*applied sciences*

MDPI

*Review*

# Challenges for the Education and Training of Seafarers in the Context of Autonomous Shipping: Bibliometric Analysis and Systematic Literature Review

**Toni Meštrović [1], Ivica Pavić [1], Mislav Maljković [1] and Andrej Androjna [2,*]**

[1] Faculty of Maritime Studies, University of Split, 21000 Split, Croatia; tmestrovi@pfst.hr (T.M.); ipavic71@pfst.hr (I.P.); mmaljkovi@pfst.hr (M.M.)
[2] Faculty of Maritime Studies and Transport, University of Ljubljana, 6320 Portorož, Slovenia
* Correspondence: andrej.androjna@fpp.uni-lj.si

**Abstract:** The maritime industry is undergoing a profound transformation with the integration of autonomous technologies, which brings new challenges and opportunities for the education and training of seafarers. This article aims to examine the evolving landscape of autonomous ships and its impact on maritime education, with a focus on the changing roles and responsibilities of seafarers. The levels of autonomy defined by the International Maritime Organization (IMO) provide a framework for understanding the evolution towards fully autonomous ships and highlight the changing roles and responsibilities of seafarers. Using a systematic review based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA), this study examines maritime education for maritime autonomous surface ships (MASS). Using Scopus, Web of Science (WoS) and Google Scholar, a comprehensive search was conducted to identify relevant studies focusing on seafarer training and the impact of automation in the maritime sector. The analysis included bibliometric assessments, historical reviews and a categorization of research topics. This systematic review contributes to a deeper understanding of the current state and trends in maritime education for autonomous shipping. The findings inform educators and industry stakeholders about the critical aspects of education and training needed to address the challenges and realize the potential benefits of autonomous technologies in the maritime sector. The inclusion of bibliometric analysis enriches the study by providing a comprehensive overview of the researchers.

**Keywords:** autonomous ships; maritime education; maritime training; literature review; bibliometric analysis



**Citation:** Meštrović, T.; Pavić, I.; Maljković, M.; Androjna, A. Challenges for the Education and Training of Seafarers in the Context of Autonomous Shipping: Bibliometric Analysis and Systematic Literature Review. *Appl. Sci.* **2024**, *14*, 3173. https://doi.org/10.3390/app14083173

Academic Editors: Vicente Julian Inglada and José A. Orosa

Received: 10 February 2024
Revised: 4 April 2024
Accepted: 7 April 2024
Published: 10 April 2024



## 1. Introduction

The maritime industry tends to adapt as technologies develop, consistently changing the nature of its operations and looking to use new technologies in many areas. Today's global maritime sector depends increasingly on digitalization, integration of operations, and automation [1]. In this context, autonomous technologies have gained prominence and have the potential to revolutionize the character of the shipping industry [2]. In order to remain competitive and innovative in the ever-evolving maritime sector, it is important to understand and capitalize on industry trends. The drivers of these trends are new technologies related to autonomous ships and maritime autonomy. The integration of autonomous technologies in the maritime industry suggests the need for an interdisciplinary education that combines traditional maritime skills with state-of-the-art technological expertise. This educational adaptation is important not only for the current workforce but also for future generations of seafarers entering this field to prepare them to capitalize on the potential benefits of autonomous shipping.

The degrees of autonomy defined by the IMO are [3]:

1. Degree one—a ship with automated processes and decision support: Seafarers are on board to operate and control the systems and functions on board. Some processes may be automated and temporarily unattended, but the seafarers are on board and can take control.
2. Degree two—a remotely operated vessel with seafarers on board: The ship is controlled and operated from a remote location. Seafarers are available on board to take control and operate the systems and functions on board.
3. Degree three—a remotely operated vessel with no seafarers on board: The ship is controlled and operated from a remote location. There are no seafarers on board.
4. Degree four—a fully autonomous ship: The ship's operating system is able to make decisions and determine actions independently.

Different types of autonomous ships are being developed for different purposes (ranging from ocean-going vessels to small units for internal shipping). The evolving degree of autonomy underlines the importance of considering the implications for education and training in the maritime industry, as technological advances require seafarers to have new skills and knowledge to adapt to changing roles and responsibilities. The MASS concept raises a number of issues, ranging from technical and technological to legal and even ethical aspects [4]. The development of MASS is very challenging and depends on the resolution of numerous technical issues, including a range of cybersecurity measures to ensure safe and efficient operations. Ship operations require the development of advanced automation systems integrated with sensors and communication devices supported by artificial intelligence. The integration of sensors, algorithms and communication systems is of the utmost importance for the interaction of the MASS with the environment and decision-making without the crew on board.

Although the MASS concept is still under development, it will bring about significant changes in many segments of the shipping industry. Many stakeholders from the shipping industry and academia will be involved in the development of the MASS concept.

Although the exact number of autonomous ships worldwide is not readily available due to the ongoing development and deployment of this technology, significant investments and pilot projects indicate a growing presence of autonomous vessels in the shipping industry. The market for autonomous ships is estimated to be worth United States dollar (USD) 3.9 billion in 2022 and is expected to reach USD 8.2 billion by 2030 [5,6]

The introduction of these ships into service will certainly lead to significant changes in the system of education and training of seafarers, as the ships will primarily be controlled from newly designed coastal centers. This will require new technical and organizational knowledge and skills from future seafarers or MASS operators, as well as from all maritime stakeholders.

Several research and development projects have been carried out to develop MASS, e.g., Maritime Unmanned Navigation through Intelligence in Networks (MUNIN), ReVolt, the Advanced Autonomous Waterborne Applications Initiative (AAWA), Yara Birkeland and the e5–Asahi Tanker project [4,7,8]. MUNIN was a project funded by the European Commission to develop a concept for an autonomous dry bulk carrier [4,7]. The ReVolt project aims to develop an autonomous 100 TEU container ship for short sea shipping. The AAWA project was launched to create a preliminary design for the next generation of advanced shipping solutions. The Yara Birkeland is the world's first totally electric container feeder ship, and the e5–Asahi Tanker project focuses on the development of renewable energy-powered commercial ships with a high level of automation [4].

As the application of the MASS concept poses significant legal challenges, a number of existing maritime conventions will be amended. In order to take a proactive approach, the IMO MSC proposed to conduct a regulatory scoping exercise (RSE) to determine how MASS can be incorporated into IMO instruments [9]. As part of the RSE, eight IMO conventions (including STCW) were selected for analysis [10]. The outcome of the RSE provides an assessment of the existing legal framework for MASS operations and guidance for future work in this area [11].

The article follows a systematic review methodology based on the PRISMA, a widely used and structured approach. We adapted PRISMA to answer specific research questions related to maritime training and education in the field of MASS.

We used three major search engines, Scopus, WoS and Google Scholar, to identify relevant studies. Originally, the use of Google Scholar was not planned, but the inclusion of this search engine became necessary because valuable scientific papers are included in that database. The screening involved assessing the title, abstract and content of publications to exclude those that were not directly related to seafarer training or that focused more on automation than autonomous ships. The eligible studies were further analyzed to select the most appropriate for a comprehensive review. We read the publications and determined their relevance to the research.

The final step consisted of a detailed analysis of the selected studies to answer specific research questions. For research question 1 (RQ1), we assessed the leading countries, leading authors, time periods and conceptual analysis through a bibliometric analysis of the scientific publications. In assessing the influence of each country, the researchers considered the total number of authors, which was weighted by the number of publications. For the historical analysis, the attention paid to the various topics of maritime education related to autonomous ships over time was determined.

For research question 2 (RQ2), we focused on the common themes and categories in research studies on maritime education related to autonomous ships. We divided the studies into four categories:

1. Maritime law and review studies;
2. Development and adaption of existing curricula;
3. Methods of training and techniques;
4. Surveys and studies of collaboration between industry stakeholders, educational institutions and training providers.

By categorizing the research studies into these four distinct themes, we aim to provide a structured framework for understanding the diverse landscape of maritime education and maritime training for autonomous ships. Each category represents an important aspect of the research and highlights different facets of educational practices, regulatory frameworks and collaboration in this rapidly evolving field. These findings contribute to a deeper understanding of the challenges and opportunities associated with preparing seafarers for the era of autonomous shipping.

We also examined the scientific methods used in these studies. The classification criteria included the aim of the publications, the methodology, the systems studied and the problems addressed.

We applied a rigorous systematic review methodology that includes comprehensive identification of studies, screening, eligibility assessment and detailed analysis to answer specific research questions related to maritime education and autonomous ships. The use of bibliometric analysis increases the depth of understanding and provides valuable insight into the research landscape in this area.

## 2. Methodology

Both quantitative and qualitative research methods were used in this study. For the quantitative data analysis, the PRISMA method [12] was used, i.e., a structured method for conducting a systematic literature review. It should be noted that there are numerous other literature review methods [13,14], but we preferred PRISMA because it is a widely used, systematic, and easy-to-follow method. Here, we adapted the PRISMA method to answer the research questions posed in the introduction. The information flow based on the PRISMA method is shown in Figure 1, and the steps are explained in the following sections. In addition, the VOS viewer 1.6.19 was used for both data analyses so that a visualization of the bibliometric networks was performed for the quantitative analysis, and the maps of the terminology networks were created based on keywords for the qualitative analysis.

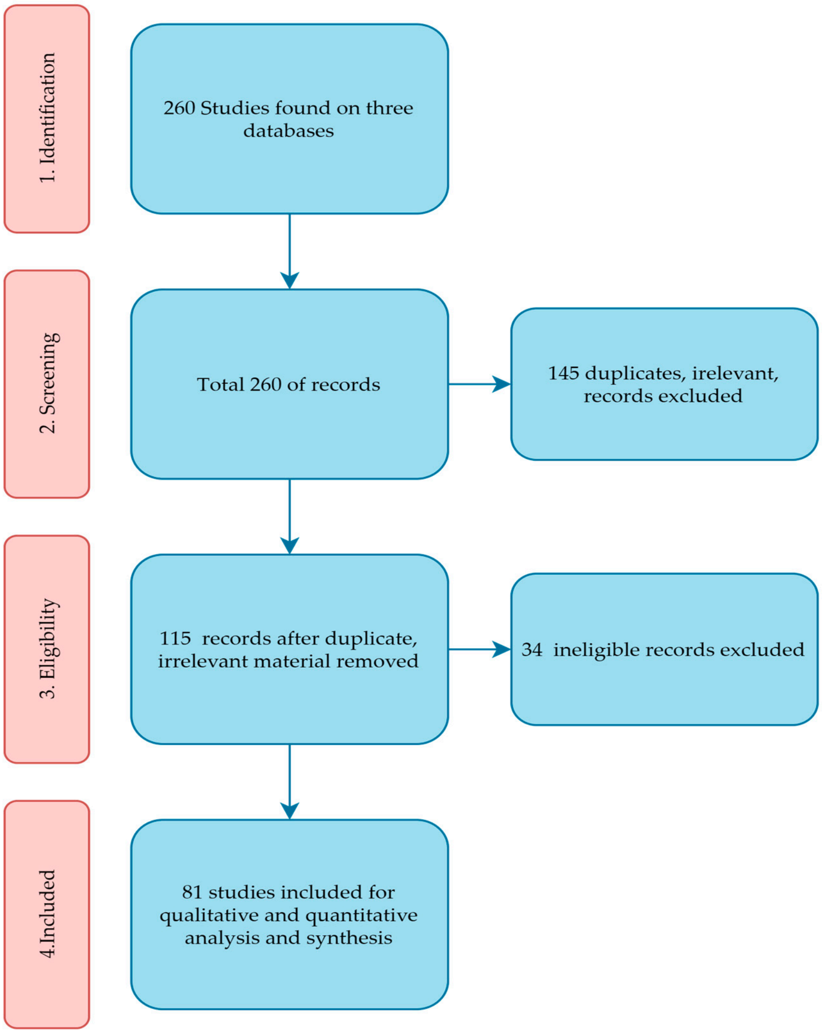


**Figure 1.** The information flow via the phases of the systematic literature review (Reported numbers valid as of 10 of October 2023).

### 2.1. Step 1: Identification of Research Studies

Relevant studies were identified using three major search engines: Scopus, WoS and Google Scholar. The selection of the search engines was based on their comprehensive coverage and reputation in the academic community. Scopus and WoS are known for indexing high-quality, peer-reviewed journals, conference proceedings and other scholarly publications, ensuring the inclusion of rigorously reviewed research in our study. Google Scholar, on the other hand, complements traditional bibliographic databases by incorporating a broader range of sources. We found 260 studies, as shown in Figure 1. In Scopus, we found 49 studies (19%), in WoS 141 (54%) and in Google Scholar 70 (27%). The lower number of articles from Google Scholar is due to the fact that we used only peer-reviewed studies. In Google Scholar, the number of articles on these topics was 1450 when the "reviewed articles" filter was not used.

The following generic keywords were used for identification:

- Autonomous ships;
- Maritime education;
- MASS ships;
- Autonomous vessels;
- Maritime training.

The choice of keywords in our study was based on a thorough consideration of the scope and objectives of our research. We wanted to identify and analyze relevant literature on the topics of "autonomous ships" and "maritime education", focusing particularly on the overlaps between these two fields. These keywords reflect the primary focus of our study and serve as the basis for our search strategy. We supplemented our primary keywords with related terms such as "MASS ships", "autonomous vessels" and "maritime training". With these additional keywords, we wanted to cast a wide net and capture all relevant literature that could not be explicitly captured by our primary keywords alone. The graphical analyses in Figures 2 and 3 demonstrate the value of the tool for recognizing the effective choice of the keywords "autonomous ships" and "maritime education" within the broader research landscape. By visually representing the semantic connections with the 30 most commonly used keywords, the VOS Viewer allows for a detailed examination of the keywords and overlaps that define the scientific discourse in these areas. This approach not only improves our understanding of the prevailing research topics but also helps to identify the potential areas of convergence or divergence within the overarching research framework.

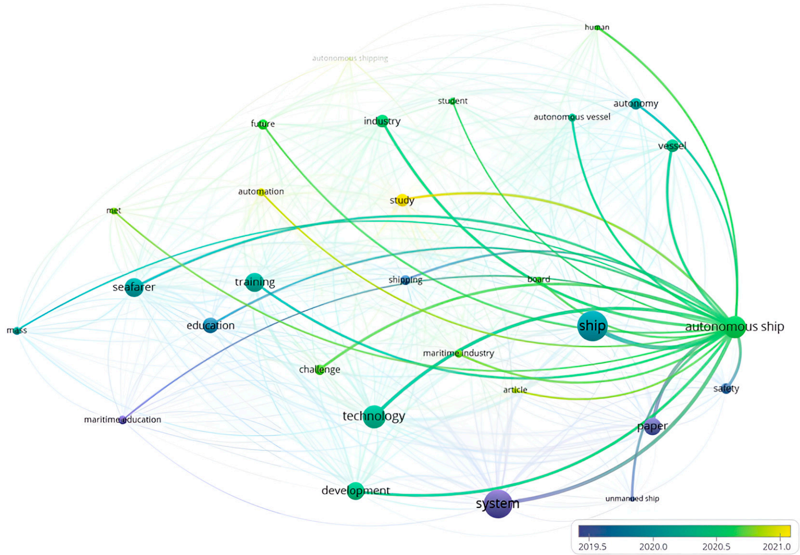


**Figure 2.** The link of the keyword "autonomous ships" with the 30 most used keywords in the research (VOS viewer).

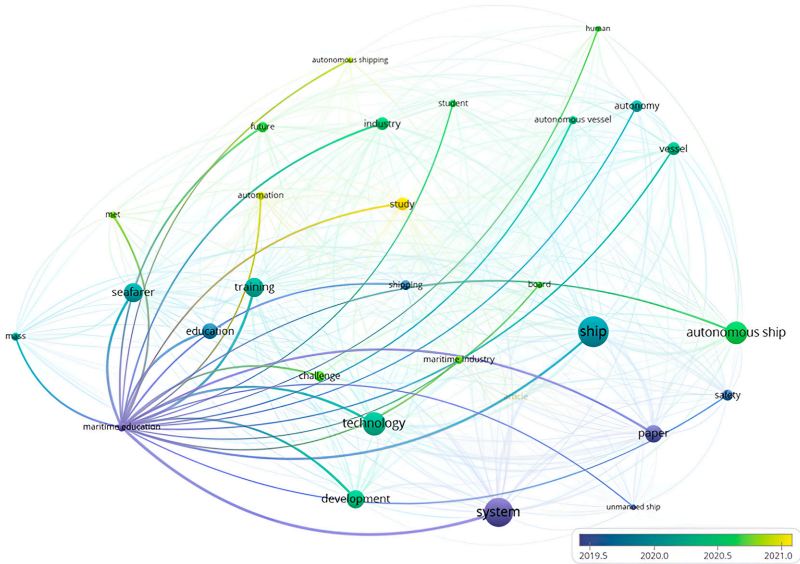


**Figure 3.** The link of the keyword "maritime education" with the 30 most used keywords in the research (VOS viewer).

### 2.2. Step 2: Screening of Research Studies

A screening was performed to reduce the number of identified publications and to perform a more thorough analysis of the most relevant publications. In this step, we read the title and the abstract of the publication and, if necessary, briefly reviewed the content of the publication. In this way, publications not directly related to the education of seafarers or related to automation rather than autonomous ships were excluded. Publications that were not available in English were also omitted. In addition, duplicate publications were identified and eliminated during this analysis step. Based on the screening, many of the originally identified research studies were excluded (retention rate of 115/260 or 44%). A limited number of relevant studies were unfortunately not accessible and had to be excluded.

### 2.3. Step 3: Eligibility Assessment of Research Studies

In the eligibility assessment, the screened studies were further analyzed, and the most suitable ones were selected for further processing. During this analysis step, we read the publications and determined their relation to the research. Some publications were outside the context of autonomous ships, i.e., they were not related to maritime education, so we discarded them. We were quite tolerant in this step and included a majority of the research studies reviewed in the analysis (81/115 or 70%). This approach was undertaken to incorporate the most comprehensive perspective into the analysis, ensuring an ample pool of data to address the research inquiries and facilitate the bibliometric analysis.

### 2.4. Step 4: Included Research Studies Analysis

In the final step, the eligible and selected studies were analyzed in more detail. Only these studies were used to answer the research questions. The analysis process is presented in the following sections.

> *RQ1: What are the leading countries, main authors, time periods and term analyses in maritime education related to autonomous ships based on a bibliometric analysis of scientific publications?*

In assessing the impact of each country, we considered the total number of authors who contributed to all the papers, where the number of individual authors was weighted by the number of publications in all 81 papers.

To explain our methodology, in this analysis, we assigned the contributions of authors from a given country to multiple articles based on the number of publications to which they contributed. In other words, if an author from a given country contributed to multiple articles (denoted as 'x'), their contribution was considered 'x' times. Thus, our approach was not to estimate the number of individual authors. Instead, we weighed the number of individual authors based on the number of articles they published, especially when evaluating their contributions to each country.

We have also carried out a historical analysis of the publications to determine the attention that researchers have paid to the different topics of maritime education related to autonomous ships. To this end, we used the results of the analysis presented in the next RQ (RQ2) to classify the studies and used the number of publications per year on each research topic to determine the historical trends. Microsoft Excel was used for this analysis.

Since the collection of articles included 81 documents, a bibliometric analysis using the open-source software VOS viewer [15] was considered feasible for the term analysis. For a term analysis, there is the full count method and the binary count method. In the full count method, the number of occurrences of a term in the articles is counted. In the binary count method, a score is assigned for whether or not a term occurs in an article, regardless of the number of occurrences. By default, 29 main keywords to be displayed in the images have been selected. This can be increased manually to include the entire set. Again, it is possible to display the entire network with all keywords or to look at the largest parts of the network. The full count method was chosen here to give more weight to the keywords that are mentioned more frequently.

Unfortunately, for the main authors and co-authors, we could not use the VOS viewer software, which would show the authors and co-authors in detail, because the software does not support the use of scientific papers from more than one source, and we used three sources, as mentioned above. For the authors and co-authors, we used Microsoft Excel for the analysis. We used the results of the analysis presented in the next RQ (RQ2) to classify the studies and used the number of publications per main author.

*RQ2: What common themes or categories are found in maritime education research studies related to autonomous ships, and what scientific methods are used in these studies?*

This was a more complicated part of our analysis because there is no simple approach to classifying research studies. After summarizing the studies under consideration, the classification was based on some criteria, such as the objective of the publications, the methodology used, the systems studied and considered, and the problems addressed. In this sense, the conceptual analysis presented was of great help since it was used to verify the different categories of studies for the classification, even if this information served more as a tool. In cases where the paper fell into two or more categories, we reassessed the most important contributions and the novelty of the paper before assigning it to a group based on the amount of text and effort devoted to a topic. We tried to find topics closely related to maritime education and autonomous ships. We obtained 4 relevant categories into which we classified 81 scientific papers.

As shown in Table 1, the classification of 81 scientific papers into four relevant categories in the field of maritime education and autonomous ships was carried out based on criteria such as the objectives, methods, systems studied and problems addressed, using the analysis as a guide.

**Table 1.** Categories of the studies in terms of education and training of seafarers for MASS.

| Category | Description |
|---|---|
| Maritime law and review studies | Explore novel concepts and potential legal regimes for new terms in this area; highlight relevant review studies and emphasize their novelty. |
| Development and adaption of existing curricula | Updating international conventions such as STCW to take account of autonomous ships; adaptation of the COLREGs for autonomous ships; and discussion of the associated challenges. |
| Methods of training and techniques | Exploring effective training for autonomous ship crews and operators that emphasizes generic skills such as quick learning and teamwork; concerns about job displacement and the technological impact on the maritime industry will be explored; analyzing the use of simulators and advanced technologies to combine theoretical and practical aspects in maritime training. |
| Surveys and studies of collaboration between industry stakeholders, educational institutions and training providers | Exploring challenges for educational institutions to close the skills gap through the development of infrastructure and innovative training programs. Looking at the seafarer's perspective shows that there are different opinions on autonomous technologies. The studies highlight the importance of addressing skills issues for future navigators in autonomous shipping. |

## 3. Results, Discussion and Outlook

### *3.1. Bibliometric Analysis of the Considered Studies with Respect to Leading Authors, Co-authorship Analysis, Leading Countries, Cluster Topics and Historical Trends*

The leading research countries based on the metrics considered (the weighted total number of authors and weighted number of first authors in the selected articles) are shown in Figures 4 and 5, respectively. Contributions made by countries such as Norway, Australia, Japan, Croatia and Poland contributed the most during the reporting period (the weighted total number of authors and weighted number of first authors in the selected articles).

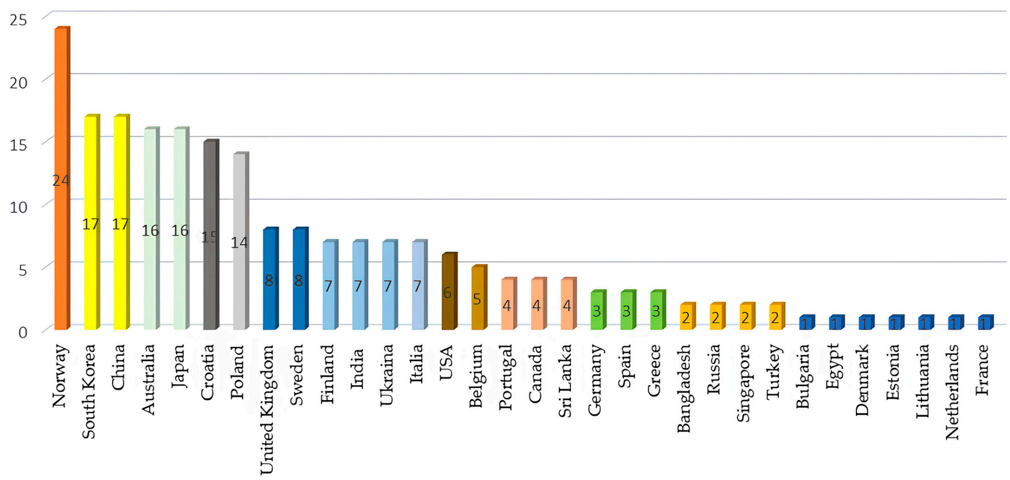


**Figure 4.** The total weighted number of authors by country.

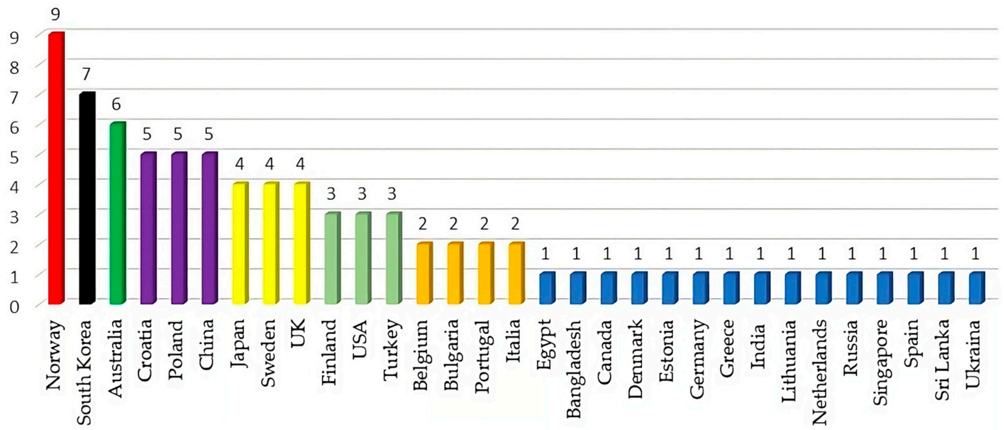


**Figure 5.** The weighted number of first authors by country.

The first 7 of the 33 (20%) countries finally identified (Norway, Republic of Korea, Australia, Japan, Croatia, Poland and China) have made the greatest contribution to research in the field of training and education of seafarers for MASS, based on the metrics (63% and 52% retrospective) and considering the selected publications.

The prominent positions of Norway, the Republic of Korea, Australia, Japan and China in both figures underline their important role in contemporary scientific research. Their constant presence in both figures indicates a robust research infrastructure and a culture of collaboration in these countries.

The high number of authors from these countries indicates not only their active participation in research projects but also the diversity and depth of expertise within their scientific communities. In addition, the significant presence of the first authors from these countries underlines their innovative capacity and leadership in promoting scientific research.

The analysis of historical trends is shown in Figure 6. The number of publications only began to increase in 2017, indicating that the research topic has only recently begun to receive adequate attention. The steady increase in the number of articles since then indicates the growing importance of this field. The diversity of topics and methods (which are discussed in more detail in the next section) being researched in the maritime community has been increasing over time.

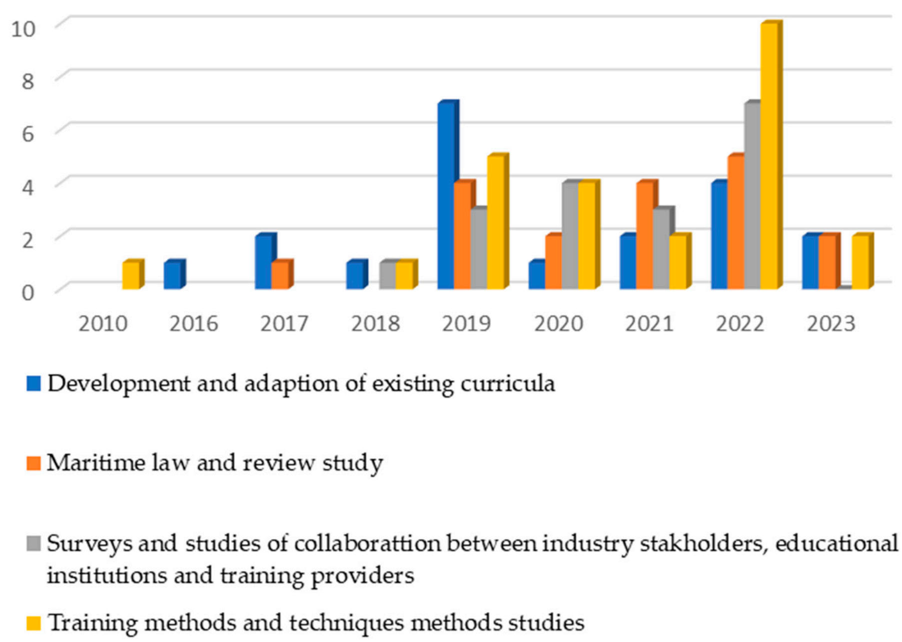


**Figure 6.** The analysis of historical trends.

Figure 7 shows the co-authorship. Of all the authors of the 81 articles, the authors to whom at least two articles belonged were selected. This resulted in 18 of the 190 (9%) individual authors meeting these criteria, suggesting that the vast majority of researchers produced a rather limited number of publications in the field of education and training of seafarers for MASS. The finding that only a small percentage of authors contributed to several articles indicates a broad engagement of different researchers in the field of education and training of seafarers for MASS. The data do not indicate a concentration of output from a small group of authors but rather a diverse and distributed network of contributors.

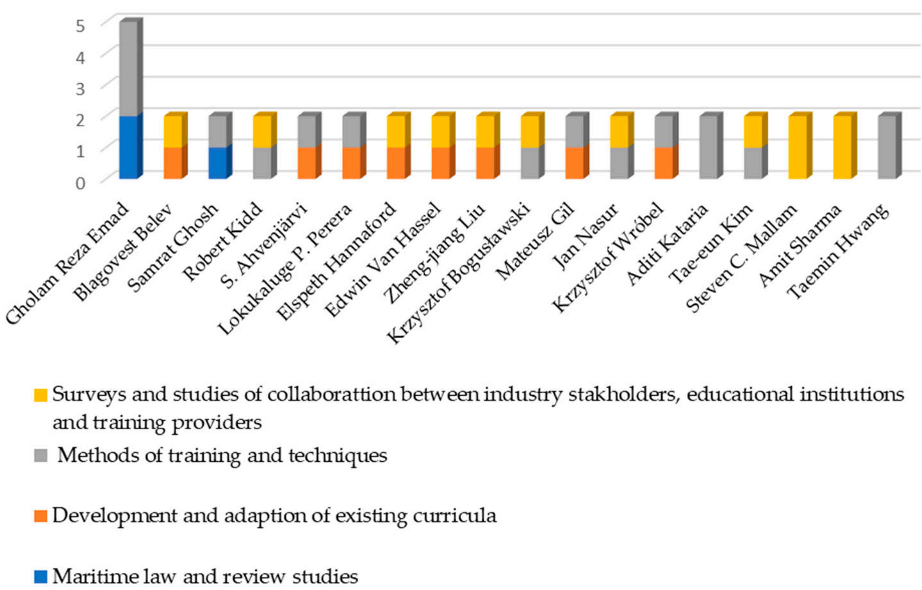


**Figure 7.** Authors with at least 2 articles.

Figure 8 shows the results of the analysis of the co-occurrence of terms. The full counting method was used instead of the binary counting method to give more weight to the more frequently occurring keywords. A total of 254 keywords were identified, from which generic terms were filtered out, leaving only 29 terms. The term analysis shows connections between terms (keywords) that frequently occur together. In addition to the obvious terms, such as ship, training, seafarer and paper, terms such as autonomous ship (automation and other variants), education, system and student also occur frequently. A closer look at the keyword analysis also shows that the researchers frequently discussed technology, systems, developments and the future. This suggests a comprehensive exploration of technical aspects, educational strategies and future implications in the discourse surrounding seafarer training for MASS.

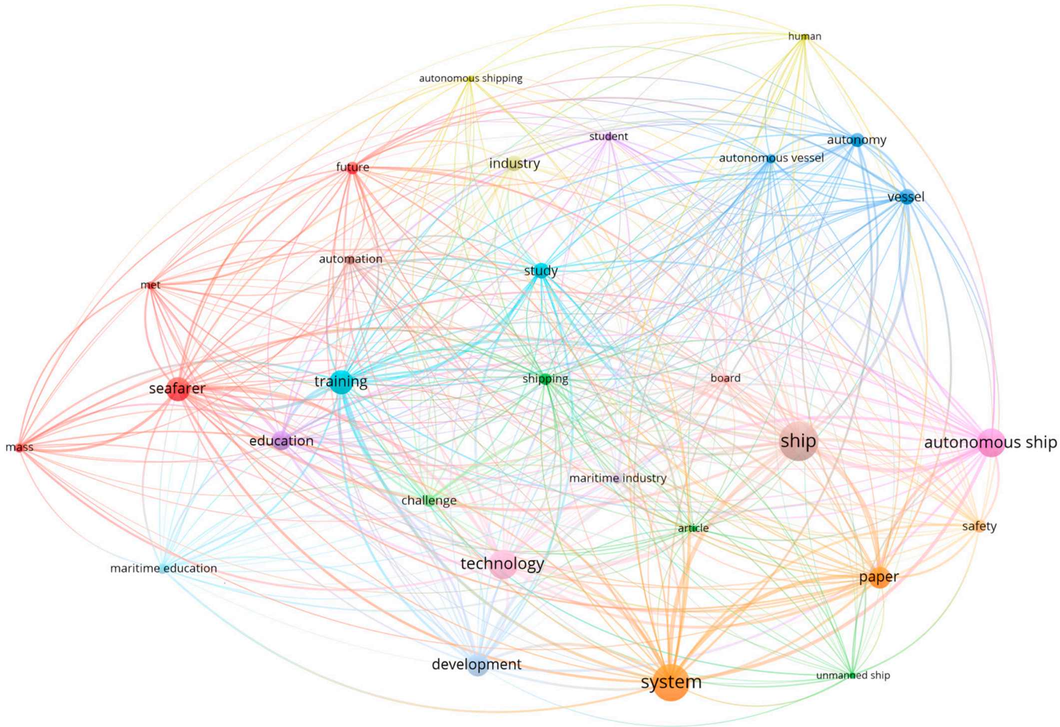


**Figure 8.** Term analysis map using full counting method, including 29 out of 254 keywords (VOS viewer).

### *3.2. Categories of Research Studies*

1. Maritime law and review studies—This category of studies has received much attention in research. Since the MASS is a new technology, legal scholars and lawyers are concerned with new concepts and the possibilities of legal regulation of new terms. The review studies were described in the introductory section of this article to establish the novelty of the present study, and therefore, the discussion of this category of studies will not be repeated here. We have linked the aforementioned scholarly work to develop the possibilities of the topic in the context of maritime education related to autonomous ships (18 papers were included in this section).
2. Development and adaption of existing curricula—These studies discuss the need to update international conventions, such as the International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW), to reflect autonomous ships. It also mentions discussions on adapting the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) for autonomous ships and the challenges involved. It highlights the importance of studying human–machine interactions between autonomous and conventional ships and the need for revised training and education programs (20 papers).
3. Methods of training and techniques—These studies address a number of issues, including the need for effective training methods for crew members and operators of autonomous ships, the importance of generic skills such as rapid learning and teamwork, concerns about potential employment disruption and the impact of tech-

nological advances on seafaring. The studies emphasize the need to adapt maritime training to the changing nature of work on board and to incorporate new knowledge and skills related to automated control systems. They discuss the potential benefits of autonomous technology, such as improved navigation accuracy and a shift to highly skilled service personnel. However, the studies warn against rushing the development of autonomous shipping and emphasize the importance of gradual and well-planned development to ensure safety and cooperation between seafarers and automation experts. In addition, the studies look at the use of simulators and modern technologies, such as augmented and virtual reality, to improve training and close the gap between theoretical and practical components in maritime training (27 papers).

4. Surveys and studies of collaboration between industry stakeholders, educational institutions and training providers—The studies discussed in this section examine the transformative impact of autonomous technologies on the maritime industry. The researchers examine the challenges arising from the integration of autonomous systems and emphasize the need for educational institutions to proactively close the skills gap through the development of infrastructures and innovative training programs. The perceptions of seafarers are analyzed and show that there are differing opinions in regard to autonomous technologies, including concerns about employment stability and trust in the systems. The studies also highlight the competency issues that are important for future navigators in autonomous shipping, as well as the importance of adapting leadership practices and competency requirements to the evolving technological landscape (16 papers).

As can be seen in Figure 9, the analysis shows that the focus in maritime education in relation to autonomous ships is primarily on maritime law and revision studies, highlighting the need to adapt existing curricula and training methods to effectively address the evolving challenges and opportunities of autonomous shipping.

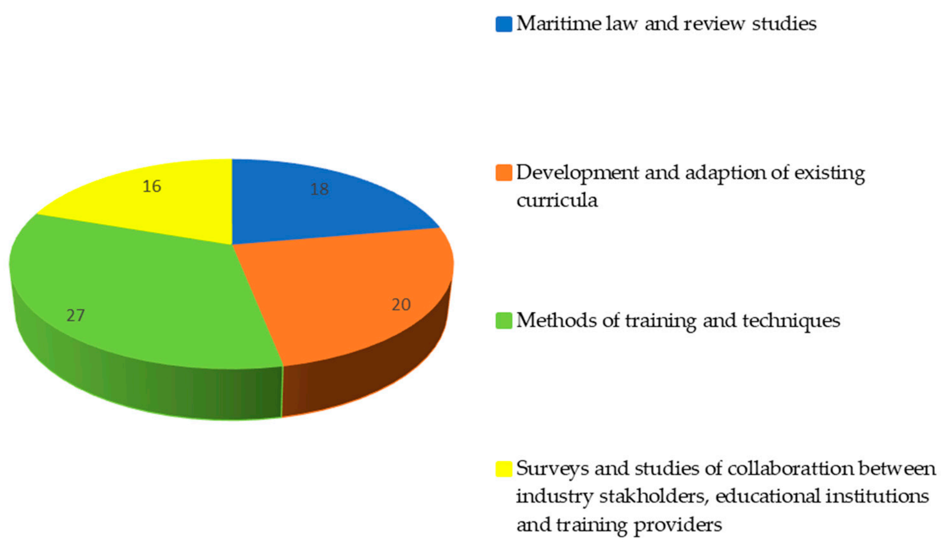


**Figure 9.** The number of studies in categories of research.

### 3.2.1. Maritime Law and Review Studies

The intersection of maritime law, terminology, regulatory requirements, safety and legal issues has received little research attention. The few studies we have found are presented below.

The introduction of autonomous ships, exemplified by projects such as Dittmann's [16], offers a transformative solution to key challenges in the maritime industry, promising lower operating costs, better environmental practices and reduced human fatigue. Despite the potential benefits, the lack of international rules and regulations for these innovative ship designs is a regulatory hurdle that must be overcome in order to fully realize the efficiency gains, human resource improvements and accident prevention associated with the widespread use of autonomous ships.

The STCW Convention sets out the minimum requirements for education and training that must be met by the signatory states to the Convention [17]. The Convention, therefore, defines the concept to which states must adhere. The differences may be technical as well as the implementation aspects at the level of the states and their training organizations. At this stage, it is not possible to predict how a future convention will regulate the training of MASS personnel.

The STCW Convention applies to seafarers on board seagoing ships. Therefore, prima facie, the STCW Convention does not apply to an autonomous ship. However, since the purpose of the Convention is to promote the safety of life and property at sea and the protection of the marine environment, it is foreseeable that the Convention will be extended to shore personnel [18]. The fundamental question will be to explain and regulate the operations of coastal control centers, as well as to define the status of human resources, and to answer the question of whether they could be considered as crew members of the ship in order to accept and apply their obligations and duties determined by the STCW and other IMO instruments [19]. However, the STCW Convention, like the other regulatory instruments, has regulatory problems that apply to MASS and the remote operator (RO). Article 3 of the Convention states that it applies to "seafarers serving on board seagoing ships". There is currently no clear understanding in the STCW Convention about whether the RO is regarded as a master or a crew onboard [20]. IMO must adopt new regulations to deal with autonomous ships that do not have a crew on board. Finally, training and certification standards for remote onshore controllers will need to be added to the STCW [4].

In their article, Fenton and Chapsos [21] look at the current technological developments in the field of the unmanned MASS, examine the legal and regulatory challenges they pose and describe how the intergovernmental bodies (IMO) are dealing with the daunting task of regulating this new development in the maritime sector. The authors conclude that the IMO, as the umbrella organization for maritime transport, must issue new regulations through conventions or other legal means. In 2018, IMO began addressing the regulatory gaps by exploring how existing international regulations can be applied to autonomous ships and maritime technologies. Due to the number and scope of regulations involved, it is expected that the revision of existing regulations and the addition of new regulations for autonomous ships will take at least eight to ten years [22]. Any significant level of introduction of worldwide traffic for international unmanned cargo ships was estimated to take more than 40 years. This is due to a number of obstacles that, for many years, will have an impact on the choice for ship owners to adopt now or postpone the decision. Finally, the estimated periods show that the profession of seafarer will still exist in the near future. The content of the profession will, of course, change depending on the phase of implementation of the degree of digitalization, but there will always be a need for maritime knowledge and understanding. This calls for careful updates of curriculums in maritime academies concerning specific competence requirements related to different concepts and combinations of the types of ships and traffic areas [23].

The IMO has now taken a more proactive and leading role in MASS due to the rapid technological developments in recent years. The Maritime Safety Committee (MSC) and the Legal Committee (LEG) have now agreed on regulatory scoping exercises and gap analysis to see if, where, and how unmanned ships will fit into existing maritime conventions and regulations [24].

In the article by Vojković and Milenković [25], the responsibility of the master was examined across four levels of automation, accompanied by an exploration of the legal possibilities to address the issue of legal responsibility. It was also found that the legal terminology related to autonomous and remotely operated vessels is still insufficiently developed. In conclusion, the researchers emphasized the urgent need to adapt legislation to technical progress in the shipping industry, especially in the context of remote-controlled and autonomous vessels, while pointing out the paramount importance of safety.

Review studies allow us to see how much a topic and technology evolve in practice, i.e., how many studies have been conducted on it so far. The topic of education related to autonomous ships is very narrow, and few researchers have conducted review studies to date.

However, as the systematic literature review suggests, autonomous shipping and the research relevant to future seafarers' training is very limited; thus, this paper reflects on how Industry 4.0 has led to the modification of training programs for personnel in four selected industries [26]. In their study, Shahbakhsh et al. present all sectors of transportation and their connection to automation. Industry 4.0 is naturally linked to Shipping 4.0, i.e., autonomous ships in this sector. To be prepared for the future of shipping, it is important to know the different aspects of Shipping 4.0 or autonomous and unmanned ships in the age of Industry 4.0. Evolution through each industrial revolution highlights the relationship between environmental needs, industrial revolutions and educational changes [27].

Based on a literature review, Munim and Haralambides [28] conclude that maritime education and training (MET) in the countries that serve the world's seafarers must adapt their curricula to include training for MASS operations through remote control centers. Machine learning and artificial intelligence models are of great help to facilitate training. Machine learning and artificial intelligence are actually two important factors in the digitization of the industry. These technologies have become remarkable and continue to be at the forefront of the successful implementation of the fourth industrial revolution (I4.0) [29].

The Tuerkistanli review study [30] conducted an in-depth review and bibliometric analysis of the advanced teaching methods in the field of MET and showed a steady increase in publications, especially under the influence of regulatory bodies such as the IMO and STCW. The challenges in disseminating different perspectives within research on advanced teaching methods in MET highlight the need for regulatory changes to accommodate innovative approaches, especially in response to disruptive events such as the COVID-19 pandemic.

After a comprehensive literature review and evaluation of the existing research, it is clear that there is a significant gap in meeting the demand for MET in autonomous ships. The main focus is on identifying the essential skills and competencies required for future crews. Despite challenges such as regulatory barriers [31], it is crucial for maritime universities, colleges, training institutions and authorities to actively follow the progress of MASS. It is imperative that they contribute by creating relevant knowledge, improving maritime education and attracting talent capable of leading the development of navigation technology [27].

#### 3.2.2. Development and Adaption of Existing Curricula

Over 1.2 million people are directly employed in the shipping industry as seafarers and port workers. If logistics, supply chain management and other shipping-related businesses are included, the figure increases to tens of millions worldwide.

Although there is a major potential benefit, the autonomous system, however, brings challenges in the maritime domain, especially for seafarers [32]. As technology advances, seafarers must adapt to evolving maritime practices by acquiring digital skills and mastering automated systems. This change requires a comprehensive reassessment of training programs to ensure that seafarers are equipped for the complexity of modern maritime operations. Subsequently, the seafarer's job profile in the traditional work environment will be transformed and will require seafarers to be qualified with a new set of skills and competencies [33].

Ongoing digitalization requires the development of a trustful dialog between educational and training institutions, in addition to the promotion of education and training. The development of qualified personnel will be the main task of the future [34]. Investments not only in hardware and software but also in human resources will secure and create many maritime jobs, even if their profile will change dramatically.

The STCW is an international maritime convention that establishes minimum standards for the training, certification and watchkeeping of seafarers [17]. It is the most important document for the education and training of seafarers. With the advent of autonomous ships, they will certainly need to be amended and supplemented. The quality of the maritime education system can be considered one of the most important pillars for safe and efficient shipping. The scientific problems related to the education and training of seafarers for MASS primarily revolve around developing curricula that combine traditional maritime skills with new technologies, ensuring competence in the use of autonomous systems, and addressing safety and regulatory issues in an autonomous ship environment. In addition, research is needed to understand the psychological and behavioral aspects of the transition to autonomous ships and to optimize human–machine interactions on board. These challenges make the topic of training and education an attractive research problem for MASS, as it is interdisciplinary and has the potential to shape the future of the maritime industry.

Of particular importance is maritime education at the college level and training that ensures seafarers a first-class qualification in accordance with the STCW Convention [35]. Several articles explore and discuss the modernization of the STCW convention. Vidan et al. conclude that it is necessary to adopt a global and unified regulation for training, education, certification and watchkeeping that considers all the opportunities and challenges that autonomous ships bring. Certainly, it is necessary to maintain and apply the existing regulations of the STCW Convention until a new or amended set of regulations is adopted [36]. In addition, it is recognized that there will be different levels of education and training for support, operational and management levels on autonomous ships in the future (as required by the STCW Convention) [37]. The STCW, which governs the MET system, is primarily based on existing requirements but is not forward-looking. The STCW should be constantly revised by the IMO in light of new policy guidance [38]. STCW sets out the minimum requirements for the training of seafarers and has governed the training of seafarers worldwide. The Convention has subsequently been updated several times due to its limitations. The most recent revision, the Manilla Amendments, was adopted in 2010 to address issues anticipated in the near future [39]. The STCW Convention, which is critical to the regulation of seafarers' standards, needs to be updated in a timely manner to reflect technological advances, environmental concerns and the changing landscape of global crises, especially considering that it has been 13 years since the last amendments. These revisions should include modern technology, mental health provisions, pandemic preparedness and increased cooperation to ensure that the Convention remains relevant and effective in protecting the welfare and professionalism of seafarers.

COLREGs convention is a set of international rules and regulations designed to ensure the safe navigation of ships at sea [40]. These rules were developed by the IMO to minimize the risk of collisions between ships, especially in areas of heavy maritime traffic. The COLREGs provide a standardized set of rules that all seafarers must follow, regardless of their nationality or the flag their ship flies. Several papers examine the connection of autonomous ships with the COLREGs' rules. Currently, there is no unanimous answer on how instruments such as the COLREGs for autonomous ships should be changed, if at all, but it is an important topic of conversation in the maritime industry. It is expected that the first-generation autonomous ships should follow the existing rules and regulations of the COLREGs due to the mixed environment [41]. Hannaford, Maes and Van Hassel [42] conducted a survey of experienced sailors, and the results show that there are many obstacles to implementing the COLREGs with autonomous ships. The original COLREGs were preferred by the majority of participants for most rules, but minor changes were preferred for some rules. A similar survey was also conducted by Zhou et al. [43]. The results of the authors' survey show that there are no insurmountable obstacles to the operation of autonomous ships in the COLREGs' rules. However, further elaboration and revisions should be made to remove uncertainties in interpretation. When rearranged, the current COLREGs can be divided into provisions for information gathering and decision-making. Since the primary objective of the COLREGs is to protect human life by avoiding collisions, each provision should be considered with autonomous ships in mind [44]. Vagale et al. [45] believe that it is of great importance to study in depth the human–machine interactions between autonomous and traditional ships in order to prepare for a future in which autonomous and traditional ships will operate side by side. Therefore, it is necessary to revise the education and training scheme for the seafarers who engaged in MASS to ensure the ship's safety navigation [46]. Batalden, Leikanger and Wide [47] conclude that the COLREG convention and rules are outdated and were developed primarily based on the technology available at the time they were adopted, so a new convention may be needed to address collision avoidance when autonomous operations are introduced. According to Wrobel et al. [48], addressing the challenges of autonomous collision avoidance at sea requires a comprehensive and collaborative approach that involves stakeholders from industry, academia and practice, emphasizes the need for a thorough integration of all COLREG rules into the collision algorithms, and explores the development of artificial intelligence capable of understanding the explicit aspects of navigation at sea while enabling effective human–machine interactions.

In his article, Kim [49] considers factors such as "narrow channels", "collision avoidance" and "restricted visibility", recommends specific criteria for the application of navigation rules and points out the need for new equipment. He highlights the existing practice of communication between traditional ships and approaching ships and emphasizes the need for future research on ship navigation information and effective methods for fully autonomous ships.

Ahvenjarvi [50] emphasizes the continuing importance of the human element in autonomous ship technology, particularly in areas such as software development and safety testing. He highlights the impact of autonomous ships' behavior on conventional ship officers and underlines the importance of user-centric design for the remote control center of autonomous ships. Ahvenjarvi also recognizes the resilience and adaptability of ship officers as a potential advantage over fully autonomous systems. Ventikos and Louzis [51] emphasize the need to combine proactive safety approaches, inspired by the memory property of the immune system with experiential learning to effectively manage the risk knowledge associated with autonomous ship operation and traditional ships, with the aim of preventing accidents and improving risk management in maritime systems.

Fonseca et al. [52] conclude that automation is challenging the traditional role of manned ships and that the maritime industry must adapt to a changing socio-technical environment. The authors emphasize the importance of continuous review, collaboration and a holistic framework that integrates technical, human capital and economic aspects to ensure the efficiency, safety and versatility of MET programs for future seafarers.

Demirel [53] highlights the significant technological knowledge gap between older generations, who received their education decades ago, and younger generations, who are accustomed to the everyday use of computers. He underscores the urgent need to introduce comprehensive training in automation, operations and safety-critical systems for both age groups and, in particular, emphasizes the importance of preparing cadets for the coming era of unmanned, autonomous ship operations by equipping them with the necessary knowledge in robotics and automation. The education sector is strongly influenced by economic needs and experiencing nonlinear dynamics due to the technological boom. It has led to the emergence of new professions and qualifications while existing professions are being phased out. The task of integrating highly autonomous ships with conventional ships is a major challenge for maritime education systems, which underscores the importance of adapting maritime education and its skills as a first step to addressing the complexity of the modern environment [54].

#### 3.2.3. Methods of Training and Techniques

The rapid integration of autonomous and remote-controlled ships into the maritime industry requires a profound development of seafarers' skills. As the Warsash MASS

Research Center points out, technological advances require a comprehensive analysis of the human–machine interface and a shift in the training of seafarers to the remote operation of ships [55]. The Australian Maritime College (AMC) searches for a proactive approach to developing training on autonomous maritime systems, including a proposed addition to the Maritime Training Package and a MASS Mate/Master' course, which responds to the industry's pressing need for standardized and forward-looking training [56].

Training methods and techniques for autonomous ships should be designed to effectively instruct crew members, operators and other relevant personnel in the operation and management of these advanced ships. It should be adapted to the specific needs and roles of the individuals being trained and to the type of autonomous ship technology being used. In shipping, in addition to the need for good practical training, the importance of general employee skills, such as fast learning and independence, good communication skills and the ability to work in a team, was also emphasized [57]. The future of seafaring depends on adopting autonomous governance solutions, addressing the concerns of future seafarers about possible job displacement and promoting skills diversification to ensure a sustainable maritime industry while recognizing the uniqueness and subjectivity of the responses in this specialized field [58]. As the automated control system and decision support system are widely used, new knowledge and skills need to be incorporated into the existing training [59]. The introduction of crewless technology is expected to improve the accuracy of ship navigation by eliminating human factors and providing uninterrupted information on ships' positions and movement parameters. While there are concerns about potential unemployment, there is a shift towards highly skilled service personnel for the maintenance and repair of automated control systems. Overall, automation simplifies ship control through ready-made software solutions that conform to the MASS concept to reduce operating costs, address the shortage of skilled seafarers and utilize the mathematical models of ships for practical navigation tasks [60].

Stefani and Apicella [61] emphasize the transformative potential of digital technologies to improve the safety and efficiency of ships and propose a comprehensive educational model by the Italian Maritime Academy. The model emphasizes sustainability, hard skills in modern technology and soft skills, with a focus on cybersecurity. The aim is to train the next generation of seafarers capable of piloting future ships, even remotely from shore-based control centers.

Hwang and Youn's study [62] emphasizes the growing importance of effective training for remote operators of autonomous ships. The authors propose the use of a permutation model to create diverse and practical navigation scenarios to close the gap in training time compared to conventional navigators and to ensure the empowerment of future remotely piloted operators, with the potential for a further expansion of research into additional navigation elements and scenario creation. The ongoing transformation of maritime operations towards increasing automation and digitalization requires a re-evaluation of maritime education and training and the introduction of a new conceptual approach, such as quasi-communities (QC), to foster supportive learning environments for future ship operators that adapt to the changing nature of work on board and technological advances [63].

Lušić at al. [64] assume that the maritime industry will face a growing demand for shipping and maritime personnel, with an emerging shortage of maritime officers due to different training approaches and the changing nature of seafaring under the influence of technological progress. This requires a shift towards standardized higher education programs and a focus on preparing future personnel for sophisticated and potentially autonomous ships through the timely development of curricula and continuous investment in lifelong learning and requalification to ensure a high-quality workforce. Kuneida et al. [65] examined Groupwork-Training-Groupwork-Presentation (GTGP), and they concluded that while knowledge of artificial intelligence is critical in the context of MASS, seafarers still need to have essential skills such as spatial awareness, critical thinking and quick decision-making. These skills can be enhanced through the GTGP training model, which combines actual onboard training, group work and presentations to prepare maritime personnel to master AI and not just rely on it. The system proposed by Martelli [66], combines augmented and virtual reality with machine learning for autonomous surface ships. It holds significant potential for dynamic collaboration in the maritime sector by addressing the challenges of using AI algorithms through improved information gathering and visualization.

While the transition to autonomy is a promising objective, it must be approached cautiously to avoid potential accidents and setbacks that can result from rushed development, as was the case with autonomous cars. The industry's historical reliance on backup systems underscores the need for a gradual and well-planned evolution towards autonomy that involves collaboration between seafarers, automation experts, lawyers and educators to create a realistic timeline that considers technological advances and modern training of seafarers to ensure safer shipping for the present and future [67].

Lokuketagoda et al. [68] point out that the historical philosophy of marine engineering education, with its emphasis on separate theoretical and practical training, has led to a disconnect between theory and practice, hindering the development of critical thinking and problem-solving skills that are crucial for future marine engineers operating autonomous ships. The authors propose the use of modern simulators in the engine room to bridge this gap and integrate theoretical and practical components in training and assessment; in this way, future remote operators will be able to deal with complex operational and emergency situations and ultimately ensure the safe operation of autonomous ships without the need for repairs and maintenance on board.

Kim, Park and Cho [69] aim to address the challenges of reinforcement-based learning (RL) in autonomous ships by proposing an intelligent learning system that reduces the learning time and costs and enables autonomous ships to adapt efficiently to the real marine environment.

Bartuseviciene [70] concludes that the feasibility of autonomous shipping is recognized due to the acknowledged safety, financial and social benefits in the maritime industry. However, successful implementation requires overcoming the emerging challenges in terms of legal, commercial, technological and human factors through proactive adaptations in the MET, as well as the creation of international, regional and national regulatory frameworks and the continuous improvement in instructors' competencies.

Simulators are used by some researchers as a training tool to prepare people for careers related to autonomous ships. Minami et al. [71] emphasize the importance of the safety assessment for autonomous ships through a scenario-based approach that includes normal and emergency situations, physical principles for incident scenarios, a fast time ship simulator (FTSS) tool, as well as the importance of a simulator for handling ships at full speed. In a technologically saturated future for the maritime industry, cloud-based simulation training is a promising means of preparing marine engineers and operators. However, issues of accessibility, cost and harmonization of training experiences in different environments need to be addressed in order to successfully integrate it into future maritime education and training [72]. Smirnov and Tomforde [73] present a proof-of-concept for agent-based simulations in real maritime environments. Although more work is needed to integrate a full motion model with six degrees of freedom and overcome the limitations of continuous action space algorithms, the results of this study show promise for advancing autonomous ship navigation through a combination of deep reinforcement learning and supervised learning that is based on historical data and collision avoidance mechanisms. Sandaruwanin et al. [74] experimentally evaluate an algorithm for simulating ship motion with six degrees of freedom. It shows different capabilities compared to the existing methods and achieves satisfactory predictions in terms of waves, sway and yaw; while there are limitations in pitch and heave, the system demonstrates its effectiveness in virtual maritime learning and training and offers a cost-effective alternative to traditional ship maneuvering training with a potential application in maritime education.

In their article, Ahvenjaervi et al. [75] conclude that the rapid development of shipping technology poses a challenge for maritime education providers and necessitates an adaptation of competence requirements for professionals. Satakunta University of Applied Sciences is addressing this challenge with ISTLAB, a simulator-based laboratory, demonstrating a proactive approach to research and education that is aligned with the evolving landscape of smart shipping technology and anticipates future skill requirements in collaboration with international partners. Perera [76] discusses a comprehensive framework to support navigation in autonomous ships and emphasizes the importance of integrating deep learning-based ship intelligence for decision-making. Felski and Zwolak [77] conclude that the maritime community, which includes both research and industry, is actively advancing the integration of unmanned systems, including autonomous ships, into maritime operations. Despite varying levels of control, ranging from remote control to near complete autonomy on prototype ships, the successful introduction of this technology must consider the safety concerns regarding equipment, cargo and seafarers.

Kakarkostas [78] presents the current advances and challenges in the field of autonomous ship technologies, highlighting the lack of a comprehensive framework that encompasses technical, human and legal aspects. He highlights the complicated dynamics of navigation coordination and emphasizes that autonomous ships must make decisions on their own, especially in collision avoidance, while understanding and responding to human-operated ships. The discussion further addresses the integration of machine learning into simulation environments for crew training and points to the need for more sophisticated, intelligent agent-based simulations to prepare for the evolving landscape of autonomous shipping.

The future success of the shipping industry depends to a large extent on effectively addressing the challenges associated with autonomous shipping, such as training [79]. Emad and Gosh project [80] that preparing for the age of autonomous navigation is a major challenge. The authors note that there is a gap in preparation and uncertainty in training and skills, and he emphasizes that traditional maritime skills are still needed and points to the complex task facing the IMO as it attempts to write regulations, education and training to address the absence of the human element. At present, there is no definitive clarity in theory and training as to what the future autonomous ship operators might be in terms of their responsibilities, competencies, etc. [81].

#### 3.2.4. Surveys and Studies of Collaboration between Industry Stakeholders, Educational Institutions and Training Providers

Education must follow technological and social developments, both in terms of curricula and methods. Only in this way will it be possible to provide today's students—tomorrow's professionals—with the skills that will enable them to respond to the future challenges of their respective sectors [82]. Rapid advances in autonomous systems technology, characterized by ongoing pilot projects and the development of full-scale autonomous ships, have meant that the obstacles are no longer primarily technological but also include human–technology dynamics and emerging regulatory, liability and safety concerns. While autonomous technologies are advancing, challenges remain in areas such as system trust, decision predictability and the skills required to develop, operate and maintain them, highlighting the need for a nuanced understanding of the role of humans in the development of complex and safety-critical maritime systems [83].

Kid [84] highlights that while the maritime industry expects a revolutionary shift towards autonomy, the lack of consensus on how this should be implemented is leading to uncertainty about the skills required, making academic institutions reluctant to fund training programs. To close the projected skills gap in engineers familiar with both traditional maritime operations and automation, academic institutions must make proactive efforts to build infrastructure, develop cost-effective programs and explore high-tech training initiatives to prepare the next generation for the evolving industry landscape. The development of autonomous ships, along with education and training, requires a thorough understanding of the unique challenges posed by the sea, such as extreme weather conditions and the historical legacy of maritime technology [85]. Yanchin and Petrov [86] emphasize the extensive research required for the successful implementation of ocean-going autonomous ships, particularly focusing on information technology aspects in education and training.

Seafarers' opinions about autonomous ships were presented in several papers. The majority of surveyed seafarers emphasized the need for additional education and training for easier acceptance of autonomous technologies on ships and emphasized the importance of adapting to rapid technological changes. The results of the surveys show very different attitudes of the respondents. Some emphasize the potential of autonomous technologies to improve safety at sea, while others express concerns about job losses and reduced human control. A survey performed by Jo et al. [87] explores maritime cadets' views on the changing occupational landscape for seafarers as a result of MASS. The survey highlights the need for proactive adaptations in maritime education to meet the evolving demands of the MASS era. The main aim of the Nasur and Bogusławski survey [88] was to investigate the awareness and attitudes of maritime students towards autonomous ships. The main results show that the coverage of the topic of MASS in the MET of the respondents is generally inadequate, with their level of knowledge being predominantly classified as average. Statistically, however, the respondents see automation as an improvement to safety at sea rather than a threat to maritime jobs. The survey of 108 seafarers by Kennard, Zhang and Rajagopal [89] revealed that seafaring experience, situational awareness and safety awareness are the most important priorities for new professions such as remote operators. They recommend updating the STCW training, promoting international cooperation and investing in training programs to prepare the maritime industry for autonomous shipping.

Research by Sharma and Kim [90], using quantitative and qualitative analyses of maritime professionals from around the world, identified 11 competency themes that are essential for future navigators in manned and remotely piloted MASS, and it provides valuable insights for possible revisions to the STCW Convention and for curriculum development at the MET institutions. In summarizing and analyzing the questionnaires, Li, Duan and Liu [91] show that younger people in management positions are more confident in becoming autonomous ship captains, with the deck department expressing more confidence than the engine department, while older crew members express concerns about their competence due to deficits in learning skills, leading younger crew members to gain more navigation experience and acquire the necessary knowledge and skills for autonomous ship operations in order to adapt to career changes. Hannaford and Van Hassel's survey [92] points to the potential negative implications for licensed deck officers, such as concerns about the increasing reliance on sensors and doubts about replicating situational awareness ashore, while highlighting the need for adaptability and the potential emergence of new roles in the evolving maritime landscape. They recommend the use of inter-institutional platforms for collaboration and further research in the field of MET to address the expected changes and identify the necessary capabilities for future requirements. Chan et al. [93] examine seafarers' attitudes towards autonomous shipping and show that these are generally positive, with concerns focused on job security and trust in autonomous systems. While participants, regardless of rank, generally welcome technological advancement, the survey suggests that understanding seafarers' perspectives and addressing their concerns is critical to the successful implementation of autonomous shipping, particularly as the maritime industry approaches the 2050 milestone set by the IMO.

The aim of the Hwang, Hwang and Youn survey [94] was to evaluate the effectiveness of the current training methods, particularly in preparing remote operators to navigate the mobile autonomous surface ship (MASS). Through a comparative analysis of two groups that received onboard training and one group that did not, the study identified specific navigation skill improvements and highlighted the importance of features such as "Mean ROT"," "Mean rudder" and "Hard rudder". The results suggest that these features may be useful in the development of simulation-based navigation skill assessment methods for SRCO training in the future implementation of a dedicated MASS remote control simulator.

Chae, Kim and Lee's survey [95] compared the educational satisfaction and impact of virtual reality (VR) training for disembarking from passenger ships with conventional video-based methods. They found that VR training significantly outperformed video training in terms of learning impact and participant preference. Despite the effectiveness of VR, challenges such as difficulties with the equipment and discomfort with prolonged use need to be addressed. This survey underscores the importance of continuing research and providing adequate education and training for the use of VR on MASS.

Kim and Mallam's survey [96] examined the impact of autonomous technologies on leadership practices and STCW competency requirements. They showed that competencies such as decision-making techniques, handling system information and maintaining situational awareness are critical for the safe and efficient operation of autonomous ships.

Misas et al.'s survey [97] identifies five key challenges for the future of maritime autonomy, including low cyber awareness in the industry, leading to potential over-reliance on digital tools, the need for regulatory adaptation to the evolving cyber threat landscape, as well as concerns that critical decisions will be influenced by inaccurate data or mistrust in accurate systems, the reduction of over-reliance on digital tools, and the potential obstruction of operators' security controls due to their physical separation from the ship. They emphasize the importance of equipping long-distance mariners with the necessary knowledge and skills, particularly in the use of digital systems, and highlight the need for future training of seafarers to meet the evolving challenges and incorporate new skills such as communication and multi-ship management.

Adaptability is needed in the development of maritime education, with a focus on lifelong learning strategies for seamless transitions from shipboard to shore-based work. The emergence of unmanned ship management requires the development of an environment conducive to this new activity [98]. This requires the use of advanced simulation tools and technologies such as virtual and augmented reality to fully prepare naval professionals for the different levels of autonomous ship management. The world merchant fleet is constantly growing, and with it, the need for competent crews, whether on board or ashore. This growth is expected to continue. The shipping workforce of the future is likely to require seamanship and new skills, including human–autonomous collaboration, maintenance and AI mediation [99].

This month, the maritime industry is presenting a new container ocean-going ship with IMO Level 3 autonomy [100]. In addition to the maritime industry, the United States Navy is also making an important contribution to the development of autonomous ships. As one of the driving forces behind this development, the United States Navy analyzes the research and progress of autonomous ships several times a year. The Navy's programs to develop and procure unmanned surface vehicles (USVs) of various sizes include programs to develop two large USVs—the large unmanned surface vehicle (LUSV) and the medium unmanned surface vehicle (MUSV) [101]. USV ships sail across the Pacific, leave California and sail to Hawaii as part of an extensive test program for the Navy's future USV fleet [102]. As the United States Navy spearheads the advancement of autonomous vessels, its ongoing evaluation and investment underscore a pivotal moment in maritime innovation.

## 4. Conclusions

In this article, a systematic literature review and bibliometric analysis of the available research studies in the field of training and education of seafarers for MASS was performed. The bibliometric analysis helped to identify the leading countries, the most frequent researchers and the historical trends in the field of education and training of seafarers for MASS (RQ1). The literature review also identified the categories of research studies and the methodologies used to date for maritime studies in the field of seafarers' education and training for MASS (RQ2). In this way, this article provides a concise summary of the advances in the field of seafarer education and training for MASS through academic publications.

The analysis of research trends in the field of training and education of seafarers for MASS reveals several important findings. The leading countries in this research area, including Norway, Australia, Japan, Croatia, Poland, China and the Republic of Korea, have contributed significantly to the body of knowledge, as shown by the weighted metric of the total authors and first authors in the selected articles. The seven most important countries together represent a significant proportion of the research output. The historical analysis shows a significant increase in publications from 2017 onwards, suggesting a current and increasing interest in the topic. This growing attention indicates the increasing importance of training and education for seafarers in relation to MASS.

The intersection of maritime law, terminology, regulatory requirements, safety and legal issues related to autonomous ships is still relatively under-researched. The lack of international rules represents a regulatory hurdle. Existing conventions, such as the STCW, may need to be adapted to cover autonomous ships and remote operators, necessitating new regulations. The IMO is actively involved in drafting regulations to integrate autonomous ships into the existing conventions. Legal scholars emphasize the urgency of addressing evolving terminology and responsibilities to ensure safety and highlight the need for continuous updating of maritime education to prepare for autonomous ships. Despite advances in digitalization, the literature shows that autonomous shipping is only addressed to a limited extent within maritime education and training, indicating a critical area for future research and curriculum development.

The development of a trusting dialog between educational institutions and the promotion of education and training is crucial for adapting to change. The COLREGs, which were designed for safe navigation, also present challenges and uncertainties when applied to autonomous ships and need to be comprehensively revised. Adapting maritime education is crucial to closing the significant technological knowledge gap and preparing seafarers for an era of unmanned, autonomous ship operations.

The effective training of personnel for autonomous ships is crucial and should be tailored to the specific needs and roles of the people involved. The maritime industry's shift towards autonomy requires a focus on generic skills such as fast learning, independence, communication and teamwork. While automation can reduce operational costs, it requires the integration of new knowledge and skills into existing training programs. Various studies emphasize the importance of effective training for mariners of autonomous ships, the need to re-evaluate maritime education and the integration of modern technologies such as simulators and deep learning for autonomous ship navigation.

The future development of autonomous systems in the maritime industry requires a flexible and proactive approach to education and training. While the technological hurdles are decreasing, the dynamics between humans and technology, as well as legal concerns, remain key challenges. The different perspectives of seafarers on autonomous ships underline the need for additional education and training to promote acceptance of the new technologies. The future success of the maritime industry depends on the adaptability of education that includes lifelong learning and advanced simulation tools to prepare professionals for the complexities of autonomous shipping.

For future research, it is important to investigate the socio-economic, cultural and technological factors that influence the introduction of autonomous shipping. Exploring the challenges and opportunities of new legal frameworks is crucial for policy and industry adaptation.

In addition, future studies could focus on the socio-ethical impacts, tailored training programs and the integration of advanced technologies into maritime education. Addressing these areas will promote understanding and facilitate a responsible introduction of autonomous shipping.

Although the paper primarily uses bibliometric analysis to examine the research trends in maritime education for autonomous ships, it also emphasizes the need for interdisciplinary education to accommodate the development of technologies such as autonomous ships. The further development of autonomous ships requires continuous updating of education and training programs to equip seafarers with the necessary skills and knowledge. Further research into the specific training content and methods could certainly enrich the discussion and improve our understanding of this area. In various cases, our thoughts as researchers are restrained given the assumption that various experts (for instance, educational, legal, etc.) will apply their specific research qualities to the changing technological landscape.

The information from this paper can help determine the course of future investments in research. A future review study could consider additional research questions or focus on a more detailed analysis of one of the topics covered in this review.

**Author Contributions:** Conceptualization, T.M. and I.P.; methodology, T.M., I.P. and A.A.; validation, A.A., I.P., T.M. and M.M.; formal analysis, A.A. and I.P.; resources, T.M., A.A., I.P. and M.M.; writing—original draft preparation, T.M., I.P. and M.M.; writing—review and editing, A.A. and I.P.; visualization, T.M. and M.M.; supervision A.A and I.P. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

| | |
|---|---|
| AAWA | Advanced Autonomous Waterborne Applications Initiative |
| AMC | Australian Maritime College |
| COLREGs | Convention on the International Regulations for Preventing Collisions at Sea |
| FTSS | Fast Time Ship Simulator |
| GTGP | Groupwork-Training-Groupwork-Presentation |
| IMO | International Maritime Organization |
| LEG | Legal Committee |
| LUSV | Large Unmanned Surface Vehicle |
| MASS | Maritime Autonomous Surface Ships |
| MET | Maritime Education and Training |
| MSC | Maritime Safety Committee |
| MUNIN | Maritime Unmanned Navigation through Intelligence in Networks |
| MUSV | Medium Unmanned Surface Vehicle |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| RSE | Regulatory Scoping Exercise |
| QC | Quasi-Communities |
| STCW | International Convention on Standards of Training, Certification and Watchkeeping for Seafarers |
| USD | United States dollar |
| USV | Unmanned Surface Vehicles |
| VR | Virtual Reality |
| WoS | Web of Science |

## References

1. Androjna, A.; Brcko, T.; Pavic, I.; Greidanus, H. Assessing Cyber Challenges of Maritime Navigation. *J. Mar. Sci. Eng.* **2020**, *8*, 776. [CrossRef]
2. Ghaderi, H. Autonomous Technologies in Short Sea Shipping: Trends, Feasibility and Implications. *Transp. Rev.* **2019**, *39*, 152–173. [CrossRef]
3. IMO Autonomous Shipping. Available online: https://www.imo.org/en/mediacentre/hottopics/pages/autonomous-shipping.aspx (accessed on 12 October 2023).
4. Issa, M.; Ilinca, A.; Ibrahim, H.; Rizk, P. Maritime Autonomous Surface Ships: Problems and Challenges Facing the Regulatory Process. *Sustainability* **2022**, *14*, 15630. [CrossRef]
5. Markets and Markets, Autonomous Ships Market by Autonomy, Ship Type, Solution, and User, Propulsion and Region; Autonomous Ship Market. Available online: https://www.marketsandmarkets.com/Market-Reports/autonomous-ships-market-267183224.html (accessed on 3 April 2024).

6. Review of Maritime Transposrt 2023 by United Nations Conference of Trade and Development. Available online: https://unctad.org/publication/review-maritime-transport-2023 (accessed on 3 April 2024).
7. Ziajka-Poznańska, E.; Montewka, J. Costs and Benefits of Autonomous Shipping—A Literature Review. *Appl. Sci.* **2021**, *11*, 4553. [CrossRef]
8. Komianos, A. The autonomous Shipping Era. Operational, Regulatory and Quality Challenges. *TransNav Int. J. Mar. Navig. Saf. Sea Transp.* **2018**, *12*, 335–348. [CrossRef]
9. IMO, Maritime Safety Committee (MSC), 98th Session Agenda Item 23, 7–16 June 2017. Available online: https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/MSC-98th-session.aspx (accessed on 14 March 2024).
10. IMO; MSC. 99th Session, Agenda Item 5; 22 February 2018. Available online: https://www.itfglobal.org/sites/default/files/node/resources/files/2018%20MSC%2099-5-1%20-%20Comments%20and%20proposals%20on%20the%20way%20forward%20for%20the%20regulatory%20scoping%20exercise%20(IFSMA%20and%20ITF)_1.pdf (accessed on 14 March 2024).
11. IMO, Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS), 3rd June 2021. Available online: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/MSC.1-Circ.1638%20-%20Outcome%20Of%20The%20Regulatory%20Scoping%20ExerciseFor%20The%20Use%20Of%20Maritime%20Autonomous%20Surface%20Ships...%20(Secretariat).pdf (accessed on 14 March 2024).
12. Liberati, A.; Altman, D.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidis, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. *Proc. J. Clin. Epidemiol.* **2009**, *62*, e1–e34. [CrossRef]
13. Booth, A.; Papaioannou, D.; Sutton, A. *Systematic Approaches to a Successful Literature Review*; Sage Publications: Thousand Oaks, CA, USA, 2012; ISBN 0857021354.
14. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; Antes, G.; Atkins, D.; Barbour, V.; Barrowman, N.; Berlin, J.A.; Clark, J.; et al. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097. [CrossRef]
15. VOSviewer Software Tool. 2023. Available online: https://www.vosviewer.com/ (accessed on 1 October 2023).
16. Dittmann, K. Autonomy for Ships: System Thinking and Engineering. In Proceedings of the International Conference on Software, Telecommunications and Computer Networks, Split, Croatia, 22–24 September 2022. [CrossRef]
17. IMO. *The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers*; IMO Publishing: London, UK, 2010; ISBN 978-1-913997-33-5.
18. Carey, L. *All Hands Off Deck? The Legal Barriers to Autonomous Ships*; NUS Centre for Maritime Law Working Paper 17/06; National University of Singapore: Singapore, 2017. [CrossRef]
19. Vio, I.; Brdar, M. Maritime Autonomous Surface Ships-International and National Legal Framework. *Pomor. Zb.* **2022**, *62*, 141–145. Available online: https://hrcak.srce.hr/file/408033 (accessed on 6 April 2024). [CrossRef]
20. Yoshida, M.; Shimizu, E.; Sugomori, M.; Umeda, A. Regulatory Requirements on the Competence of Remote Operator in Maritime Autonomous Surface Ship: Situation Awareness, Ship Sense and Goal-Based Gap Analysis. *Appl. Sci.* **2020**, *10*, 8751. [CrossRef]
21. Fenton, A.J.; Chapsos, I. Ships without Crews: IMO and UK Responses to Cybersecurity, Technology, Law and Regulation of Maritime Autonomous Surface Ships (MASS). *Front. Comput. Sci.* **2023**, *5*, 1151188. [CrossRef]
22. Liu, D. Autonomous Vessel Technology, Safety, and Ocean Impacts. In *The Future of Ocean Governance and Capacity Development*; Brill Nijhoff: Leiden, The Netherlands, 2019. [CrossRef]
23. Hult, C.; Praetorius, G.; Sandberg, C. On the Future of Maritime Transport–Discussing Terminology and Timeframes. *TransNav* **2019**, *13*, 269–273. [CrossRef]
24. Li, S.; Fung, K.S. Maritime Autonomous Surface Ships (MASS): Implementation and Legal Issues. *Marit. Bus. Rev.* **2019**, *4*, 330–339. [CrossRef]
25. Vojković, G.; Milenković, M. Autonomous Ships and Legal Authorities of the Ship Master. *Case Stud. Transp. Policy* **2020**, *8*, 333–340. [CrossRef]
26. Emad, G.R.; Enshaei, H.; Ghosh, S. Identifying Seafarer Training Needs for Operating Future Autonomous Ships: A Systematic Literature Review. *Aust. J. Marit. Ocean Aff.* **2022**, *14*, 114–135. [CrossRef]
27. Shahbakhsh, M.; Emad, G.R.; Cahoon, S. Industrial Revolutions and Transition of the Maritime Industry: The Case of Seafarer's Role in Autonomous Shipping. *Asian J. Shipp. Logist.* **2022**, *38*, 10–18. [CrossRef]
28. Munim, Z.H.; Haralambides, H. Advances in Maritime Autonomous Surface Ships (MASS) in Merchant Shipping. *Marit. Econ. Logist.* **2022**, *24*, 181–188. [CrossRef]
29. Noel, A.; Shreyanka, K.; Kumar, K.G.S.; Shameem, B.M.; Akshar, B. Autonomous Ship Navigation Methods: A Review. In Proceedings of the International Conference on Marine Engineering and Technology Oman, Muscat, Oman, 5–7 November 2019. [CrossRef]
30. Türkistanli, T.T. Advanced Learning Methods in Maritime Education and Training: A Bibliometric Analysis on the Digitalization of Education and Modern Trends. *Comput. Appl. Eng. Educ.* **2023**, *32*, e22690. [CrossRef]
31. Campos, C.; Castells-Sanabra, M.; Mujal-Colilles, A.; Lecturer, S.H. Next step on the maritime education and training in the era of autonomous shipping. In Proceedings of the Maritime Transport Conference, Barcelona, Spain, 27–29 June 2022. [CrossRef]
32. Prifti, L.; Knigge, M.; Kienegger, H.; Krcmar, H. A Competency Model for "Industrie 4.0" Employees. In Proceedings of the 13th International Conference on Wirtschaftsinformatik, St. Gallen, Switzerland, 12–15 February 2017.

33. Aboul-Dahab, K.M. The Readiness of the Maritime Education for the Autonomous Shipping Operations. *Transp. Plan. Policy eJournal* **2021**. [CrossRef]
34. Edler, J.; Infante, V. Maritime and Other Key Transport Issues for the Future–Education and Training in the Context of Lifelong Learning. *Trans. Marit. Sci.* **2019**, *8*, 84–98. [CrossRef]
35. Čampara, L.; Frančić, V.; Bupić, M. Quality of Maritime Higher Education from Seafarers' Perspective. *Sci. J. Marit. Res.* **2017**, *31*, 137–150. [CrossRef]
36. Vidan, P.; Bukljaš, M.; Vukša, S. Autonomous Systems & Ships-Training and Education on Maritime Faculties. In Proceedings of the 8th International Maritime Science Conference, Budva, Montenegro, 11–12 April 2019.
37. Manuel, M.E. Vocational and Academic Approaches to Maritime Education and Training (MET): Trends, Challenges and Opportunities. *WMU J. Marit. Aff.* **2017**, *16*, 473–483. [CrossRef]
38. Demirel, E. Maritime Education and Training in the Digital Era. *Univers. J. Educ. Res.* **2020**, *8*, 4129–4142. [CrossRef]
39. Roos, N.; Sandell, P. STCW-convention and future of joint curriculums for autonomous and remotely operated vessels in maritime education and training (MET). In *Maritime Transport VIII: Proceedings of the 8th International Conference on Maritime Transport: Technology, Innovation and Research: Maritime Transport'20*; Universitat Politècnica de Catalunya: Barcelona, Spain, 2020.
40. IMO. Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) 1972. Available online: https://www.imo.org/en/About/Conventions/Pages/COLREG.aspx (accessed on 14 October 2023).
41. Perera, L.P.; Batalden, B.M. Possible COLREGs Failures under Digital Helmsman of Autonomous Ships. In *Oceans 2019-Marseille*; IEEE: Piscataway, NJ, USA, 2019. [CrossRef]
42. Hannaford, E.; Maes, P.; Van Hassel, E. Autonomous Ships and the Collision Avoidance Regulations: A Licensed Deck Officer Survey. *WMU J. Marit. Aff.* **2022**, *21*, 233–266. [CrossRef]
43. Zhou, X.Y.; Huang, J.J.; Wang, F.W.; Wu, Z.L.; Liu, Z.J. A Study of the Application Barriers to the Use of Autonomous Ships Posed by the Good Seamanship Requirement of COLREGs. *J. Navig.* **2019**, *73*, 710–725. [CrossRef]
44. Miyoshi, T.; Fujimoto, S.; Rooks, M. Study of Principles in COLREGs and Interpretations and Amendments COLREGs for Maritime Autonomous Surface Ships (MASS). *IEEE Trans. Aerosp. Navig. Electron.* **2021**, *6*, 11–18. [CrossRef]
45. Vagale, A.; Osen, O.L.; Brandsæter, A.; Tannum, M.; Hovden, C.; Bye, R.T. On the Use of Maritime Training Simulators with Humans in the Loop for Understanding and Evaluating Algorithms for Autonomous Vessels. *Proc. J. Phys. Conf. Ser. Inst. Phys.* **2022**, *2311*, 012026. [CrossRef]
46. Lee, C.-H.; Yun, G.; Hong, J.-H. A Study on the New Education and Training Scheme for Developing Seafarers in Seafarer 4.0. *J. Korean Soc. Mar. Environ. Saf.* **2019**, *25*, 726–734. [CrossRef]
47. Batalden, B.M.; Leikanger, P.; Wide, P. Towards Autonomous Maritime Operations. In Proceedings of the 2017 IEEE International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA), Annecy, France, 26–28 June 2017. [CrossRef]
48. Wróbel, K.; Gil, M.; Huang, Y.; Wawruch, R. The Vagueness of COLREG versus Collision Avoidance Techniques—A Discussion on the Current State and Future Challenges Concerning the Operation of Autonomous Ships. *Sustainability* **2022**, *14*, 16516. [CrossRef]
49. Kim, I. Systematization of Legal Procedures for Collision Avoidance between a Fully Autonomous Ship and a Traditional Manned Ship. *J. Mar. Sci. Eng.* **2023**, *11*, 1850. [CrossRef]
50. Ahvenjärvi, S. The Human Element and Autonomous Ships. *Int. J. Mar. Navig. Saf. Sea Transp.* **2017**, *10*, 517–521. [CrossRef]
51. Ventikos, N.P.; Louzis, K. Learning from Experience in the Context of Autonomous Ships: An Opportunity for a Step Change in Generating Safety Knowledge? *Proc. J. Phys. Conf. Ser. Inst. Phys.* **2019**, *1357*, 012035. [CrossRef]
52. Fonseca, T.; Lagdami, K.; Schröder-Hinrichs, J.-U. Emergent technologies and maritime transport: Challenges and opportunities. In Proceedings of the International Associationof Maritime Universities (IAMU) Conference, Tokyo, Japan, 30 October–1 November 2019.
53. Demirel, E. The Prospective Posture of Maritime Education in Support of Smart Shipping. *J. Mar. Technol. Environ.* **2022**, *2022*, 26–39. [CrossRef]
54. Belev, B. Maritime Education Development for Environment Protection Behavior in the Autonomous Ships Era. *Sci. Bull. Nav. Acad.* **2019**, *22*, 21–27. [CrossRef]
55. Warsash Maritime Autonomous Surface Ships (MASS) Research Centre. Available online: https://www.solent.ac.uk/research-innovation-enterprise/research-at-solent/research-areas/environment-and-engineering/warsash-maritime-autonomous-ships-research-centre (accessed on 5 December 2023).
56. AMSC, AMC Search, Marine Autonomous Surface Ships (MASS) for Mates/Masters. Available online: https://www.amcsearch.com.au/news/2022/mass-for-mates-masters (accessed on 5 December 2023).
57. Alop, A. The Challenges of the Digital Technology Era for Maritime Education and Training. In Proceedings of the European Navigation Conference (ENC), Warsaw, Poland, 9–12 April 2019. [CrossRef]
58. Bogusławski, K.; Gil, M.; Nasur, J.; Wróbel, K. Implications of Autonomous Shipping for Maritime Education and Training: The Cadet's Perspective. *Marit. Econ. Logist.* **2022**, *24*, 327–343. [CrossRef]
59. Wang, D.; Wu, D.; Huang, C.; Wu, C. Marine Autonomous Surface Ship—A Great Challenge to Maritime Education and Training. *Am. J. Water Sci. Eng.* **2020**, *6*, 10. [CrossRef]

60. Melnyk, O.; Onishchenko, O.; Onyshchenko, S.; Voloshyn, A.; Kalinichenko, Y.; Rossomakha, O.; Naleva, G. Autonomous Ships Concept and Mathematical Models Application in Their Steering Process Control. *TransNav* **2022**, *16*, 553–559. [CrossRef]
61. Stefani, A.; Apicella, L. A New Educational Model for Marine 4.0 Technologies. In *Conference Proceedings of iSCSS*; Institute of Marine Engineering, Science and Technology: Singapore, 2022. [CrossRef]
62. Hwang, T.; Youn, I.H. Navigation Scenario Permutation Model for Training of Maritime Autonomous Surface Ship Remote Operators. *Appl. Sci.* **2022**, *12*, 1651. [CrossRef]
63. Reza Emad, G.; Narayanan, S.; Kataria, A. On the Road to Autonomous Maritime Transport: A Conceptual Framework to Meet Training Needs for Future Ship Operations. In *Proceedings of the Human Factors in Transportation*; AHFE International: Nice, France, 2022; Volume 60. [CrossRef]
64. Lušić, Z.; Bakota, M.; Čorić, M.; Skoko, I. Seafarer Market–Challenges for the Future. *Trans. Marit. Sci.* **2019**, *8*, 62–74. [CrossRef]
65. Kunieda, Y.; Shimada, A.; Kashima, H.; Murai, K. Education and Training to the Mariner of the Maritime Autonomous Surface Ships (MASS) Era. *J. Mod. Educ. Rev.* **2020**, *10*, 365–373. [CrossRef]
66. Martelli, M.; Virdis, A.; Gotta, A.; Cassara, P.; DI Summa, M. An Outlook on the Future Marine Traffic Management System for Autonomous Ships. *IEEE Access* **2021**, *9*, 157316–157328. [CrossRef]
67. Kidd, R.; McCarthy, E. Maritime Education in the Age of Autonomy. In *Proceedings of the WIT Transactions on the Built Environment*; WIT Press: Billerica, MA, USA, 2019; Volume 187, pp. 221–230. [CrossRef]
68. Lokuketagoda, M.G.; Miwa, T.; Jayasinghe, S.; Dev Ranmuthugala, P. Training engineers for remotely operated ships of the future. In Proceedings of the 19th Annual General Assembly–AGA, International Association of Maritime Universities (IAMU), Barcelona, Spain, 17–19 October 2018; ISBN 9781527213470.
69. Kim, J.; Park, J.; Cho, K. Continuous Autonomous Ship Learning Framework for Human Policies on Simulation. *Appl. Sci.* **2022**, *12*, 1631. [CrossRef]
70. Bartuseviciene, I. Maritime Education and Training as a Tool to Ensure Safety at Sea in the Process of Introduction of Maritime Autonomous Surface Ships in Shipping. In Proceedings of the 24th International Scientific Conference, Dubna, Russia, 9–13 November 2020.
71. Minami, M.; Kobayashi, M.; Hikida, K.; Kokubun, K. Development of the Comprehensive Simulation System for Autonomous Ships. *Proc. J. Phys. Conf. Ser. Inst. Phys.* **2022**, *2311*, 012012. [CrossRef]
72. Reza Emad, G.; Kataria, A. Challenges of Simulation Training for Future Engineering Seafarers—A Qualitative Case Study. In *Proceedings of the Human Factors in Transportation*; AHFE International: Nice, France, 2022; Volume 60. [CrossRef]
73. Smirnov, N.; Tomforde, S. Navigation Support for an Autonomous Ferry Using Deep Reinforcement Learning in Simulated Maritime Environments. In Proceedings of the IEEE International Conference on Cognitive and Computational Aspects of Situation Management, CogSIMA, Virtual, 6–10 June 2022. [CrossRef]
74. Sandaruwan, D.; Kodikara, N.; Keppitiyagama, C.; Rosa, R. A Six Degrees of Freedom Ship Simulation System for Maritime Education. *Int. J. Adv. ICT Emerg. Reg. (ICTer)* **2011**, *3*, 34–47. [CrossRef]
75. Ahvenjärvi, S.; Lahtinen, J.; Löytökorpi, M.; Marva, M.M. Istlab–New Way of Utilizing a Simulator System in Testing & Demonstration of Intelligent Shipping Technology and Training of Future Maritime Professionals. *TransNav* **2021**, *15*, 569–574. [CrossRef]
76. Perera, L.P. Autonomous Ship Navigation Under Deep Learning and the Challenges in COLREGs. In Proceedings of the 37th International Conference on Ocean, Offshore and Arctic Engineering, Madrid, Spain, 17–22 June 2018. [CrossRef]
77. Felski, A.; Zwolak, K. The Ocean-Going Autonomous Ship-Challenges and Threats. *J. Mar. Sci. Eng.* **2020**, *8*, 41. [CrossRef]
78. Karakostas, B. *Perspective Chapter: Training Autonomous Ships for Safe Navigation*; IntechOpen: London, UK, 2023. [CrossRef]
79. Askari, H.R.; Hossain, M.N. Towards Utilizing Autonomous Ships: A Viable Advance in Industry 4.0. *J. Int. Marit. Saf. Environ. Aff. Shipp.* **2022**, *6*, 39–49. [CrossRef]
80. Emad, G.R.; Ghosh, S. Identifying Essential Skills and Competencies towards Building a Training Framework for Future Operators of Autonomous Ships: A Qualitative Study. *WMU J. Marit. Aff.* **2023**, *22*, 427–445. [CrossRef]
81. Sencila, V.; Kalvaitiene, G. Industry 4.0: Autonomous Shipping and New Challenges for Maritime Education and Training. In Proceedings of the 23rd International Scientific Conference. Transport Means, Bansko Town, Bulgaria, 12–15 December 2019.
82. Frias, A.; Água, P.; Simões-Marques, M. Education as a Maritime Safety Improvement Factor. In *Proceedings of the Human Factors and Systems Interaction*; AHFE International: Nice, France, 2022; Volume 52. [CrossRef]
83. Mallam, S.C.; Nazir, S.; Sharma, A. The Human Element in Future Maritime Operations–Perceived Impact of Autonomous Shipping. *Ergonomics* **2020**, *63*, 334–345. [CrossRef]
84. Kidd, R. An Open-Source Autonomous Vessel for Maritime Research. In Proceedings of the ASEE Virtual Annual Conference Content Access, Virtual, 22 June 2020. [CrossRef]
85. Benson, C.L.; Sumanth, P.D.; Colling, A.P. Standing on the Shoulders of Giants: How the Maritime Industry Can Leverage Developments in Autonomy from Other Domains. In Proceedings of the International Naval Engineering Conference and Exhibition (INEC), Glasgow, UK, 2–4 October 2018; IMarEST: Singapore, 2018; Volume 14. [CrossRef]
86. Yanchin, I.; Petrov, O. Towards Autonomous Shipping: Benefits and Challenges in the Field of Information Technology and Telecommunication. *TransNav* **2020**, *14*, 611–619. [CrossRef]
87. Jo, S.; D'agostini, E.; Kang, J. From Seafarers to E-Farers: Maritime Cadets' Perceptions towards Seafaring Jobs in the Industry 4.0. *Sustainability* **2020**, *12*, 8077. [CrossRef]

88. Nasur, J.; Bogusławski, K. Awareness and Attitude of Maritime Students towards the Introduction of Autonomous Merchant Ships–Preliminary Results. *TransNav* **2020**, *14*, 859–863. [CrossRef]
89. Kennard, A.; Zhang, P.; Rajagopal, S. Technology and Training: How Will Deck Officers Transition to Operating Autonomous and Remote-Controlled Vessels? *Mar. Policy* **2022**, *146*, 105326. [CrossRef]
90. Sharma, A.; Kim, T. Exploring Technical and Non-Technical Competencies of Navigators for Autonomous Shipping. *Marit. Policy Manag.* **2022**, *49*, 831–849. [CrossRef]
91. Li, Y.; Duan, Z.; Liu, Z. Study on Risk-Based Operators' Competence Assessment of Maritime Autonomous Surface Ships. In Proceedings of the 5th International Conference on Transportation Information and Safety (ICTIS), Liverpool, UK, 14–17 July 2019. [CrossRef]
92. Hannaford, E.; Van Hassel, E. Risks and Benefits of Crew Reduction and/or Removal with Increased Automation on the Ship Operator: A Licensed Deck Officer's Perspective. *Appl. Sci.* **2021**, *11*, 3569. [CrossRef]
93. Chan, J.; Golightly, D.; Norman, R.; Pazouki, K. Perception of Autonomy and the Role of Experience within the Maritime Industry. *J. Mar. Sci. Eng.* **2023**, *11*, 258. [CrossRef]
94. Hwang, H.; Hwang, T.; Youn, I.H. Effect of Onboard Training for Improvement of Navigation Skill under the Simulated Navigation Environment for Maritime Autonomous Surface Ship Operation Training. *Appl. Sci.* **2022**, *12*, 9300. [CrossRef]
95. Chae, C.J.; Kim, D.; Lee, H.T. A Study on the Analysis of the Effects of Passenger Ship Abandonment Training Using VR. *Appl. Sci.* **2021**, *11*, 5919. [CrossRef]
96. Kim, T.-e.; Mallam, S. A Delphi-AHP Study on STCW Leadership Competence in the Age of Autonomous Maritime Operations. *WMU J. Marit. Aff.* **2020**, *19*, 163–181. [CrossRef]
97. Misas, P.; Hopcraft, R.; Tam, K. Future of Maritime Autonomy: Future of Maritime Autonomy: Cybersecurity, Trust and Mariner's Situational Awareness. In *Conference Proceedings of iSCSS*; Institute of Marine Engineering, Science and Technology: Singapore, 2022. [CrossRef]
98. Belev, B.; Penev, A.; Mohović, Đ.; Hadžić, A.P. Autonomous Ships in Maritime Education Model Course 7.01. *Pomorstvo* **2021**, *35*, 388–394. [CrossRef]
99. Lutzhoft, M.; Hynnekleiv, A.; Earthy, J.V.; Petersen, E.S. Human-Centred Maritime Autonomy-An Ethnography of the Future. *Proc. J. Phys. Conf. Ser. Inst. Phys.* **2019**, *1357*, 012032. [CrossRef]
100. Korea Launches First Containership Built for Autonomous Operations. Available online: https://maritime-executive.com/article/korea-launches-first-containership-built-for-autonomous-operations (accessed on 14 March 2024).
101. Navy Large Unmanned Surface and Undersea Vehicles: Background and Issues for Congress. Available online: https://crsreports.congress.gov/product/details?prodcode=R45757 (accessed on 14 March 2024).
102. Navy Ghost Fleet Unmanned Ships Now in the Western Pacific. Available online: https://news.usni.org/2023/09/21/2-navy-ghost-fleet-unmanned-ships-now-in-the-western-pacific (accessed on 14 March 2024).