp. 1–5. Available: https://doi.org/10.1109/BEC49624.2020.9277067.

[22] J. Hippolitus, R.Senthilnathan and O. Malla, “Simulation of grasp localization inferences for a dual-arm collaborative robot,” IOP Conference Series: Materials Science and Engineering (2021), v. 1012: 012004, pp. 1–12. Available: https://doi.org/10.1088/1757-899X/1012/1/012004

[23] P. P. Modi, M. S. H. Sunny, M. M. R. Khan, H. U. Ahmed and M. H. Rahman, “Interactive IIoT-based 5DOF robotic arm for upper limb telerehabilitation,” IEEE Access (2022), v. 10, pp. 114919–114928. Available: https://doi.org/10.1109/ACCESS.2022.3218053.

[24] A. Mohammed, B. Schmidt and L. Wang, “Energy-efficient robot configuration for assembly,” J Manuf Sci Eng. (2017), 139: 051007. Available: https://doi.org/

[25] Y. Feng, Z. Ji, Y. Gao, H. Zheng and J. Tan, “An energy-saving optimization method for cyclic pick-and-place tasks based on flexible joint configurations,” Robot Comput-Integr Manuf 2021, 67: 102037. Available: https://doi.org/

[26] V. Vodovozov, Z. Raud and E. Petlenkov, “Intelligent control of robots with minimal power consumption in pick-and-place operations,” Energies 2023, 16: 7418. Available: https://doi.org/

[27] M. Pellicciari, G. Berselli, F. Leali and A. Vergnano, “A method for reducing the energy consumption of pick-and-place industrial robots,” Mechatronics 2013, v. 23, no. 3, pp. 326 – 334. Available: https://doi.org/

[28] M. Hovgard, B. Lennartson and K. Bengtsson, “Energy reduction of stochastic time-constrained robot stations,” Robotics and Computer-Integrated Manufacturing 2023, 81: 102511. Available: https://doi.org/

[29] M. Gorkavyy, Y. Ivanov and M. Melnichenko, “Research the potential for energy saving and maximizing productivity in rectilinear transitions of a collaborative robot,” 2024 International Russian Smart Industry Conference (SmartIndustryCon), Sochi, Russia, 2024, pp. 912 – 916. Available: https://doi.org/

[30] V. Vodovozov, M. Lehtla, Z. Raud, N. Semjonova and E. Petlenkov, “Managing energy consumption of linear Delta robots using neural network models,” Energies 2024, 17: 4081. Available: https://doi.org/

[31] V. Vodovozov, Z. Raud and M. Lehtla, “EuroTeQ as an alliance to promote European engineering education,” 15th International Conference on Computer Supported Education, Prague, Czech, pp. 601-607 (2023). Available: https://doi.org/10.5220/0011824900003470.

[32] V. Vodovozov, Z. Raud and E. Petlenkov, “Active blended learning as a tool focused on Industry 5.0 at EuroTeQ Engineering University,” IEEE Global Engineering Education Conference (2024), Kos, Greece, pp. 1-5. Available: https://doi.org/10.1109/EDUCON60312.2024.10578688.

[33] V. Vodovozov, Z. Raud and E. Petlenkov, “Strengthening active learning with a reinforcement approach in engineering education,” IEEE 65th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (2024, Riga, Latvia, pp. 1-5, Available: https://doi.org/10.1109/RTUCON62997.2024.10830891.

[34] V. Vodovozov, Z. Raud and E. Petlenkov, “Active blended learning engineering students: A case study,” Education Sciences (2022), 12 (5) pp. 344. Available: https://doi.org/10.3390/educsci12050344.