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Cold Climate Maritime Engineering: The Need for Development of Educational Materials

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ABSTRACT: Maritime activity in the Arctic has increased significantly due to declining sea ice, longer open-water seasons, and growing interest in shipping, tourism, fisheries, and natural resources. While these developments create new opportunities, they also increase operational, environmental, and safety challenges in remote and vulnerable regions. This paper argues for the development of a dedicated one-year, 60-ECTS programme in cold-climate maritime engineering to address competency gaps in current maritime education and training (MET) for Arctic operations. The objective of the study is to present key learning requirements based on real challenges and threats as a result of increased activity. The study draws on historical polar maritime accidents, Arctic search-and-rescue exercises, and evaluations of Polar Code training. Case studies, including Maxim Gorkiy (1989), Explorer (2007), Northguider (2018), and Ocean Explorer (2023), reveal recurring challenges related to grounding, ice navigation, emergency response, remoteness, and organizational decision-making. Although accident rates relative to traffic appear to have declined after the introduction of the IMO Polar Code, grounding remains the dominant accident type in Arctic passenger shipping. The paper argues that existing international training standards are insufficient for the complexity of polar operations. To address this, the proposed curriculum combines theoretical instruction, simulator training, laboratory exercises, and case-based learning grounded in resilience and professional competence formation. The programme is organized into six modules covering Arctic operations, marine technology, safety, resilience, and emergency preparedness. The paper concludes that strengthening Arctic maritime resilience requires not only regulation and technology, but also specialized education adapted to the realities of cold-climate operation.

1 INTRODUCTION

Maritime traffic in the Arctic has increased significantly in recent years. Diminishing sea-ice extent, reduced ice cover and ice severity, and longer open-water seasons create new opportunities for maritime transportation but also new challenges. The growing interest in Arctic resources and shipping routes has been accompanied by an expansion of fishing, tourism, and research activities in this region, while the increased traffic also leads to concerns about safety and environmental impacts from these activities.

The growth in maritime activity is well documented, as the Arctic Council's Working Group on the Protection of the Arctic Marine Environment (PAME) reports that the number of ships entering the Arctic Polar Code area rose from approximately 1,300 in 2013 to 1,781 in 2024, an increase of 37% over eleven years, while approximately 500 additional unique vessels have been involved [28]. The distance sailed increased even more between 2013 and 2019 alone, as the total nautical miles sailed rose 75% from 6.51 to 9.5 million nautical miles. The report confirms continuing growth thereafter, with bulk carrier distances up 160%

and continued increases for fishing, general cargo, and cruise vessels. Müller et al. [26] estimate that aggregated annual growth is approximately 7% over the past decade and that the time vessels spend operating under hazardous weather and sea-ice conditions has tripled, which is driven by increased winter sailing. Fishing vessels remain the single largest category, representing approximately 41% of unique ships in the Polar Code area, and the number of general cargo ships is the second largest. The cruise activity has increased with respect to passenger capacity and also in the geographic extension of operations, mainly from calls at Longyearbyen toward expedition cruising along the Northeast Greenland coast and circumnavigation of Svalbard.

In recent years, more focus has been channeled towards maritime safety due to the introduction of the Polar Code [13] and other national, international, and industrial regulations. The regulatory regimes for maritime traffic in the Arctic region are nevertheless still complex and dispersed. There should be a recognized increase in need for further specialized skills to handle these challenges, where this paper argues that such skills could be formed through a coherent, modular cold-climate maritime engineering programme and grounded in the historical records of polar maritime accidents and Arctic resilience.

2 MARITIME ACCIDENTS IN ARCTIC WATERS

2.1 *Resilience as a course outcome*

Arctic maritime operations are shaped by a tightly coupled set of environmental, technical, human, and systemic challenges that together raise operational risk and complexity. Climate-driven loss and variability of sea ice is the dominant environmental driver: reduced ice extent opens new navigation windows and routes, but increases seasonal unpredictability and exposure to weather extremes and remnant ice hazards [27].

Key operational hazards include marine icing (sea-spray and atmospheric icing), rapidly changing ice conditions, limited survey and hydrographic coverage, long distances from search-and-rescue (SAR) and salvage services, and fragile ecosystems with low capacity for recovery after spills or accidents [32, 27].

Technological and design challenges arise because vessels and port infrastructure must operate in extreme cold, contend with ice accretion on superstructures, and satisfy polar class and ice-strength requirements. Anti- and de-icing technologies and ice-resilient design choices are therefore essential but not universally implemented [32].

Human and organizational factors further complicate the operations: human factors and ergonomics (HF/E), including bridge design, workload, crew scheduling, communication, and interface design, have a measurable influence on safety and efficiency in Arctic ship operations and should be integrated early in ship design and operational planning [24].

Finally, the Arctic maritime system is embedded in global supply chains; port disruptions or accidents can propagate widely, exposing systemic interdependencies and economic vulnerability. Scenario-based and input–output modeling demonstrates how port inoperability can cascade through regional and national economies [43].

Arctic maritime resilience is defined as the capacity of the coupled socio-technical-ecological system of Arctic shipping and coastal communities to anticipate, absorb, adapt to, and rapidly recover from disturbances such as physical shocks, operational accidents, environmental incidents, and systemic supply-chain disruptions, while preserving essential functions and livelihoods.

Resilience requires multiple dimensions:

- Physical and technical robustness (ice-class ships, infrastructure, de-icing systems)
- Operational readiness (route planning, contingency procedures, SAR coordination)
- Governance and regulation (multi-level adaptive policy frameworks)
- Social capacity (community preparedness, Indigenous knowledge)
- Ecological safeguards (pollution prevention and ecosystem monitoring)

Resilience cannot rely on a single measure but depends on redundancy, situational awareness, data-sharing, and integrated governance across stakeholders [27, 43].

Quantitative resilience assessment in Arctic systems includes probabilistic and network-based methods such as Bayesian networks for accident scenario analysis, composite resilience indices, and systems-level vulnerability modeling. These approaches help identify causal chains and support targeted mitigation strategies [1].

Education and training are critical for building resilience due to the interaction between technology, people, and institutions.

2.2 *Overview*

Maritime accidents in polar regions are caused by a combination of operational, environmental, and organisational stressors that rarely occur together elsewhere. We have ice in many forms, prolonged darkness, sea spray icing, sub-zero temperatures, unreliable hydrographic information, polar lows, intermittent communications, and great distances to search-and-rescue (SAR) infrastructure [18, 25]. The cases described below span over thirty-five years of incidents in the Arctic and Antarctic, and they have been selected because each illustrates a different combination of these factors. Together, they constitute an empirical foundation for the modular course described in section 5.

2.3 *Accident trends 2010–2024: pre and post Polar Code*

Before turning to the qualitative case material, it is useful to establish a broader statistical context. Figure 1 below shows the annual count of reported ship-casualty accidents in Arctic waters between 2010 and 2024, drawn from a maritime casualty database covering vessels operating in the Norwegian, Icelandic, Russian Arctic, the Bering Sea, the Canadian Arctic, and Alaska reporting zones. Data from Lloyd's List

Intelligence / Sea-web casualty records have been used by the authors to prepare the statistics. Personal injury, such as illness/fatality/injury, overboard, maritime arrest, and cargo damage, has been excluded because they were under-reported in the pre-2017 part of the dataset and would affect the totals after the Polar Code entered into force.

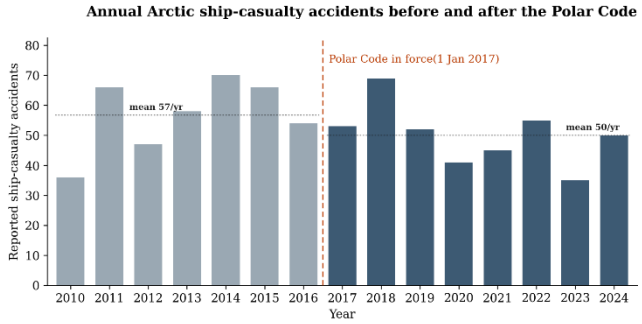

Figure 1. Reported ship-casualty accidents in Arctic waters by year, 2010–2024. The vertical reference line marks the entry into force of the IMO Polar Code on 1 January 2017. Annual means for the pre-Polar-Code (2010–2016) and post-Polar-Code (2017–2024) periods are shown as horizontal reference lines.

Two observations can be seen from the figure: the annual count is essentially flat across the fifteen years, with a small decline in absolute frequency from a pre-Polar Code mean of 57 accidents per year compared to a post-Polar-Code mean of 50 per year (−12%). Against the traffic context summarised in section 1, there is a 37% increase in ships and a substantially larger increase in distance sailed during the same period [29, 26]. This absolute decline corresponds to a substantial reduction in the per-ship accident rate.

The Polar Code, taken together with parallel developments in vessel technology, ice-aware navigation practice, and improved SAR infrastructure, appears to have absorbed much of the additional risk that the increase in maritime traffic growth would otherwise have produced.

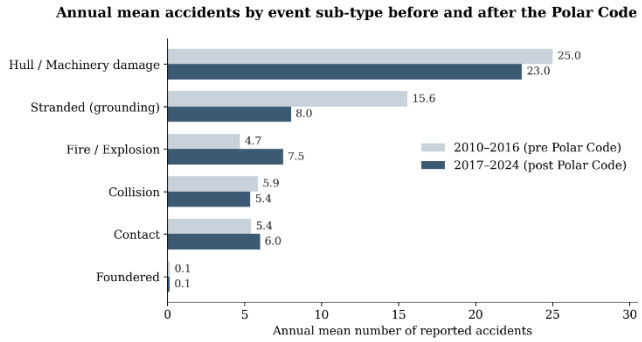

Figure 2. Annual mean number of reported accidents by event subtype, comparing the pre-Polar-Code period (2010–2016) with the post-Polar-Code period (2017–2024). Same data source as Figure 1.

Figure 2 above utilizes the same data by accident type and shows a more nuanced picture. Stranding (grounding) fell from an annual mean of 15.6 to 8.0, a 49% reduction, which is consistent with improved ice-aware passage planning, ECDIS adoption, and Polar Code-driven competence. Hull and machinery damage, the largest category, also declined moderately (−8%). Collisions and contact with fixed objects were more or less unchanged. Most strikingly, fire and explosion events rose by 59%, from an annual mean of 4.7 to 7.5. Note that this is a category that the Polar Code addresses less directly than navigation. The signal is mixed and important as the Polar Code appears to be working for the operational competencies it was designed to develop, but the reduction does not extend to all accident types, and the dominant accident in polar passenger shipping, i.e., grounding, continues to occur. The Northguider, Mikhail Somov, and Ocean Explorer cases discussed below were all post-Polar-Code groundings. The remainder of section 2 examines these cases qualitatively to identify the specific operational and organisational factors that contributed to the accidents.

2.4 *Maxim Gorkiy (19 June 1989, Greenland Sea, southwest of Svalbard)*

The Soviet cruise liner Maxim Gorkiy was on a Phoenix Reisen voyage from Bremerhaven via Iceland and Spitsbergen when, near midnight on 19 June 1989, she struck an ice floe in heavy fog approximately 180 nautical miles southeast of the Svalbard archipelago. The collision opened two gashes in the starboard hull, and the ship listed and began taking water. A coordinated rescue led by the Joint Rescue Coordination Centre (JRCC) North Norway, supported by the Norwegian Coast Guard vessel KV Senja, additional helicopters, and Soviet vessels. They evacuated 575 passengers and several hundred crew without loss of life [12, 42]. This incident remains a foundational case in Arctic SAR training because it exposed every link in the mass-rescue chain at once, which includes alerting, on-scene coordination, lifeboat-and-floe evacuation in near-freezing water, helicopter shuttling, host-nation cooperation, and triage of survivors against limited berthing capacity [18]. Lessons that remain pedagogically central include the importance of fast alarming, as the JRCC was alerted approximately thirty minutes after impact. This clearly states the value of having redundant rescue assets within reach, and the limitations of immersion suits and lifeboats designed primarily for temperate latitudes.

2.5 *M/V Explorer (23 November 2007, Bransfield Strait, Antarctic Peninsula)*

The Liberian-registered expedition cruise vessel M/V Explorer, operated by GAP Adventures, was the first cruise ship lost in Antarctic waters. Shortly after midnight on 23 November 2007, the ship entered an ice field near the South Shetland Islands and struck what her master initially identified as first-year ice but which was, in fact, harder glacial ice. The damage extended for at least 3.6 m along the hull plating, and progressive flooding through internal compartments could not be contained. All 154 persons on board were evacuated from the ship into lifeboats and were rescued by the nearby cruise ship MS Nord Norge in calm weather [21]. The official report places the primary causation and responsibility on the master's misinterpretation of ice type, compounded by speed not being reduced on the approach to the ice area. The report identifies the absence of internationally agreed competency standards for ice navigation under the STCW Convention as a systemic factor. The Explorer is a

relevant case for teaching ice recognition, the difference between cold-water survivability assumptions and Antarctic reality, and the reliance on bystander shipping for evacuation in an environment without dedicated SAR.

2.6 *MS Nordkapp (30 January 2007, Deception Island, Antarctic Peninsula)*

Ten months before the Explorer sinking, Hurtigruten's cruise vessel MS Nordkapp grounded on rocks while approaching Whalers Bay, inside the flooded caldera of Deception Island. The 11,386-GT vessel sustained a hull gash but continued under her own power, while 294 passengers were transferred to her sister ship MS Nord Norge for transit back to Ushuaia. Although there were no injuries among the passengers, between 500 and 750 liters of light marine diesel were released into Whalers Bay, with hydrocarbons subsequently detected along an approximately five-kilometer stretch of shoreline [2]. From a teaching perspective, the MS Nordkapp case is valuable because it was a "minor" event, but it demonstrates how easily a tourist call can produce ecological harm in an Antarctic Specially Protected Area. Further, it illustrates the inadequacy of generic oil-spill response equipment in a remote and ice-affected environment.

2.7 *Northguider (28 December 2018, Hinlopen Strait, Svalbard)*

The Norwegian shrimp trawler Northguider grounded at approximately 80°N on 28th of December 2018, while engaged in winter shrimp fishing inside the Nordaustlandet Nature Reserve east of the Spitsbergen island. The fourteen-person crew was rescued by helicopter lifts from the Governor of Svalbard's two SAR helicopters in temperatures around −23 °C. The rescue operation took place during the polar night, with snow showers reducing visibility — conditions later described by Norwegian authorities as "at the far limit of what was possible" [18]. The vessel was a total loss; 300 tonnes of diesel were removed by KV Svalbard before the wreck was eventually dismantled in situ in 2020. A subsequent court ruling fined the master and the owner, Opilio AS, for negligent navigation and an inadequate safety management system, citing operations in conditions of darkness, low temperatures, ice, poor charting, weak radio coverage, and long distances to rescue. Northguider is a pedagogically significant case for two reasons - it demonstrates that the sharp-end risk picture in commercial fishing differs from that in passenger shipping, and it provides a parallel to Maxim Gorkiy that allows students to compare SAR resources and outcomes across thirty years of Arctic operations [18].

2.8 *Ocean Explorer (11–14 September 2023, Alpefjord, Northeast Greenland)*

The expedition cruise ship Ocean Explorer (Bahamas flag) operated by Aurora Expeditions, grounded in Alpefjord, in the Northeast Greenland National Park, on the afternoon of 11 September 2023, with 206 persons onboard. The grounding occurred on the moraine of a glacier in an area considered poorly hydrographically charted. The nearest Danish patrol asset, HDMS Knud Rasmussen, was approximately 1,200 nautical miles away when the alarm was raised. After three days, the ship was pulled free at high tide on 14 September with assistance from the Greenlandic research trawler Tarajoq. Luckily, there were no injuries, no hull breach, and no pollution released to the environment. Despite the outcome without severe consequences, this case has high value during the teaching of the modules. It demonstrates that even modern and polar-class expedition vessels operating with experienced crews remain exposed to incomplete bathymetric data in remote fjords, and that response time from official rescue assets is measured in days rather than hours.

2.9 *Ocean 28 (October 2024, Northern Sea Route)*

The Ocean 28 event was not an accident, but it documents a near-miss where the value for teaching is precisely that it shows how regulatory and commercial pressures can place a vessel into a hazardous regime before any failure has occurred. The 154-meter-long, Panama-flagged Chinese heavy-lift carrier departed Zhangjiagang on 24 September 2024 carrying a power-generation module that was bound for the Arctic LNG 2 project at Utrenny on the Gulf of Ob. The vessel transited the Northern Sea Route under the permission from the Northern Sea Route (NSR) Administration with required icebreaker escort "in ice-free water and light ice conditions" only, while sea ice in the Laptev Sea was rapidly expanding, and only one nuclear icebreaker was reported active in the eastern sector [41]. The case is useful in several ways as it illustrates how ice-class and operational permissions can be misaligned with prevailing conditions, and the case represents the type of latent Arctic accidents that teaching modules on Polar Code, such as ice management and ice navigation, are designed to prevent.

2.10 *Synthesis*

Read together, these seven cases display three recurring patterns. First, environmental conditions do not cause accidents on their own, because in every case there is a decision: to enter ice, to maintain speed, to fish in a poorly charted bay in darkness, to accept a route permission, and so on, taken by a sharp-end operator under organisational pressure [33, 23]. Second, the consequences of those decisions are amplified by the remoteness, where the same decision in the North Sea would not require a 1,200-nautical-mile response distance, helicopter shuttling at −23 °C, or the use of bystander tourist vessels for mass evacuation. Third, the lessons accumulate slowly. The thirty years passing between Maxim Gorkiy and Northguider, and the further five years to Ocean Explorer, mark cases where similar SAR challenges had to be solved again, with similar improvisation. These three patterns contribute to shaping the syllabus argued for in the next section.

2.11 *Beyond accidents — evidence from controlled exercises*

Three full-scale Search and Rescue exercises conducted by the Norwegian Coast Guard in cooperation with the

University of Stavanger were conducted between 2016 and 2018. SAREX 1 [37], SAREX 2 [38], and SAREX 3 [39], provide complementary evidence on what can be expected to go wrong under a future Arctic evacuation scenario. The exercises tested the functionality of the IMO Polar Code Chapter 8 requirement, which states that abandoned persons should survive for a minimum of five days in lifesaving appliances. SAREX 1 ran a "Maxim Gorkiy scenario" off northwest Spitsbergen using KV Svalbard as mother vessel, with cross-disciplinary participation from the Norwegian Coast Guard, classification societies, equipment manufacturers, medical specialists, and academic institutions. During SAREX 2, the rescue equipment was modified and considerably improved. SAREX 3 studied the effect of rescuing the people to shore rather than staying in lifeboats and life rafts.

The findings repeat across all three exercises and have direct implications for the syllabus. First, none of the SOLAS-approved lifesaving appliances tested could be expected to deliver five-day survival under representative cruise-season conditions in the Svalbard area. Lifeboat occupants experienced severe heat loss through the hull structure and oxygen depletion when the engine was shut down. Persons in a life raft suffered progressive reduction of body temperature as a result of condensation buildup and combined with floor heat loss [37]. Second, the difference between groups in SAREX 3 was driven less by equipment than by leadership, where groups with leaders who managed rations, activity levels, and morale, and intervened early on signs of fatigue, fared substantially better than groups with comparable equipment but weaker leadership [39]. Third, current personal protective equipment loses much of its insulating capability when wet, and the fine motor skills required for survival tasks, like pitching tents, operating stoves, and administering first aid, are incompatible with the neoprene gloves provided as standard. These are examples of findings that are pedagogically significant because they show that competence formation for Arctic operations must address dispositional and adaptive skills that cannot be acquired through certificate-based equipment training alone, a point taken up further in section 2.1.

Furthermore, the exercises showed that fresh air must be ensured inside the rescue means, as the large group in the enclosed lifeboats and life rafts necessary in the cold climate emits dangerous levels of CO. Survival in cold weather also requires energy to keep up the body temperature, and water is needed in sufficient quantities, higher than normally provided on board the life-saving means.

3 ARGUMENTATION FOR AN ENHANCED COURSE SYLLABUS

These cases above expose competencies that are not reliably acquired through the present international minimum standards for maritime education and training (MET). The IMO STCW Convention, including the Polar Code amendments, requires baseline knowledge for ice navigators but leaves substantial freedom in how those requirements are met institutionally [13].

A clear skill gap emerges directly from the case material in section 2, as the Explorer master was an experienced Baltic ice navigator, but Baltic first-year ice and Antarctic glacier ice are different objects [21]. The Northguider master held a valid certificate of competence, but the safety management system aboard had not identified the combined hazard profile of darkness, vessel drift, and ice in the Hinlopen environment. These cases point to a shared deficiency, that standard maritime training programmes assume that competency in one domain transfers to others, and that paper-level certification is only sufficient evidence of preparedness to operate in the high Arctic.

The dominant accident type in Arctic passenger shipping reinforces this point. Sollid, Gudmestad, and Solberg (2018) report that 17 of 19 registered passenger vessel accidents in the Spitsbergen area between 1981 and 2017 were groundings, and that across the wider Arctic, the proportion is similar, where 499 of 788 accidents north of 60°N in Greenland between 1990 and 2012 were groundings, of which 85 involved passenger ships. Grounding is not a rare event in polar passenger operations, but it seems to be the modal failure mode. Macrae [22] further analyses the human factors underlying grounding accidents and finds that 30.3% of triggering factors are insufficient passage planning, 18.2% interpretation errors, and 15.2% communication failures, with 81.9% of planning failures related to personal violation rather than to lack of resources. These examples suggest that even substantial increases in technical equipment provision will under-deliver if the underlying competency in passage planning, situational interpretation, and bridge communication has not been formed in the first place.

Three recent peer-reviewed evaluations of Polar Code training validate the case for an enhanced syllabus. Chaure and Gudmestad [3] characterize the existing Basic and Advanced training modules as ineffective with respect to actual evacuation needs, and they also identify a complete absence of any required passenger survival training. Fedi, Faury, and Gritsenko (2018) describe a "Polar Code paradox" in which the Code provides a useful general framework but contains substantial unsolved gaps as advanced training is not required for all crew members. Furthermore, fishing and leisure vessels are excluded from mandatory provisions, and pollution risks are inadequately addressed. Johannsdottir and Cook [14], reviewing systemic risk in cruise ship incidents from an Arctic perspective, observe that the discretion afforded to flag states and ship owners in defining the substance of safety standards undermines the consistency of training delivery. These three evaluations make it clear that the Polar Code's present syllabus is not sufficient on its own to close the competency gap described by the few cases above. This is a finding that motivates curriculum development of the kind proposed here.

Further, two competency areas are under-represented in current education programmes. The first is the integration of national and local regulation. For example, operations in Svalbard waters are governed not only by SOLAS, MARPOL, and the Polar Code but also by the Svalbard Environmental Act, the Governor of Svalbard's instructions, AECO industry guidelines, and protected-area restrictions including

the Nordaustlandet Nature Reserve (where Northguider grounded). A maritime engineer educated for cold-climate operations must be able to navigate this regulatory forest as competently as the physical environment. The second area is the sustainability of the fragile ecosystems. The Nordkapp diesel release was small in tonnage but consequential in context, and the risk discussions of Arctic LNG transport, seabed minerals exploitation, and the continued growth of expedition cruise tourism will require operators and engineers who can reason about ecological reversibility rather than only about engineering and operative reversibility.

The remoteness that complicates rescue equally complicates oil-spill response, salvage, and personnel evacuation. The Arctic and Antarctic ecosystems are fragile, meaning that pollution loads tolerable elsewhere here will produce long-term contamination. Avoiding large-scale accidents is therefore not a pure human consideration but also operational and economic. Prevention through training should have a higher relative return on investment in polar operations than elsewhere. This is consistent with the wider argument by Saleh and Pendley [34] that engineering education must move from "learning from accidents" as a research activity to "teaching about accident causation and prevention".

Pedagogically, the case for a dedicated syllabus aligns with Shulman's (2005) concept of signature pedagogies, discussed in Section 4 below. Cold-climate maritime engineering, as an emerging professional sub-domain, should require its own signature pedagogy. A structured combination of classroom instruction in the physical and regulatory frameworks, simulator training for ice navigation and bridge resource management in polar conditions, and case-based analytical work, drawing on the historical records summarized above. Without this focus on a combination of different competences, certificates may be issued without actual competence being learned. With it, one would be more on the safe side for a syllabus that is closing the specific gaps that the Arctic and Antarctic incident record makes visible.

In summary, the argument for an enhanced syllabus rests on observations: (i) competencies for cold-climate operations are absent from current training, as evidenced by the recurring causal patterns in the cases above, (ii) grounding remains the modal accident type in polar passenger shipping, with planning and interpretation failures dominant in causation [40, 22], (iii) peer-reviewed evaluations of Polar Code training itself report ineffectiveness for evacuation preparedness [3, 6], (iv) national and local regulatory frameworks impose specific obligations not transmitted through international minima, (v) the consequences of large-scale accidents are disproportionately severe in polar regions, raising the marginal value of prevention and (vi) the pedagogical form of the syllabus must itself be consistent with how professional competence is formed [36, 19]. These points motivate the modular structure described in Section 5.

4 PEDAGOGICAL APPROACH

The pedagogical approach to the modules is implemented through a combination of theoretical and practice-oriented learning activities. More specifically, a combination of conventional classroom instruction followed by simulator-based and laboratory-based activities, comparable to the model of "Maritime education and training (MET)" for modern ship officer education [16].

Use of combined teaching methods applies to multiple professional "signature" educational programs aimed at specific occupations such as law, nursing, and medicine [35]. Educating maritime officers, and related to this article, specialized MET within the profession, requires certain specificities concerning instructional methods. When linking such distinctive pedagogical practices to educational or subject-specific didactic theories, Lee Shulman's concept of signature pedagogies is particularly relevant. Signature pedagogies describe the instructional activities that lay the foundation for students' subsequent professional practice. The characteristics of selecting specific occupationally relevant teaching methods are that they should bridge the gap between theoretical knowledge and the practical tasks students must perform in their professional practice [36].

The foundation for the theoretical content in the curricula will be learning linked to previous accidents and incident cases within the polar seas. More specifically, characteristics, aspects, and statistical patterns of recorded cases of maritime accidents centered around the Arctic and Antarctic oceans. Contextually, like real-life scenarios, case studies as described above are therefore utilized to derive new lessons based on experiences from such previous events.

Maritime accidents are rarely caused by a single factor; rather, they typically arise from a series of errors involving human or technical failures, adverse weather conditions, or communication breakdowns [4]. Furthermore, the safety aspects in these areas are important to focus on, as the areas are remote and characterized by long distances, for example, in search and rescue operations.

In addition to the focus on case studies, the foundation for the theoretical content in the curricula must be adapted to both the ongoing climate change and the current geopolitical situation. Respectively, new areas of polar lows [15] and aspects of cybersecurity.

5 DETAILS AND DISCUSSION OF THE COURSE MODULES

All lectures are estimated to have a duration of two lecture hours unless otherwise stated. The lectures could be arranged otherwise, according to the requirements of the school.

Table 1.

Module/submodule	ECTS / hours	Content
6.1 Basic considerations: working in the maritime Arctic	10	General foundation for cold-climate maritime work; sets the analytical, regulatory, and SAR vocabulary used by all later modules.
Background lectures	8	Course overview: present challenges for the young marine engineer; marine and maritime inventions and innovations; risk analysis.
General themes	12	Sustainable use of the Arctic; human effects in cold climate; winterization; design basis; effects of climate change.
Waves in the ocean	8	Waves basics; irregular waves; vessel motion; ship stability – basic.
Ice and its effects	8	Polar low and icing; ice cover; ice basics; icebergs.
Safety and environment	9	Search and Rescue (3 hours); fuel for vessels in cold climates; cybersecurity; seabed minerals.
6.2 Requirements for the maritime engineer	10	Vessel- and operation-centered engineering competencies; introduces ice-aware navigation and the bridge simulator.
Introductory lectures	6	Introduction to the maritime module; categories of vessels; ship technology (ABS reference).
Vessel-specific	10	Ship stability – advanced; vessel stability in cold climate; ship safety; marine operations WOW; autonomous vessels.
Arctic-specific	12	Navigation in Arctic seas; transport in the Arctic; loading from ice; Polar Code; ice management; the clean Arctic environment.
Wind turbines	4	Wind turbine installation; personnel transfer offshore.
Safety and security	4	Basics of marine and maritime safety and security; security issues in the maritime industry.
Ship simulator	8	Simulator training exercises (ice-edge navigation, polar low encounter, degraded GMDSS).
6.3 Marine technology	10	Phenomenon-centered engineering core: hydrodynamics, structures, design, and reliability for cold-climate operation.
Introduction	6	Hydrostatics and hydrodynamics.
Wave loads	4	Wave-induced loads on vessels and structures.
Dynamics and vibrations	4	Dynamics, vortex shedding.
Pipelines	2	Pipeline behavior in cold-climate environments.
Positioning and mooring	4	Positioning and mooring design.
Reliability issues	2	Reliability of marine systems in the Arctic.
Design	6	Arctic design standards and aspects of marine design.
Offshore wind	2	Technical challenges for offshore wind in cold climates.
6.4 Marine operations in cold climates	10	Temporal and statistical dimensions of polar operations — weather windows, extreme statistics, motions, and explicit safety-level selection.
Marine operations – overview	2	Overview of marine operations in a cold climate.
Impact effects	4	Analysis of impact effects on vessels and structures.
Ship motions	4	Heave, roll, RAO.
Modern ship design	2	Design considerations for modern Arctic vessels.
Specifics in cold climate	4	Specifics of marine operations in a cold climate.
Statistics	4	Statistics and data distributions.
Wave analysis	4	Wave analysis; extreme waves.
Weather routing	2	Weather routing for polar transit.
Operations and limitations	2	Marine operations and operational limitations.
Selection of safety level	2	Explicit selection of safety level for polar marine operations.
6.5 Support facilities onshore and project execution	10	Onshore engineering and project-execution methodology that polar maritime work depends on, but vessel-centric MET rarely covers.
Wind engineering	6	Wind engineering for Arctic onshore facilities.
Insulation	2	Insulation for cold-climate structures.
Snow, ice, and related aspects	6	Snow and avalanches; protection from snow/ice; atmospheric icing.
Ground effects	12	Freezing and thawing (2); permafrost (4); geohazards (4); coastal concerns (4).
Cold-regions hydrology	3	Cold-regions hydrology.
Project execution	16	Organization of projects (4); planning and economy (4); Front-End Engineering (4); later project phases (4).
6.6 Arctic emergency and case studies	10	Integrative module — case material first encountered in earlier modules is now treated as integrated practice; closes the programme.
Forgotten lessons	2	Forgotten lessons from the Arctic.
Communication and response	6	Communication in the Arctic: Arctic emergency response.
Arctic survival	8	Survival in the Arctic; IMO operational capabilities and limitations in ice; AECO guidelines for cruise operations.
Environment	6	Arctic environmental regulations; oil-spill response; regulations for Svalbard.
Case studies	8	Titanic; fishing-vessel loss; Maxim Gorkiy; Helge Ingstad; Explorer; Northguider; Ocean Explorer.

Each module additionally includes a course or semester project (≈15 lecture-hour equivalent for course projects, 2.5 ECTS; ≈30 lecture-hour equivalent for semester projects, 5 ECTS), making each module sum to 10 ECTS.

6 DISCUSSION

The IMO Polar Code, together with the 2017 STCW amendments for ice-water operations, prescribes a baseline of training requirements that can be met by a short course of perhaps 5–10 ECTS equivalent [13]. It would be possible to design a cold-climate add-on certificate at that scale. Three considerations argue that the 60-ECTS scope adopted here is justified despite the longer commitment. First, the case record of section 2 demonstrates that the operational gaps revealed by Arctic accidents are not addressable by certificate-level training: the Explorer master held an STCW-compliant ice-navigator endorsement, and the Northguider master held a valid certificate of competence for fishing operations, yet both incidents occurred. Closing the gap requires reformation of the underlying engineering and operational competence, not an additional endorsement on top of unchanged

competence. Second, the cross-cutting use of case material described in sections 4.4 and 7.2 above requires multiple modules across multiple semesters to function; concentrating it into a short course collapses the same case to a single reading and forfeits the multi-perspective induction that signature pedagogies require [36]. Third, simulator-based Safety-II training of the kind argued for in section 2.1 needs sustained engagement with progressively more demanding scenarios, which a short supplement cannot provide.

There is a legitimate intermediate option that the course design supports. Because the syllabus is modular, individual 10-ECTS modules can be offered as standalone professional development for officers and engineers who already hold STCW endorsements, or a shipping company seeking to upgrade its ice-experienced fleet officers might commission modules 6.2 and 6.6 only. The programme is therefore best understood not as a single 60-ECTS course in competition with STCW, but as a coherent year-long curriculum that also exposes a stack of standalone professional modules that complement STCW. The introductory bachelor-level modules mentioned in the abstract serve a parallel purpose at the entry side of the profession.

7 CONCLUSION

This paper has argued that the development of a one-year, 60-ECTS course in cold-climate maritime engineering is justified by four converging lines of evidence: the historical record of polar maritime accidents (section 2), the empirical record of controlled cold-climate exercises (section 2.11), the under-coverage of polar-specific competencies in current MET (section 3), and the pedagogical requirements of forming a profession rather than merely certifying it (section 4). Sections 2.2–2.8 set out seven cases from Maxim Gorkiy (1989) to Ocean 28 (2024) whose recurring causal patterns reveal the operational and organisational competencies the syllabus must deliver. Section 2.11 summarised the SARex 1, 2, and 3 exercises, which together demonstrate that current SOLAS-approved equipment and standard maritime training do not in practice deliver the five-day survival required by the Polar Code. Section 3 argued that those competencies are not transmitted reliably through STCW minima, supported by recent peer-reviewed evaluations of Polar Code training [3, 6] and by the dominant Arctic accident pattern of grounding [40]. Section 4 made the case for accident reports as a primary instructional resource and for their structured integration into module-level learning outcomes. Section 4 suggested a pedagogical approach based on Shulman's signature pedagogies [36] and Lave and Wenger's situated learning [19]. Section 5 described the modular structure that operationalises these arguments. Together, these sections could constitute the case for the syllabus and a starting point for collaborative refinement with partner institutions and industry.

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