DEFINING CHALLENGE BASED LEARNING AND EDUCATION IN THE AUTONOMOUS SHIPPING CONTEXT

Peter Sandell, Johanna Salokannel

Novia University of Applied Sciences, Faculty of Technology and Seafaring

Andrei-Raoul Morariu, Anastasia Tsvetkova

Åbo Akademi University, Faculty of Science and Engineering.

Victor Bolbot

Aalto University, Department of Energy and Mechanical Engineering

Jouni Saarni, Jouni Isoaho, Seppo Virtanen

University of Turku, Department of Computing

ABSTRACT

The increasing digitalization and introduction of Maritime Autonomous Surface ships (MASS) is changing the role of seafarers and other professionals in the maritime sector. The technological complexity of ships due to automation requires the development of skills related to, for example, cybersecurity, ship equipment engineering, and software development. This results in a demand for strong problem-solving abilities, adaptability to technological changes, and continuous learning, which, in turn, requires maritime education and training to become more adaptive and responsive. This includes emphasizing lifelong learning, embracing an interdisciplinary approach, and promoting project-based and problem-solving learning methods. Challenge-based learning has been established as a successful method for delivering practical real-world learning experiences in engineering disciplines and it has been proposed as an evolution of the Conceive, Design, Implement and Operate (CDIO) framework adopted widely in universities giving engineering education. In this paper, we present concrete definitions for the concepts of challenge-based learning and education in the MASS context. Such definitions for MASS education have not been previously presented in the literature. The definitions will pave the way for successfully applying challenge-based learning in this field and serve as foundations for building educational frameworks for MASS.

KEYWORDS

Challenge Based Learning, Autonomous Maritime, Shipping, CDIO Standards: 1–3, 5–8

INTRODUCTION

The increasing digitalization and the introduction of Maritime Autonomous Surface Ships (MASS) are changing the role of seafarers and other professionals in the maritime sector. For instance, it has been revealed that MASS operation from remote control centers would require a different set of skills from seafarers compared to the current situation (Sharma & Kim, 2022). The need for detailed knowledge in a narrow field would be replaced by creativity and quick problem-solving skills, similarly to other highly automated sectors like aviation, mining and ports (Emad et al., 2022). Leadership has been mentioned as one of the critical skills for seafarers to learn in the future (Hynnekleiv et al., 2020), too, also with the introduction of MASS.

Many studies on the increasing automation and digitalization impact on maritime education and training highlighted the urgent need for new competencies in ICT, cybersecurity, automation, and smart shipping technologies (Bolbot et al., 2022; Cicek et al., 2019). In particular, Alop (2019) pointed to the need to manage and interact with advanced digital systems, understand complex human-machine interactions, and utilise big data analytics. Additionally, he specified the demand for strong problem-solving abilities, adaptability to technological changes, and continuous learning, which, in turn, requires maritime education and training to become more flexible and responsive. This includes promoting lifelong learning, embracing an interdisciplinary approach, and promoting project-based and problem-solving learning methods.

The need for interdisciplinarity in education for MASS has been noted, for example, in the study by (Mogensen, 2018). The study found that a good command of matrix calculus, required for marine engineers but not accommodated by STCW education, is needed for future seafarers in order to understand the systems architecture of discrete control systems. The use of interdisciplinary teams is also expected to create a beneficial learning environment. Interdisciplinarity in education can also address the risks of errors during human-automation interactions, which are often discussed in the MASS context (Ahvenjärvi, 2016; Hogg & Ghosh, 2016).

In this paper, we formalise concrete definitions for the challenge-based learning and education (CBL and CBE) concepts in the context of MASS. While CBL and CBE have been discussed as viable learning and education strategies to promote interdisciplinarity and the application of theory to practice, a concrete definition of these concepts for the educational needs of MASS has not been previously presented. Challenge-based learning has been established as a successful method for delivering practical real-world learning experiences in engineering disciplines as reported by, for example, by Malmqvist et al. (2015). More recently, CBL and CBE have been identified by Rådberg et al. (2020) as an evolution of the Conceive, Design, Implement and Operate (CDIO) framework adopted widely in universities giving engineering education. In maritime education, CBL and CBE have been highlighted as a way to address the growing need for inter-disciplinary knowledge and the development of 21st century skills like critical thinking, problem solving, digital literacy, creativity and communication (A. R. Morariu et al., 2025).

We consider that CBL and CBE, when properly defined for the context, have the potential to address MASS needs because of their fundamental principle: students define the challenges, rooted in real-life contexts, and then attempt to solve them. Such an approach calls for critically analysing the situation at hand, developing communication skills and keeping learning close to the real-life challenges in the maritime sector. Since the challenges to be solved are defined as part of the learning process, it allows for accounting for the changing context in the maritime sector.

The development of the CBL and CBE definitions derived in this paper was commenced in the AutoMare EduNet project funded by the Ministry of Education and Culture in Finland during 2021-2023. In AutoMare EduNet, a multidisciplinary collaboration network between universities was built to ensure the delivery of high-quality education to meet the emerging educational needs of MASS.

DEFINITION OF CHALLENGE BASED EDUCATION AND LEARNING

Challenge Based Learning (CBL) shares similarities with Problem-Based Learning (PBL), as both engage students in solving real-life problems. PBL does not focus on the problem or how it is handled, but rather on the achieved knowledge and intended learning outcomes. The PBL model has existed for decades, but CBL has been introduced more recently. CBL aims to incorporate 21st-century skills, such as critical thinking, problem-solving, and technological competence, into PBL and integrate technology into the process. CBL's primary goal is for students to develop practical, real-world solutions to open-ended problems called challenges, not just to complete a critical thinking exercise. This renders CBL a natural extension of the previously existing methods like PBL.

In Challenge-Based Learning, students achieve a deep learning experience by solving real-world challenges. The challenges are sociotechnical and multidisciplinary, and they do not have an exact predictable outcome (in comparison to problems with expected solutions). The challenge solving process determines the direction the solution will take. Student groups define the details of the initial challenge and identify the knowledge needed to tackle the challenge and progress towards a solution. In the AutoMare project, CBL is applied as a pedagogical paradigm rather than used as the implementation style for each course. As such, in the AutoMare context, we use the term Challenge Based Education (CBE).

In CBE, we can identify three main phases:

1 **Engage**: start from the conceptual challenge and proceed to define a concrete and actionable challenge.
2 **Investigate**: apply and acquire knowledge and skills to conduct activities that lead towards possible solutions; simulations, experiments, research and subprojects.
3 **Act**: develop and implement solutions in an authentic real-world environment, and evaluate the obtained solutions and results.

CBE is already reflected in the teaching of courses related to the design of advanced (autonomous) ship concepts and the analysis of risks of autonomous technologies at Aalto University. Courses such as Principles of Naval Architecture, Ship Design Portfolio, and Marine and Ship Systems Engineering enable a teaching and learning experience with M.Sc. students in the development of a new ship concept in a project/assignment. Other courses such as Marine Risks and Safety teach the composition and management of the safety-critical systems for enabling maritime ship operations. This is particularly critical for MASS as this demands an understanding of the functioning of the onboard and onshore systems which requires the incorporation of multiple safety viewpoints and interpretations. In these courses, the students engage better with real-life challenges, and the courses have supported collaboration in a multidisciplinary way. In addition, students are capable of exploring, discussing, and meaningfully constructing concepts and relationships in contexts that involve real-life challenges and projects

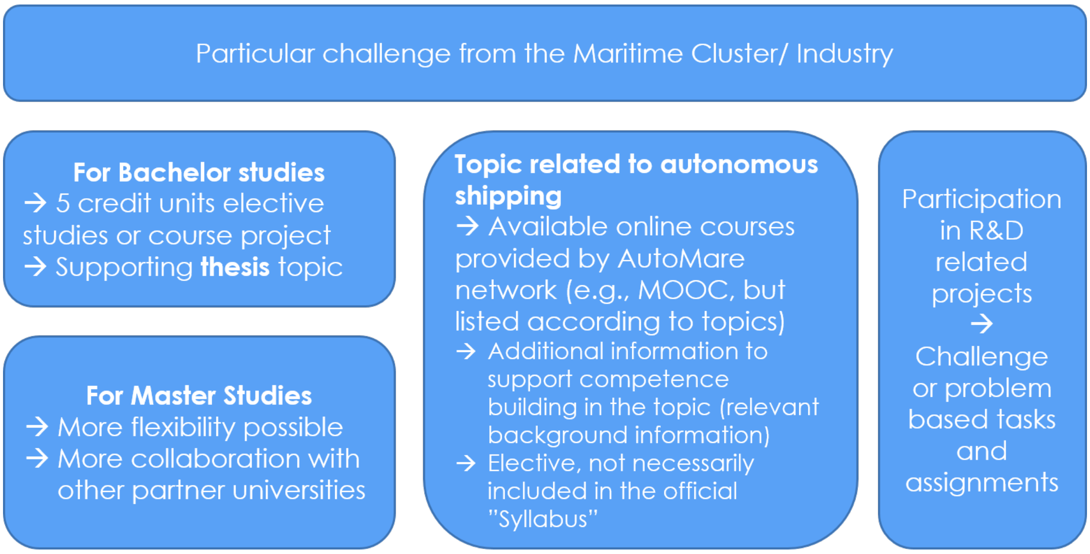

Figure 1. Integrating challenges to education and degree programs

(mainly with the industry) that are relevant to the learner. Overall, CBE at Aalto University has offered benefits such as establishing new teaching and learning practices that are better aligned with work-life environments and therefore can increase the students' employability.

CBE can, and in most cases, needs to be brought incrementally into the curricula of different educational institutes. Even though challenges are often extensive, some curricula may define a specific amount of challenge-based coursework to be included, meaning that the students following those curricula contribute to the challenges at some specific stage for some specific amount of work, but do not necessarily participate in solving the challenge from the beginning to the end. The same challenge can bring together students from different courses and disciplines. Figure 1 presents a proposal for integrating challenges to education and degree programs.

For a successful deployment of CBE in educational institutions, a close and continuous collaboration between them and stakeholders in the field is essential. For this reason, CBE as defined in the AutoMare EduNet project includes the innovative concept of AutoMare Challenges and Novelties Pool. The Pool is needed to ensure continuous challenge availability to student groups. Without continuous availability, delays in obtaining challenges can severely hinder the application of CBE as part of the educational offerings of different institutions. To create such a Challenges and Novelties Pool, real-world challenges need to be collected from the industry. This would conveniently be achieved by organizing regular workshops and seminars between instructors, students, and the representatives of the stakeholders and maritime industry to identify and disseminate challenges and relevant knowledge. The actual process for organising the Pool as a form of collaboration between educational institutes, stakeholders and industry would need to be defined by the collaborators in their joint co-operation planning. The ways in which CBE as defined in this paper fosters peer learning within student-instructor-industry collaboration is elaborated further in another CDIO 2025 paper by the authors (A.-R. Morariu et al., 2025).

In Finland, bachelor's degrees in maritime education are divided into two categories: degrees based on the STCW Convention (Seafarer Training), and degrees in which education is based on marine technology and shipbuilding/design. The STCW Convention, which regulates the training of seafarers, is a mandatory convention that strongly regulates the content of maritime bachelor's degrees. Compliance in Bachelor's degree studies based on STCW is monitored and audited periodically by national authorities. The development of MASS training is strongly linked to the expected changes to the STCW Convention, the work that is about to begin in the International Maritime Organization (IMO) (Sandell, 2024).

For Master of Maritime Management degrees, the situation is very different. Master's degrees act as a bridge from sea to land, so that in the future, a growing number of people with experience at sea can work in the land organizations of the maritime cluster. For these, the skills requirements will increase in line with the requirements of increasing autonomy. The role of these persons, as shipping companies adapt to the changes brought about by autonomy, is essential for the development of the maritime cluster as a whole (Sandell, 2024).

Traditionally, minor subject students are studying the basics of the MASS field, sometimes even having different courses than the major students. However, with AI and autonomous technologies rapidly transforming the maritime field towards autonomous shipping, the role of minor students has significantly evolved. They are now central to this renewal process, making it essential to integrate them with MASS major subject students. This integration involves working together to define and solve challenges, as well as developing cooperation and communication skills. Often the minor subject students are from the ICT field, with key areas of focus including autonomous technology, artificial intelligence, data science, software engineering, interaction technologies, and cybersecurity.

In PBL, different subjects are integrated together in the curriculum. Based on this, the student can form topics that meet the working life needs during their studies and start developing their professional competence. PBL is described at two levels, micro and macro. At the micro level, activities take place in classrooms or online, allowing students to develop self-direction and teamwork skills. In order for PBL goals to be achieved, the actions of both the learner and the teacher must be reflected. PBL at the macro level is a strategy that should be reflected not only in the learner's behaviour but also in the curriculum, teaching and collaboration of the entire educational institution. The teaching of all subjects combined into a broad whole, simulating the operation of a company, is suitable especially for Bachelor-level teaching, where students are physically present. Continuous collaboration between all teachers is needed to advance and support the students' work; for example, in the fields of business, accounting, languages and law. On the macro level, all courses and lectures are integrated into PBL learning, where continuous company development and problem solving require the presence and close cooperation of each teacher. PBL at macro level can also be combined with CBE, and CBE based assignments can be part of macro PBL teaching strategy (Sandell, 2024). Given the uncertainty regarding the development of the maritime sector with a more abundant introduction of MASS, it is necessary to develop flexible teaching and learning frameworks, which would allow for agile adjustments and modifications according to emerging needs. Therefore, CBE is a method that enlarges the methodological choices compared to traditional PBL methods (Sandell, 2024).

Both PBL and CBE have their roles in the future of Maritime Education and Training (MET) when Education relating to autonomous shipping is being transformed and shared in Digivisio 2030 (a program involving all Finnish higher education institutions that aims to create a future for learning that benefits higher education institutions, learners and our society as a whole) starting in autumn 2025. As the Digivisio 2030 consortium of higher education institutes is developing

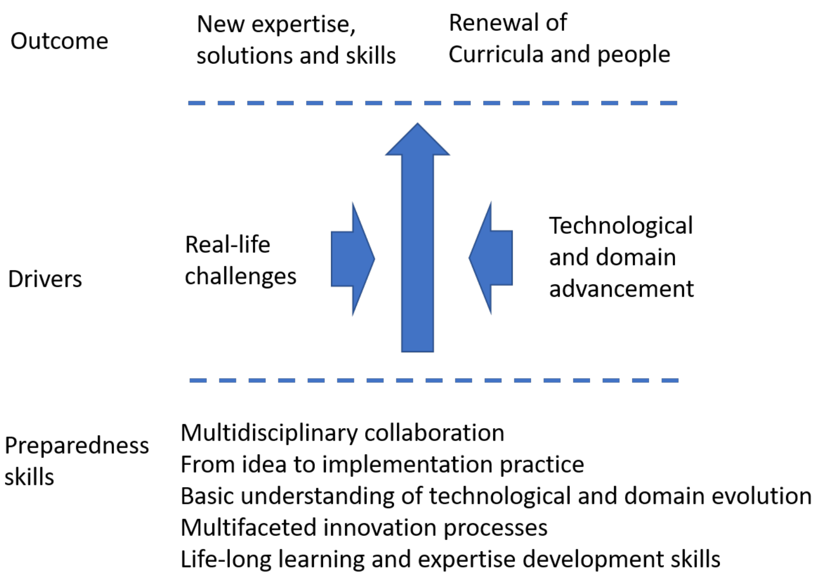

Figure 2. Challenge based education process

and relies more on cooperation of both institutions of more technological science Universities and the Universities of Applied Sciences which have the responsibility for MET for the STCW standards, it is evident that there are two approaches which need to be combined. MET is more strictly tied to education as it is strongly regulated by the STCW convention. Therefore, it is also more tied to solving problems on the basis of international regulation which determines the possibilities for solutions which are legally enforceable and which follow the IMO regulations and guidelines. CBE is suitable for the development of technological standards and solutions for how technological problems can be solved. As MASS Code will enter into force based on a goal-based instrument, both PBL and CBE will be suitable methods in their own practice areas. As autonomous shipping is strongly combining traditional seafaring with technology, the consortium will use both methodological approaches as the work continues. It is evident that the mixing of methods will develop new kinds of co-operations for the future of autonomous seafaring when the IMO standards are finalized (Sandell, 2024).

Readiness and preparedness of students and teachers for adopting CBE

There are three key elements in the CBE process: **1)** educational outcome, **2)** impacting drivers, and **3)** preparedness skills. The process is illustrated in detail in Figure 2 and discussed in the following. The development of technology and automation enables innovations from existing and new companies, and applications related to artificial intelligence are increasingly being seen. Artificial Intelligence can bring more value to maritime companies' decision making, operation optimisation and automating different tasks. For example, AI can be used in a ship's voyage planning and forecasting weather as well as in ship maintenance and fuel consumption optimisation. Artificial intelligence can also be utilised on board vessels in safety-related functions, such as behaviour-based safety, where the aim is to improve the shipping company's awareness of the safety culture on board. Other safety-related benefits can be seen in bridge systems and collision risk assessment, as well as fire risk detection. On the other hand, the use of artificial intelligence brings new risks and issues to be taken into account for the shipping company, such as cybersecurity, ensuring reliable data in AI analytics, and taking into account the training needs of personnel and data protection. All this needs to be reflected in the intended learning outcomes of the educational curriculum.

Especially in technology, we have faced continuously disruptive or incremental transitions that impact and drive research, education, business, work-life balance changes. This in turn affects the required expertise and skills and intended learning outcomes. In the past, those impacts were very narrow, influencing specific fields or business areas, and lasted for limited time. Now in the AI era, the change will cover all fields and have very diverse impact. Also, one special dimension is the timeframe of change. The AI related changes are typically very fast and involving multiple fast sequential changes implemented over a long period of time. The scale is so massive that it is impossible to fill the expertise gap on a global scale using new recruitment. In the AI transformation process, we need to understand a) how technology/AI will develop, b) how this evolution impacts this field, c) what it requires as an expertise, and d) how this transformation can be implemented with a high diversity of expertise to be integrated. It is relevant for the students to learn how to use AI efficiently for their work and how to communicate with it. The role of AI is also changing and increasing in time. One problem is that AI technology is developing extremely fast. In this development, it is relevant to see how people are able to give added value to the work of AI staying competitive in the working market. CBE is a very natural approach for studying challenges and solutions relating to the AI transformation. One strength in this approach is also easy integration of several disciples together solving the problem and considering multiple angles in the solution.

To adequately prepare students for CBE, a diverse array of skills and knowledge tailored to each student's background and academic/work discipline is essential. Not every student needs to master all the skills required; however, each working group collectively should. Effective communication within the group is crucial, allowing students to share their expertise and contribute to solving the challenge. A solid understanding of technological development, its challenges, impacts, and the causalities in the domain characterized by digitalization, artificial intelligence, and robotization is an excellent starting point. In this context, we focus on maritime operations.

Students must establish a comprehensive and forward-looking vision of the domain and technology in order to effectively address the challenge in the right context providing sustainable solutions. Sustainability should be considered from environmental, technological, economic, and social perspectives. The vision-building process begins with an understanding of key technological trends and their implications for the field's development and the renewal of students' expertise. Challenges often require such a broad range of expertise that no single individual can possess it all. Therefore, learning to critically retrieve, analyze, and synthesize information and collaboratively produce new knowledge is a necessity in addressing multidisciplinary challenges. It is essential that students are able to go deeper into the content and see things from different peoples' angles, not only divide the work between each other. Students must be able to discuss their own topics and fields with others in student/layman's terms.

The process commences with defining the challenge and culminates in its implementation. For this process several concepts and platforms exist. For more than 10 years, the CDIO framework — Conceiving, Designing, Implementing and Operating systems and products — has been utilized to guide this process in the field of engineering (Malmqvist et al., 2020). Students benefit from preparing for a multifaceted innovation process or at least separately multifaceted approach and thinking, and innovation processes. It is essential to recognize that problems should not be approached from a single perspective; for instance, engineers should not design systems solely from a technological standpoint aimed at other engineers.

The educational outcomes to the students clearly are the obtained new expertise and skills, and the reached sustainable solutions provided to the identified challenge. This also provides a platform for continued renewal of curricula and teachers' expertise. In general, when a challenge is approached from multiple perspectives by a multidisciplinary team, involving students, teachers and industry professionals, peer learning takes place. Participants will learn to see the challenge from a wider perspective, deepen their knowledge of the subject and also learn from each other. The role of the teacher is to enhance this kind of dialogue and open communication to harness the knowledge and competence of the team participants. Furthermore, even though the teacher is an expert within his/her subject field, it might be that the teacher will not be an expert of the whole context of the challenge. Therefore, the role of the teacher changes from teaching the actual subject to more of being the person who guides the actual challenge solving process operating more as a coach than a subject expert sharing information. In CBE, addressing the challenge needs to be consistent to ensure that the whole process is proceeding systematically from challenge formulation towards the wanted end result and an innovative solution, hence providing guidance, support and supervision, which requires preparedness from students and teachers alike.

In CBE, both the targeted end result and the main objective is an innovative solution. In the engineering education programs represented by the authors, students are prepared for embracing CBE by building on their ability to accept some levels of uncertainty is needed along with the ability to adapt as the process proceeds. This is achieved through individual and group work project courses where the assignments are open-ended and require the students to accept that a need for changes is likely to emerge. The outcome is students with a mindset for understanding that even though there are good plans made in the beginning, these might have to change according to situational needs. This also includes teaching methods and tools as well as the educational infrastructure where the teacher manages and guides the CBE process with different pedagogical methods and a multidisciplinary team where participants have different backgrounds. The CBE process is also a learning process for the teachers as well as for the students, which gives both an opportunity and a requirement for constant learning, adaptability and renewal.

CONCLUSION

In this paper, a systematic definition for challenge based education (CBE) in the autonomous shipping context was presented. We compared the new CBE definition with problem based learning. For CBE, we identified three main phases: 1) engage, 2) investigate, and 3) act. The presented CBE definition promotes multidisciplinary collaboration towards multifaceted innovation processes. We highlighted the importance of systematically building preparedness skills for students through their studies before they start identifying and solving real-life challenges. The outcome is to provide new expertise, solutions and skills, but it also gives an excellent opportunity for continued renewal of curricula and people. Even though this paper focused on the autonomous shipping context, the presented definition for CBE is generalizable to all engineering fields. Similarly as for autonomous shipping, major subject students from other disciplines have an important role in incorporating their technological substance through participation in the challenges to induce development and transformation in the primary field of engineering targeted by the CBE process in question.

ACKNOWLEDGEMENTS

The authors received no financial support for this work.

REFERENCES

Ahvenjärvi, S. (2016). The human element and autonomous ships. *TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation*, *10*(3), 517–521.

Alop, A. (2019). The challenges of the digital technology era for maritime education and training. *2019 European Navigation Conference (ENC)*, 1–5.

Bolbot, V., Methlouthi, O., Chaal, M., Valdez, O., BahooToroody, A., Tsvetkova, A., Hellström, M., Saarni, J., Virtanen, S., Owen, D., Lei, D., & Basnet, S. (2022). Identification and analysis of educational needs for naval architects and marine engineers in relation to the foreseen context of maritime autonomous surface ships (MASS). *Aalto University publication series SCIENCE + TECHNOLOGY no. 2, Helsinki, Finland*.

Cicek, K., Akyuz, E., & Celik, M. (2019). Future skills requirements analysis in maritime industry. *Procedia Computer Science*, *158*, 270–274.

Emad, G. R., Enshaei, H., & Ghosh, S. (2022). Identifying seafarer training needs for operating future autonomous ships: A systematic literature review. *Australian Journal of Maritime & Ocean Affairs*, *14*(2), 114–135.

Hogg, T., & Ghosh, S. (2016). Autonomous merchant vessels: Examination of factors that impact the effective implementation of unmanned ships. *Australian Journal of Maritime and Ocean Affairs*, *8*(3), 206–222.

Hynnekleiv, A., Lutzhoft, M., & Earthy, J. V. (2020). Towards an ecosystem of skills in the future maritime industry. *Proceedings of Human Factors 2020*, 1–5.

Malmqvist, J., Rådberg, K., & Lundqvist, U. (2015). Comparative analysis of challenge-based learning experiences. *Proceedings of the 11th International CDIO Conference*, 87–94.

Malmqvist, J., Edström, K., & Rosén, A. (2020). CDIO standards 3.0–updates to the core CDIO standards. *16th International CDIO Conference*, 60–76.

Mogensen, J. (2018). Rethinking STCW education to cope with increased autonomy and autonomous shipping. *19th Annual General Assembly – AGA 2018 of the International Association of Maritime Universities (IAMU)*, 158–164.

Morariu, A. R., Tsvetkova, A., Hellström, M., Bolbot, V., & Virtanen, S. (2025). Investigating educational solutions in the field of autonomous shipping at Finnish universities. *Transportation Research Interdisciplinary Perspectives (accepted for publication)*.

Morariu, A.-R., Tsvetkova, A., Bolbot, V., Sandell, P., Salokannel, J., Saarni, J., Isoaho, J., & Virtanen, S. (2025). A challenge based education framework for autonomous shipping. *Proceedings of the 21st International CDIO Conference (accepted for publication)*.

Rådberg, K., Lundqvist, U., Malmqvist, J., & Svensson, O. (2020). From CDIO to challenge-based learning experiences –expanding student learning as well as societal impact? *European Journal of Engineering Education*, *45*(1), 22–37.

Sandell, P. (2024). AutoMare EduNet project and pedagogical choices for MET relating to autonomous shipping. *Proceedings of the International Maritime Lecturers Association (IMLA) Conference*, 1–8.

Sharma, A., & Kim, T.-E. (2022). Exploring technical and non-technical competencies of navigators for autonomous shipping. *Maritime Policy & Management*, *49*(6), 831–849.

BIOGRAPHICAL INFORMATION

Peter Sandell, Dr.(Econ), L.L.Lic in Laws, is Senior Lecturer in Novia University of Applied Sciences and a Deputy Average Adjuster in Finland. His current interests are maritime law, marine insurance Law, autonomous shipping law and maritime economics.

Johanna Salokannel is a lecturer and researcher in Novia University of Applied Sciences. Her research focus is on Autonomous, Intelligent and Remote maritime operations, human factors and safety management including competence needs for future seafaring and education.

Andrei-Raoul Morariu is a doctoral candidate in Embedded Systems at the department of Informational Technology of Åbo Akademi University, Finland. His research interest is maritime logistics, autonomous shipping, data lakes, and engineering education advancements.

Anastasia Tsvetkova, Dr.(Tech.), is an Associate Professor at the Laboratory of Industrial Management, Åbo Akademi University. Her interests are green technologies in maritime logistics and smart ports. Anastasia has over 10 years' experience in teaching and course design.

Victor Bolbot is a post-doc researcher at the Marine Technology group of Aalto University. His research interests focus on design, energy efficiency, educational aspects, safety and cyber-security assurance of complex and autonomous marine systems.

Jouni Saarni is a Development Manager at the Centre for Collaborative Research CCR, University of Turku. In an industry-academia research collaboration role he contributes to research in areas that bridge industrial change, maritime clusters and supplier networks and innovation.

Jouni Isoaho has been a professor with the University of Turku, Finland since 1999. His current research interests include security of autonomous systems and AI, human and societal cybersecurity, and smart technology and digitalization.

Seppo Virtanen, D.Sc.(Tech.), is professor of cyber security engineering at the University of Turku, Finland. His current research interests are on the application of AI and LLMs to network and cyber security, security of smart environments, and cyber security in societal processes.

Corresponding author

Peter Sandell
Novia University of Applied Sciences
Juhana Herttuan puistokatu 21
Turku, Finland
peter.sandell@novia.fi