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Stories From the Front Lines

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The Polarstern Atlantic Transect as a concept for shipboard training on ocean science

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Abstract

The significance of global marine education in ocean science and management is critical, especially in regions with weak infrastructure and economies. Therefore, knowledge generation as basis to establish and maintain essential research infrastructure, expertise, and management systems is crucial. In this context, we present the Polarstern Atlantic Transect Training (PSATT) as a versatile and proven shipboard training programme. This training is suitable for medium (50-100 m length, duration of at least5 days) and large (>100 m length, duration of > 14 days) research vessels, by scaling the modular nature of the educational concept. This programme can be adjusted to cater for vessels of various sizes and cruise durations, making it a valuable blueprint for similar marine education initiatives at sea. As a result, this tested concept provides an effective and adaptable framework for training at sea; it hasbeen conducted four times on board the research vessel (RV) Polarstern in 2015, 2016, 2019 and 2022 and trained so far 97 scholars on board. In this paper, we present a straightforward yet efficient framework for training at sea, designed to be inclusive, intercultural and international, as well as transdisciplinary and operational on research vessels. This approach aims to contribute to the development of skilled professionals in the field of ocean science and management.

Keywords: oceanography; climate science; capacity building; NoSoAT; POGO; SMART; SoNoAT; UN Ocean Decade; capacity exchange

Abbreviations

AANChOR:	All AtlaNtic Cooperation for Ocean Research and innovation
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
CTD:	Conductivity, Temperature, and Depth
ECOPS:	Early Career Ocean Professionals
FAO:	Food and Agriculture Organization of the United Nations
GMIT:	Galway-Mayo Institute of Technology
IFREMER:	Institut Français de Recherche pour l'Exploitation de la Mer
IOC:	Intergovernmental Oceanographic Commission of UNSECO
IPBES:	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC:	Intergovernmental Panel on Climate Change
JAMSTEC:	Japan Agency for Marine-Earth Science and Technology
NANO:	NF-POGO Alumni Network for the Ocean
NOOA:	National Oceanic and Atmospheric Administration
NERC:	Natural Environment Research Council
NoSoAT:	North-South-Atlantic Transect
PML:	Plymouth Marine Laboratory
POGO:	Partnership for Observation of the Global Ocean
PSATT:	PolarStern Atlantic Transect Training
RV:	Research vessel
SCOR:	Scientific Committee on Oceanic Research
SoNoAT:	South-North-Atlantic Transect
SMART:	Strategic Marine Alliance for Research and Training
xBT:	Expendable BathyThermograph
WASCAL:	West African Science Service Center on Climate Change and Adapted Land Use

Introduction

Global sustainability hinges upon the health and resilience of our oceans (OECD 2020). Knowledge generation, especially in economically disadvantaged regions and countries is lacking. It is related to the significant challenges of building and sustaining essential infrastructure, expertise, and management (Dañobeitia et al. 2023). A crucial aspect of these challenges is the imbalance in the global distribution of marine research infrastructure and the number of ocean management experts (UNESCO-IOC, 2015, 2017, 2022; www.ocean-ops.org/board). Especially in countries with emerging economies, many of which have long coastlines and big Exclusive Economic Zones (EEZ), this disparity is threatening the regional resources lacking a strong international impact. This disparity is further exacerbated by complex political and transnational stakeholder issues that shape how oceans are utilized and managed (United Nations 2017b; UNGA 2013, 2015). However, all regions are required to contribute data to global databases, following internationally-agreed standards, as well as its transformation into useful information for decision-makers (Miloslavich et al. 2019). This is linked not only to a lack of funding and instrumentation in countries with emerging economies, but also to a lack of scientific personnel capable to collect, analyse, and interpret oceanographic data (Krug et al. 2021). Furthermore, local and international careers in the ocean sciences are largely unavailable or inaccessible to interested students and graduates from countries with emerging economies as financial and infrastructural resources are limited (Osborne et al. 2022) . Therefore, the significance of global marine education, particularly in the realms of ocean science and management, cannot be overstated (Miloslavich et al. 2018). The ability of nations to manage their own coastal and marine environments and their resources is vital to the development and maintenance of national blue economies following the 2030 Agenda (Miloslavich et al. 2019, 2022). Strengthening education and training for various stakeholders can help to create an appropriately trained workforce able to develop, implement, and expand blue economies. While theoretical marine sciences and marine education is well-represented in countries with well developed economies and high GDP, providing practical and applied oceanographic education poses a substantial logistical challenge for educational institutions even there. One key obstacle lies in providing students and scholars with training experiences that mirror real-world conditions on board scientific research vessels (Hempel et al. 2016, Calazans 2022). Unfortunately, such opportunities are rare. Due to a severely strict, time efficient schedule of station work on board of research vessels, less time is spent on training the next generation of experts. This emphasizes the importance of shipboard experience and shipboard training of young researchers to learn about ocean technologies and simultaneous building a network. When available, trainings are usually within the framework of university teaching, and single berth opportunities (see Table 1).

Apart from the absence of opportunities on board or sea going training and infrastructure as operating research vessels the greatest issue is the lack of flexible, rigorously tested, shipboard teaching methods and educational concepts. Thus, training is often rather "*ad hoc*" and thus less effective. The development of an effective and useful training programme is thus pivotal for the seamless integration of education into the practical work of ocean professionals. Young ocean experts should have enough knowledge and understanding to be prepared for interactions with research and ship's crew at sea as well as governance and management processes in different countries. Therefore, the objectives of the Polarstern Atlantic Transect Training (PSATT) are to provide (1) a sound knowledge in deploying, using and retrieving instrumentation at sea and gathering quality controlled data, (2) ensuring that trainees can implement what they have learnt and (3) that trainees can operate in a team, communicate professionally with persons of different disciplines, nationalities and mind sets even under stressful and time-constrained conditions.

The major question arising with ship board trainings is what exactly should be taught. In some cases, training priorities are based on national interests. For instance, in Ireland trainings focus on multidisciplinary surveys including seabed mapping, whereas in Norway fishing assessment is of high interest (Groeneveld and Koranteng 2017), and in Japan, a deep understanding of seismic activity relies on developing capacity for use of sensor arrays and moorings. Keeping this diversity in mind, we realized the need to develop a flexible shipboard training concept. This is based on the premise, that if the educational structure is sound, then inserting a curriculum of different topics and specialties should be easy. Overall, a great degree of flexibility and pragmatism is required when setting up international ship-board trainings as the "Before-During-After" expedition requirements and needed actions will always be dependent on the disciplines, the overall cruise topic and route.

Additionally, science communication defined as generally understandable, dialogue-oriented communication of research and scientific content to target groups outside the scientific community is essential. Science communication has become an integral part of scientific research and is included as a selection criterion for many research funding decisions (BMBF 2019). To cope with general scepticism towards complex scientific results (Kearns 2021, Mede 2022), science communication and tailored outreach programmes are essential and therefore these aspects should be included in the training as well. In this article, we outline an effective structure for training at sea.

Methodological approach to develop a shipboard training

Programme development

In order to design and test the structure of a flexible shipboard training, we first refer to successful shipboard training setups. The Strategic Marine Alliance for Research and Training (SMART) programme, run in Ireland since 2011, is a collaborative partnership between the Marine Institute (MI), the Atlantic Technological University (ATU), the University of Galway (UG), the University College Cork (UCC), INFOMAR and the Geological Survey of Ireland. SMART provides vessel-based training in ocean science for undergraduates and postgraduates via pooling of infrastructure and teaching support. Then, over a period of ten years, as part of a cooperation between the Alfred-Wegener-Institute, Helmholtz Zentrum für Polar- und Meeresforschung (AWI), the Nippon Foundation (NF) and the Partnership for Observation of the Global Ocean (POGO) (https://pogo-ocean.org/capacity-development/centre-of-excellence/), and in collaboration with SMART, Stiftung MERCATOR (https://www.stiftung-mercator.de/en/), All-Atlantic Ocean Research and Innovation Alliance (AANChOR; https://allatlanticocean.org/) and more recently the All-Atlantic Floating University Network (@SeaNetwork), we set up and tested new ways of teaching ocean monitoring and *in situ* sampling. As the first "proof of concept" collaboration, the Atlantic Summer School on Deep Water Coral Ecosystems was carried out on the RV Celtic Explorer over five days in the Porcupine Bank (NE Atlantic). First operability tests were carried out on five one or two-week national research cruises on the RV Celtic Explorer (Ireland) in the Irish Sea. Next training activities in-

Table 1. Overview of existing shipboard training activities, with grey background groups of trainees, white background single berth training activities.

Training title |expedition title	Ship	region	year	Host institution	Target group
NF-POGO-SeaNetwork Shipboard Trainings	RV Belgica	English Channel, Bay of Galway, Atlantic	2023	University of Gent	
NF-POGO-Eurofleets + Shipboard Trainings	RV Dana, RV Sarmiento de Gamboa,	Baltic Sea, Off Spain/Portugal coast, Iberian Upwelling system , Atlantic	2021 -2023	Eurofleets+	
Radiales del Mediterráneo (RADMED)	RV Francisco de Paula Navarro, B/O Ángeles Alvariño	Western Mediterrean region	2018, 2019, 2021, 2022, 2023	Spanish Institute of Oceanography	
Radial Profunda de Finisterre (RADPROF)	B/O Ramon Margalef	Northwest Iberia basin. Atlantic	2023	Spanish Institute of Oceanography	
CSIRO Operated Cruises	RV Investigator	Southern Ocean	2023	Commonwealth Scientific and Industrial Research	
GEOMAR South Atlantic Research Cruises	RV Meteor	Angolan and Benguela upwelling system	2023, 2019, 2018	GEOMAR Helmholtz Centre for Ocean Research	
WASCAL Floating University	RV Polarstern	Cape Verde to Bremerhaven , Atlantic, English Channel, North Sea	2023	GEOMAR Helmholtz Centre for Ocean Research	WASCAL Students
Atlantic Meridional Transect (AMT)	RRS James Clark, RRS James Cook, RRS Discovery	Atlantic, between the UK and the Falkland Islands	2008- 2014, 2017, 2018, 2019, 2023	Plymouth Marine Laboratory	early scientists, technicians, postgraduate students (PhD or MSc) and Post-doctoral Fellows
POLMAR	RV Polarstern	Atlantic, Bay of Biscay, English Channel, North Sea	2014, 2016, 2017, 2022, 2023	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung	POLMAR scholars (PhD candidates)
NoSoAT; SoNoAT	RV Polarstern	Atlantic (N-S), Angolan and Benguela upwelling system, Bay of Biscay, English Channel, North Sea	2015, 2016, 2019, 2022	Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung	postgraduate students (PhD or MSc
seRies temporAles De oceanografIA en eL norte de ESpaña (RADIALES)	RV Lura, B/O Ramon Margalef	Bay of Biscay	2022, 2019	Spanish Institute of Oceanography	postgraduate students (PhD or MSc)
NF-POGO-NIOMR Shipboard Training Fellowship	RV Bayagbona	Gulf of Guinea	2020	Nigerian Institute for Oceanography and Marine Research	postgraduate students (PhD or MSc
British Antarctic Survey (BAS) operated cruise	RRS James Clark Ross	South Georgia, South Atlantic.	2019	British Antarctic Survey	career scientists, technicians, postgraduate students (PhD or MSc) and Post-doctoral Fellows
Porcupine Abyssal Plain (PAP) Observatory	RRS James Cook, RRS Discovery	Atlantic, Porcupine Abyssal Plain	2017–2019	National Oceanographic Institution	career scientists, technicians, postgraduate students (PhD or MSc) and Post-doctoral Fellows
Mediterranean Ocean Observing System on Environment (MOOSE)	RV Thalassa	Mediterranean	2019	Institut francais pour la recherche et l'exploartion de la mer	early career scientists, technicians, postgraduate students (PhD or MSc) and Post-doctoral Fellows
Antarctic Deep Water Rates of Export (ANDREX)	RRS James Clark Ross	Scotia Arc	2019	Plymouth Marine Laboratory	early career scientists, technicians, postgraduate students (PhD or MSc) and Post-doctoral Fellows

Table 1. Continued

Training title |expedition title	Ship	region	year	Host institution	Target group
NF-POGO Shipboard Training Fellowship	RV Maria S. Merian	Mediterranean	2018	Spanish Institute of Oceanography	postgraduate students (PhD or MSc)
NF-POGO Shipboard Training Fellowship onboard GEOTRACES GA13-FRidge cruise	RRS James Cook	North Atlantic	2018	University of Liverpool, University of Southampton and Plymouth Marine Laboratory (PML)	postgraduate students (PhD or MSc)

cluding fish biology and macrofaunal aspects were carried out on RV Heincke (Germany) and RV Uthörn (Germany) in the North Sea, with small groups of international students to evaluate our concept. The modular teaching structure offered more than one topic, with different teachers as experts on board. Having established this and realizing that sea-sickness was generally a problem for the scholars in the beginning, we decided that cruises of at least five days were needed, in order to allow scholars to get used to the vessel and its movements.

After this "proof of concept" phase, the teaching concepts were scaled up for the largest European ship and on the longest research transect (4–6 weeks) available to us, namely the RV Polarstern (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung 2017) during her transits between ports. This required funding, which was sought from international organisations, such as the Nippon Foundation and POGO. 30 training fellowships were offered in an international tender to participate in the 2015 North-South Atlantic Training Transect (NoSoAT). The next training transects in 2016 and in 2019 attracted 380 and 793 applications respectively (from 88 countries) for 25 scholarships respectively. This is an overwhelming demonstration of the high interest and need for this type of training. The shipboard training was then tested and implemented as described below, on RV Polarstern (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung 2017) on the PS95 (2015), PS102 (2016), PS 120 (2019) and PS 132 (2022) expeditions (Knust and Lochte 2016, Wiltshire et al. 2017, Wiltshire and Brodte 2020, Wiltshire and Dummermuth 2023).

Pre-training cruise planning

Based on experiences of planning and conducting shipboard trainings during several expeditions on board the RV Heincke and RV Polarstern the following strategic considerations, sampling routines and educational concepts were developed. Before starting the expedition actually at sea, a period of one to two years is needed for preparing this educational expedition years. The organisational considerations and issues, which may occur, are presented in a flow diagram of process in time frame in Fig. 1.

Selection of ship and instrumentation for on board training

The choice of the research vessel includes considerations of requirements for the successful execution of the training. Especially, considering that the proposal for ship time needs to be handed in two years in advance of the expedition, multi-purpose ships, which are adaptable to various conditions and topics, are a good, versatile option. The vessels should provide at least twelve berths for scholars and teachers, and the operational area should be suitable for the training topic. The duration of the expedition should include at least five days at sea to allow the scholars to adapt to the sea going conditions during the training and immerse in the board routine.

At least a variety of three different main gears or devices should be available on board (1) deployment of CTD rosette, plankton nets, expendable bathythermographs (xBT), (2) links to modern technology (e.g. satellite images and sonar

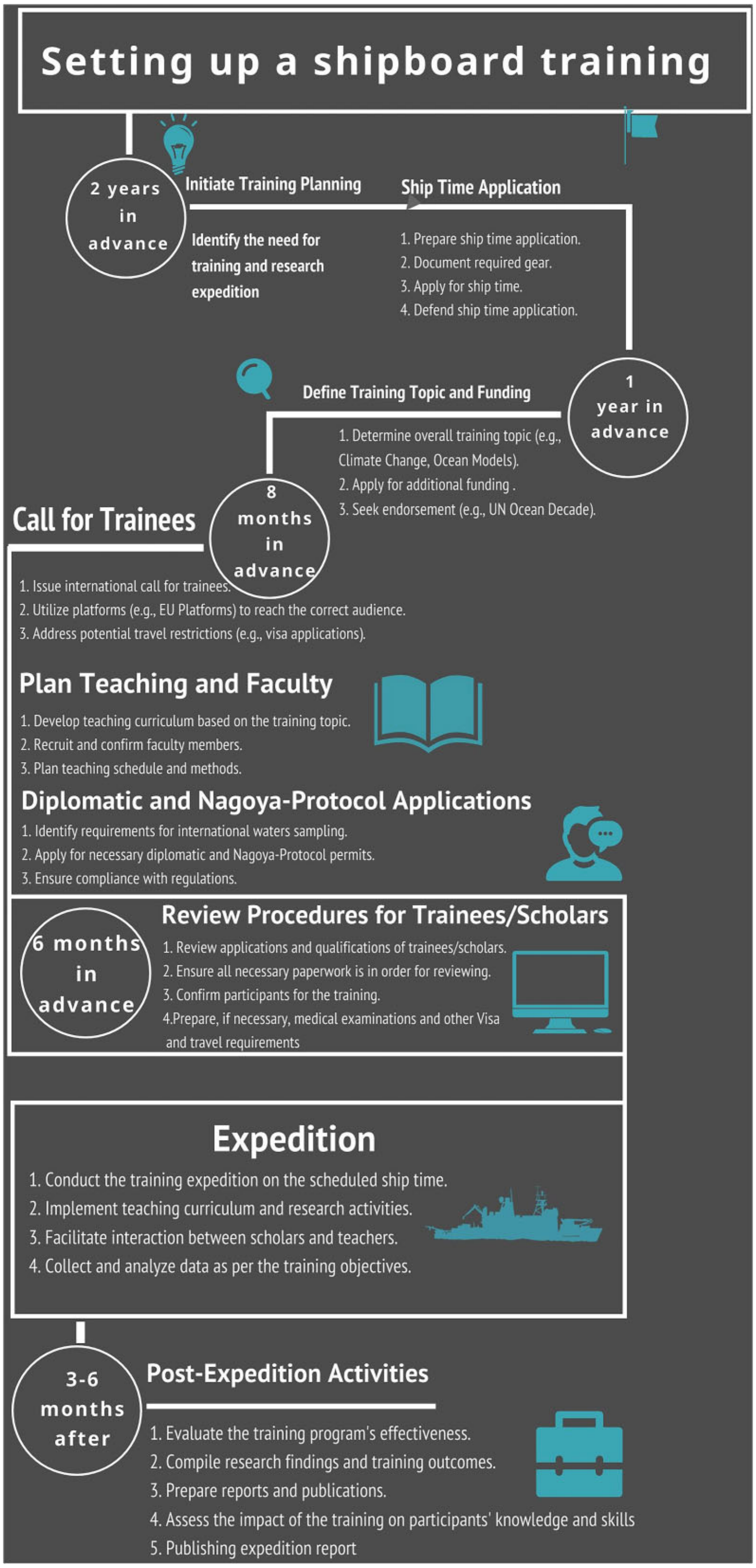

Figure 1. Flow diagram providing an overview of the steps involved in setting up the training, ensuring that each aspect is carefully planned and executed to achieve a successful training programme.

devices), and (3) a good balance between low-costs devices (Secchi discs and buckets) and high-tech devices, which are mostly in the high-cost category, is important (see Table 2) allowing students to get acquainted with the full spectrum of oceanographic instrumentation. Especially the application and use of low cost or cost efficient instrumentation should be included in the training. Examples of developments of these devices can be found e. g. in the OPENMOD project

Table 2. Useful marine sampling devices and gear on board a training expedition.

Gear	acronym	Interoperability	Low cost	Medium cost	High cost	Use on station	Use En-route
Multibeam Swath-mapping system Atlas Hydrosweep DS-3	DS3	partly			X		X
Single beam echosounder		partly			X		x
Gravimetry	GRAV	partly			X		X
Magnetometer	MAG	partly			X		X
ParaSound	PS	partly			X		X
Acoustic Doppler Current Profiler	ADCP	partly			X		X
Expendable Bathythermograph	xBT	Yes		x			x
PAR Light meter		Yes		x			x
Continuous plankton recorder (CPR)	CPR	Yes			X		X
Bucket		Yes	x			x	
Secchi disc		Yes	x			x	
Plankton nets		Yes		x		x	
Water rosette sampler		Yes			x	x	
Conductivity Temperature Density Profiler	CTD	Yes			x	x	
Underway Conductivity Temperature Density Profiler	Underway CTD	Yes		x			x

(https://pogo-ocean.org/innovation-in-ocean-observing/activities/openmods-2-0-open-access-marine-observation-devices-implementation/) or the SAGITTA project (https://nf-pogo-alumni.org/projects/global-citizenscience/). Instruments developed and used in terrestic or limnic fields of application may serve as well as a good cost-efficient option for sampling in the marine or oceanographic context when they are applied to only the upper water layers.

Specific examples of funding agencies and partners

Shipboard training is costly. German and European research vessels can be accessed with a proposal for ship time according to their respective guidelines and via web portals (https://www.eurofleets.eu/access/calls-application-procedure/and https://www.portal-forschungsschiffe.de/en/cruise-proposals.html). However, each berth dedicated to training is a berth less for other professional activities. Only institutions with secured funding, together with funding agencies or international organisations can offer an/or fund berths for training (Table 3). Inclusive, inter-cultural and international trainings particularly addressing scholars with little or no financial opportunities require full scholarships including travel and accommodation.

In 2003, POGO, in partnership with its member Japan Agency for Marine Earth Science (JAMSTEC) offered training opportunities for 17 young researchers from countries with weak economies on the six legs of the circumpolar Blue EArth GLobal Expedition (BEAGLE) on board the RV Mirai. Since 2008, POGO established a partnership with Plymouth Marine Laboratory (PML) and National Oceanography Centre (NOC), to guarantee one or two berths for trainees from countries with emerging economies on board the annual Atlantic Meridional Transects. In 2009, SMART, a consortium of Irish Higher Education Institutes and the Marine Institute, developed a series of multidisciplinary marine science training courses for university students on board the national research vessels and was part of the Eurofleets programme that delivered “Floating Universities” across Europe.

In 2014, combining their acquired knowledge, AWI, POGO, Nippon Foundation, Mercator Stiftung, AllAtlanticTraining programme (AtlantOS), SMART, AANChOR and others, joined efforts on developing training concepts. During the process, the need for a platform to aggregate all available opportunities became apparent. In 2017, the AWI, NF, POGO and SMART launched the Ocean Training Partnership (OTP, https://www.oceantrainingpartnership.org). OTP makes both training programmes, berths and funding for training internationally more visible and, to this date, lists over 50 successfully delivered shipboard trainings that involved nearly 170 young researchers over the years. In 2022, the global training network @SeaNetwork was founded. Run by a governing board of volunteer scientists, this initiative is a direct result and continuation of the successful training concepts presented here and an output of the AllAtlanticTraining programme and AANChOR. As an implementation of the Belém Statement on Atlantic Research and Innovation Cooperation and a triangular declaration between South Africa, Brazil and the EU these programmes seek to increase the understanding of the relationship between marine ecosystems and climate (Claassen et al. 2019) and promote the need for training at different professional levels (e.g. scholars, young scientists and technicians). The training of several scholars simultaneously in a group as a cohort is additional beneficial as they can interact and learn from each other. We found that for each training, even though we had secured core funding, additional financial support was needed, along with “in kind” contributions. The most generous volunteer support was provided by the ship crews, other scientists and especially from the teachers, who received only flight, food and berth.

Application and selection process

In order to ensure equal opportunities, the calls for applications to the training expeditions PS95 (2015), PS102 (2016), PS120 (2019) and PS132 (2022) were advertised broadly via email and social media. The different social media channels were particularly accessible and useful in terms of global dissemination, different age and regional groups (Shabir et al. 2019; Nicholas and Rowland 2011).

The evaluation procedure of the applications mainly followed the suggestions of Miloslavich et al. (2018) with the selection criteria (1). relevance to research or career, (2) quality of motivation to join the training, (3). quality of grades,

Table 3. Examples of institutions with secured funding, funding agencies or international organisations providing support for shipboard training.

Helmholtz Association of German Research Centres	Helmholtz	Germany
Natural Environment Research Council	NERC	UK
Centre National de la Recherche Scientifique	CNRS	France
Institut Français de Recherche pour l'Exploitation de la Mer	IFREMER	France
Commonwealth Scientific and Industrial Research Organisation	CSIRO	Australia
National Oceanic and Atmospheric Administration	NOAA	US
Japan Agency for Marine-Earth Science and Technology	JAMSTEC	Japan
Partnership for Observation of the Global Ocean	POGO	
Intergovernmental Oceanographic Commission of *UNESCO*	UNESCO- IOC	
Eurofleets		Europe

reference letter and (4). experience listed in the CV. With this strategy, an applicant with stronger professional potential (e.g. high grades or good references) and lower chances of taking part in scientific expeditions (e.g. parent institutes do not own a research vessel) scored highly.

The reviewing process itself was done by a panel of volunteering scientists also involved in the on-board training and/or support of the expedition. The applications were randomly partitioned into batches which were reviewed by a team of up to twelve reviewers. Once the top 30 candidates had been chosen, the potential scholars were interviewed to gain an insight into their personal attributes, team spirit and general potential.

Choice of training topics/modules and teachers

The selection of educational subjects and instructors aimed to align with societal needs. For instance, in 2016, the focus of NoSoAT (PS102) was on addressing climate change following the UNFCCC COP-22 meeting in Marrakech. Eminent international educators were invited to teach relevant subjects. In 2019, the SoNoAT training (PS120) emphasized the importance of ocean sustainability and supported the global climate movements, advocating for a sustainable future. The 2022 NoSoAT programme (PS132), focused on the theme "Healthy and Resilient Ocean," endorsed by the UN Ocean Decade, in a dedicated cruise (UNESCO-IOC 2022, 2021). The chosen topics always revolved around fundamental concepts, highlighting the ocean's vital role in Earth's weather, climate, terrestrial environment, and human sustenance.

A constant component of this on board training was practical oceanography. This module is designed in the same manner as would be a land-based class, being built around a set of defined learning outcomes, which are relevant to global ocean observing networks, and that would enable participants to acquire all the research skills and tools required for example, to identify and characterize various water masses throughout the water column along an Atlantic Transect. The training includes introduction to the theory and standard operating procedures with regards to the setup, calibration, maintenance and deployment of CTD equipment, sensors and water sampling in open ocean or coastal waters. Students then take part in all aspects of the CTD station. Beginning with pre-deployment setup and planning, including the examination and interpretation of historical data. Followed by the deployment of the CTD into the water and selection of the depths for the water sampling, and the safe recovery of the CTD from water and subsequent water sampling from the Niskin bottles. The Health and Safety aspects of every activity are also central to this module, along with communication skills for shipboard work, with a vocabulary agreed before starting deck work, as students have differing abilities in English and/or German, the languages used onboard. This exercise was crucial for capacity development in oceanography as it equipped the scholars to manage their resources in their home countries more effectively, but also to build the global scientific capacity to monitor, manage and adapt to ocean change (Bax et al. 2018).

Our training approach was flexible, adapting to prevailing global concerns and issues such as COP-22, the Intergovernmental Panel on Climate Change (IPCC), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES reports), or Marine Plastic Pollution and Marine Protected Areas awareness. Topics of regional or temporal relevance for scholars (e. g. projects or (weather-) events) can be integrated in the educational concept by adapting of change in modules, e.g. swapping microplastic and eDNA or marine microbiology. Additionally, maritime law, diplomacy, and regulations governing sampling in national and international waters were integral to our training. The applications for sampling in national waters and for permission under the Nagoya Protocol are of pivotal importance for the training of the next generation of scientists.

Safety protocols, personal well-being, and effective professional communication under stressful sea conditions were actively integrated. Conflict management techniques were also part of the training curriculum. Furthermore, we emphasized the significance of transdisciplinary communication of scientific matters to the wider public. Participants practised effective communication strategies, including social media engagement, discussions with politicians and diplomats, public lectures, and video conferences with school children. This holistic approach ensured that our training did not only impart scientific knowledge, but also nurtured essential skills for effective communication and problem-solving in the field of ocean sciences.

Evaluation of the developed concept on sea

The Polarstern Atlantic Transect Training (PSATT) was the final and most comprehensive product and could be used as a blueprint for similar capacity development and marine education projects at sea. The PSATT was conducted between the ports of Bremerhaven and Cape Town (Fig. 2) and consists of about 10 stations.

The PSATT training concept and structure

The training structure which we developed could easily slot into a ship's routine sampling and operation. It started with the adaptation of scholars to professional ship routines and

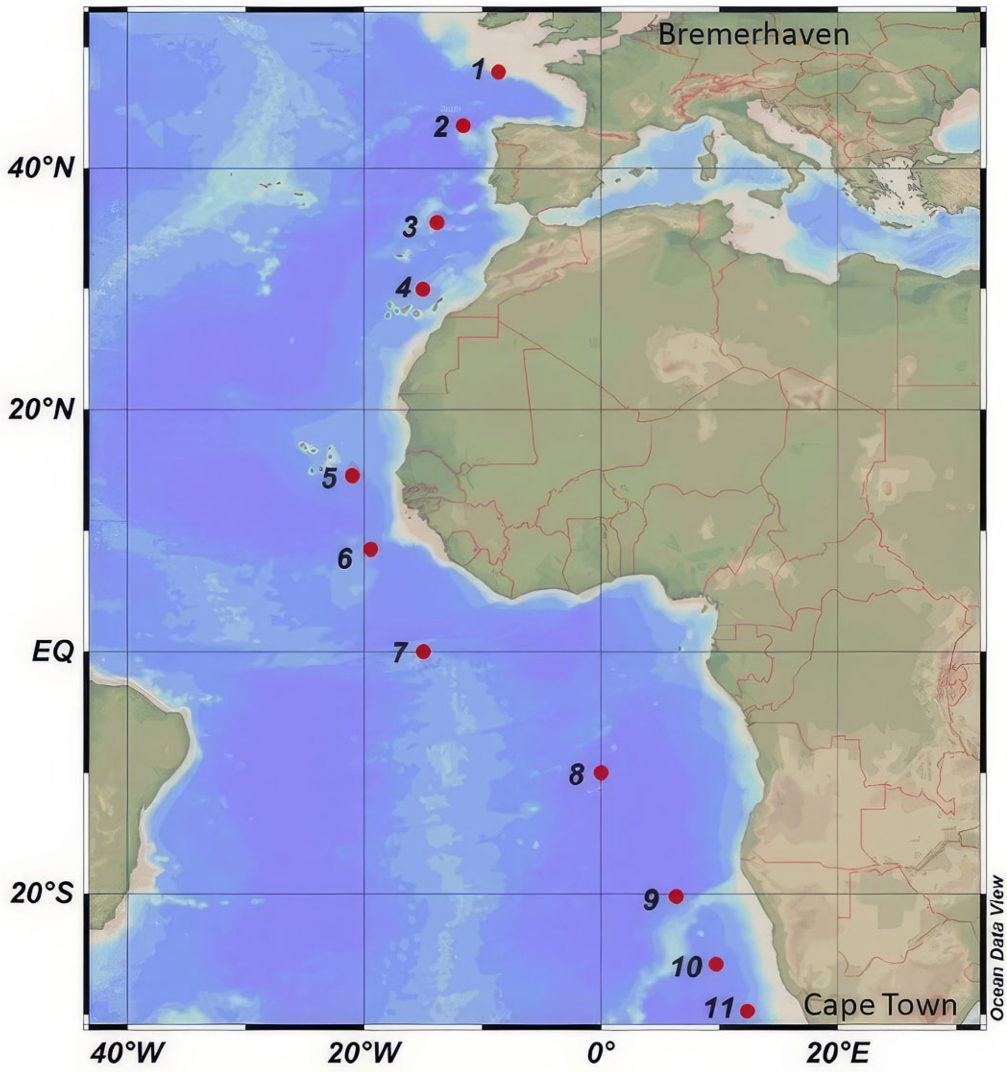

Figure 2. Map of the transect of the PSATT, the dots represent stops for station work along the transect. 10 stations are mandatory, the 11th station is optional.

group discussion based on an overall question chosen with the scholars (e.g.: how does warming affect the biogeochemistry of the ocean?). The group session was usually in a short pre-cruise workshop or in the days following departure from port. With the ship underway, a rotational training structure was adopted, with five to six modules related to the overall question (Fig. 3).

For the NoSoAT and SoNoAT expeditions, on which this concept was tested, five modules with groups of five scholars for five days proved to be a very workable option (Table 4, Table 5).

The modules were very practical in nature and the lectures and discussions related to the data resulting from sampling and en-route measurement. As the training needed to be hands-on, eleven deep ocean sampling stations for the CTD and water-rosette were included. At each station, sampling with the 24 Niskin bottles and CTD-derived profiles were conducted by the trainees, as well as subsequent nutrient analyses in the laboratories. Where possible, underway measurements were planned like e.g. XBT deployments, surface water bucket samples, weather observations, bathymetric surveys and echo sounding with multibeam or sidescan. Scholars were given reading materials in advance and encouraged to download data from satellites, seabed mapping and underway ship instruments from data archives. On-deck and crew communication skills and safety were taught in real-life situations jointly with crew on board the vessels.

Summary of the PSATT training concept and structure

We trained 97 young researchers on the training expeditions, all of which were invited to join the NF-POGO Alumni Network for the Ocean (NANO; https://nf-pogo-alumni.org/). We evaluated the effects of the training via a survey after one year (Fig. 4) and found that 88% of the former scholars had continued their careers in climate, ocean or marine research. 89% of the former scholars claimed that the training had a supportive influence on their careers. We asked the scholar what their main intention was to join the shipboard training, 95% named gaining experience on sea and gaining knowledge in observational technologies; 75% stated that “they were looking for an opportunity that would give them tools that they did not feel were available to them in their home

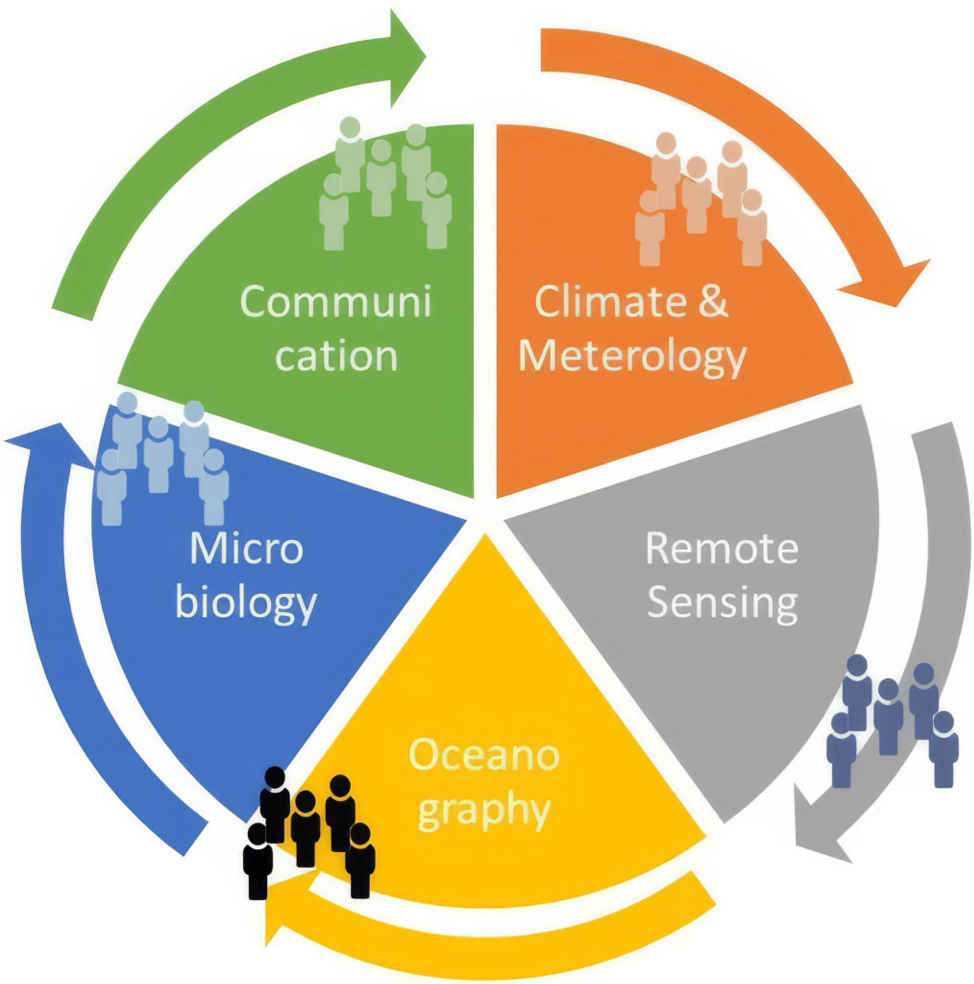

Figure 3. The rotating scheme of groups of scholars between the modules.

Table 4. List of modules during four expeditions with the overlying topic interlinking Ocean, atmosphere and climate.

Expedition	NoSoAT PS95	NoSoAT PS 102	SoNOAT PS 120	NoSoAT PS 132
Module 1	Climate system	Climate system	Climate system	Climate system
Module 2	Oceanography	Oceanography	Oceanography	Oceanography
Module 3	Remote sensing	Remote sensing of ocean and atmosphere	Remote sensing of ocean and atmosphere	Modelling
Module 4	Communication	Ocean and climate governance	Organisms and microplastics	Bathymetry
Module 5	Foodwebs of the ocean	Viewing science and nature through art	Data crunching and statistics	Microbiology

country". Multidisciplinary, hands-on learning and the international intercultural aspects of the expedition were named as the personally most appreciated aspects.

We set out from the beginning to combine both aspects of "training" and "science"-driven expeditions under the premise of a long-term monitoring programme with rigorous, scientific quality control of the data. Because of the insertion of the trainings onto scientific research vessels, we had not only trained scientists, but also provided valuable fundamental data sets to the marine community which had been archived and made accessible via PANGAEA (https://www.pangaea.de/). These data sets and expeditions are listed below (Table 6). Data sets include data on deep profiles on 10 stations (temperature, salinity, pigments, oxygen and in some expeditions nutrients) sampled by using the CTD and water sampler. Bathymetry data and xBT profiles along the transect were taken as well. Information on plankton (qualitative) and microplastic enroute as well as microbial communities were available for some of the four expeditions. The data sets are available via PANGEA under the links listed in Table 6.

The conducted training expeditions provided the public with valuable and highly visible science, by simultaneously teaching the scholars different levels of communication skills. In terms of social media engagement, which increased from 2015 to 2022, the posts and feeds reached a wide audience. As on the first hashtag #NoSoAT from the official AWI account on X (former Twitter; "@AWI_media") in total 11 posts were found. There were 297 engagements including likes, retweets and comments, 12 242 impressions and 688 interactions. The next expeditions produced 179 posts with

Table 5. Content of possible modules.

REMOTE SENSING	This module introduced to atmosphere and ocean colour remote sensing, satellite sensors such as Ocean and Land Colour Imager, and products for ocean colour and aerosols. It also included computer exercises with software for satellite data visualisation and processing daily practical measurements of *in situ* optical ocean colour and aerosols parameters with sensors (Ramses, Hamamatsu, Microtops), and analysis of results (blue-green ratio, algae algorithms, and aerosol) with programming language Python.
CLIMATE & METEROLOGY	The climate and meteorology module provided evidence of climate variations on all time-scales, and presented an introduction to the physics of the climate system, with a special focus on atmosphere, ocean and ice. Exercises dealt with specific climate processes and with the energy balance of the Earth and other planets. In addition, various atmospheric measurements were taken and discussed. A standard task was the interpretation of the data from radiosonde ascents provided by the weather station of the German Weather Service on RV Polarstern
MICROBIOLOGY	Scholars took water samples and filtered it sequentially through a pore size of 10 μm, 3 μm and 0.2 μm on board in the lab. Filters containing the smallest size fraction (3 μm to 0.2 μm) were processed on the ship, beginning with DNA extraction, followed by a PCR with barcoded primers and a subsequent gel electrophoresis of the amplicons. Unfiltered seawater (750 μl) from different depths were additionally stored in 750 μl glycerol (30%) and frozen, and 100 μl was plated to observe CFU growth. At every depth, where the samples for the eDNA were taken, samples (filters) for FISH were collected
COMMUNICATION	The scholars were trained in outreach and science communication projects, such as blog writing, social media feeds, creating short videos for educational purposes, answering questions from school kids via video conferences. One specific outreach activity was the “miniboat” outreach project in collaboration with Educational Passages (USA), National University of Ireland (Ireland), Spanish Institute of Oceanography (Spain), South African Environmental Observation Network and the Department of Forestry, Fisheries and the Environment (South Africa). School children from Germany, Ireland, South Africa, and Spain assembled and decorated 1.5 m long sailboats carrying satellite transmitters and sensors for air and water surface temperature, which were shipped to board the cruise. On board, the scholars prepared and deployed the miniboats, which sent data and locations to a public webpage. The activity included live interactions between the scholars and the children and proved to be an extraordinary opportunity for children in different countries to interact with one another, with their local oceanographic institution, and with the scientists on board the RV Polarstern.
OCEANOGRAPHY	Scholars were introduced to different sampling concepts, planning, techniques and devices, learning different measurement techniques and accuracy, and common oceanographic instrumentation, including CTD and flow-through systems (thermosalinograph/Ferrybox). The scholars learned how to identify the different sensors (including conductivity, temperature, density, pressure along with an integrated fluorometer for fluorescence (Chlorophyll A) and a turbidity sensor.) on the CTD rosette. How to set-up and check a Niskin bottle prior to deployment was as well part of this module. They were taught how to plan their bottle sampling strategy on the upcast, prior to deployment, based on the expected locations of the different water masses anticipated to be encountered at that location. All deck and winch room operations during deployment were explained to the students prior to beginning the station and they were taught the basic operations of the Seabird CTD software, the event logger on the RV Polarstern and the programmes for post processing of the data into Ocean Data View software. The scholars collected water samples for dissolved gases, nutrients and phytoplankton from the Niskin bottles for use in this and other modules. Upon completion of the station, the students cleaned the CTD and prepared the Niskin bottle set for the next deployment. In this module, the scholars were also taught to deploy the xBT and to communicate with the ship’s crew for its safe and successful release.

#SoNoAT written by 79 users increasing engagement. There were 566 engagements and 159.571 impressions reported. In general, 77% of the posts were retweeted. The visibility of these expedition in social media were likely much higher, as posts from POGO, external partners, scholars and teachers were not included in this overview. The posted content focused on the scientific results of each expedition edited for the public audience. Examples of infographic tweets based on the data collected by scholars on the cruise are given in Fig. 5 below.

Apart from using social media channels to target different age groups (Kalmus et al. 2013), direct engagement with school children was established by videoconference sessions involving multiple schools from 2016 to 2022 (Table 7). The chief scientist and senior scientists were promoting, teaching and direct live conferencing at different venues (Table 7).

Numerous blog posts were written by scholars regarding their experience on board (group-written) or personal professional journey (individually written). The blog posts were published in the Helmholtz/Polarstern webpage and partly translated into different languages and, in 2022, in the Polarstern App, enabling live tracking including position and weather data as well as photos and reports from the ship.

Discussion

Presently, oceans and their ecosystems face significant challenges due to pollution, warming, and increasing acidity. More people than ever are dependent on coastal and shelf seas for their livelihoods, in means of transport and resources (Burke et al. 2001, Duedall and Maul 2005). Ocean and coastal management policy based on practical knowledge is increasingly required to ensure a marine future. This is highly dependent on provision and maintenance of environmental infrastructure, management concepts, legislation and especially on well-trained and practical experts in ocean and coastal environmental science. Developing enduring capacities for observing and monitoring the ocean requires investments in people and their institutions to build infrastructure, ownership, knowledge and long-term support networks (Bax et al. 2018).

This manifests in a complex marine research environment with a great need for applied and practical marine scientific education (Brusca 2024). Already in the late 1990s, organizations such as POGO identified a lack of practical shipboard training and education for graduate students (Isensee 2020, Urban and Seeyave 2021) and set up cooperation in capacity development with the Scientific Committee on Oceanic Research (SCOR) (Urban and Seeyave 2021). Many institu-

Table 6. Data resources gained during the training expeditions. .

Expedition	PS132	PS120	PS102	PS95.2	PS95.1
Expedition alias	NoSoAT	SoNoAT	NoSoAT	NoSoAT	NoSoAT
Embarkation (date, harbour)—Disembarkation (date, harbour)	2022–08–30 (Bremerhaven)–2022–09–29 (Cape Town)	2019–06–02 (Port Stanley)–2019–06–28 (Bremerhaven)	2016–11–16 (Bremerhaven)–2016–12–13 (Cape Town)	2015–11–09 (Las Palmas)–2015–12–01 (Cape Town)	2015–10–29 (Bremerhaven)–2015–11–08 (Las Palmas)
Research Locations	Atlantic Ocean	Atlantic Ocean; Canarias Sea; South Atlantic Ocean	Canarias Sea; Celtic Sea; South Atlantic Ocean	Canarias Sea; South Atlantic Ocean	Bay of Biscay; Celtic Sea; English Channel; South Atlantic Ocean
Chief scientists	Wiltshire, Karen Helen	Wiltshire, Karen Helen	Wiltshire, Karen Helen	Lochte, Karin	Knust, Rainer
Expedition programme	hdl:10013/epic.c09eb9fd-ce31-4587-bdfd-a9f805d54f33	hdl:10013/epic.7704c489-c54c-4c02-aa1b-b834aee91abd	Expedition program: hdl:10013/epic.48850.d001	Expedition program: hdl:10013/epic.46084.d001	Expedition program: hdl:10013/epic.46084.d001
Report	doi:10.57738/BzPM_0771_2023	doi:10.2312/BzPM_0740_2020	Report: doi:10.2312/BzPM_0713_2017	Report: doi:10.2312/BzPM_0702_2016	Report: doi:10.2312/BzPM_0702_2016
BSH ID	*BSH ID:* 20220012	*BSH ID:* 20190004	*BSH ID:* 20160160	*BSH ID:* 20150014	*BSH ID:* 20150014
Expedition map	Expedition map PS132	Expedition map PS120	Expedition map PS102	Expedition map PS95.2	Expedition map PS95.1
Event list	Event list PS132	Event list PS120	Event list PS102	Event list PS95.2	Event list PS95.1
Data	Data PS132	Data PS120	Data PS102	Data PS95.2	Data PS95.1
Mastertrack	doi:10.1594/PANGAEA.952489	doi:10.1594/PANGAEA.904054	doi:10.1594/PANGAEA.872695	doi:10.1594/PANGAEA.848843	doi:10.1594/PANGAEA.859019

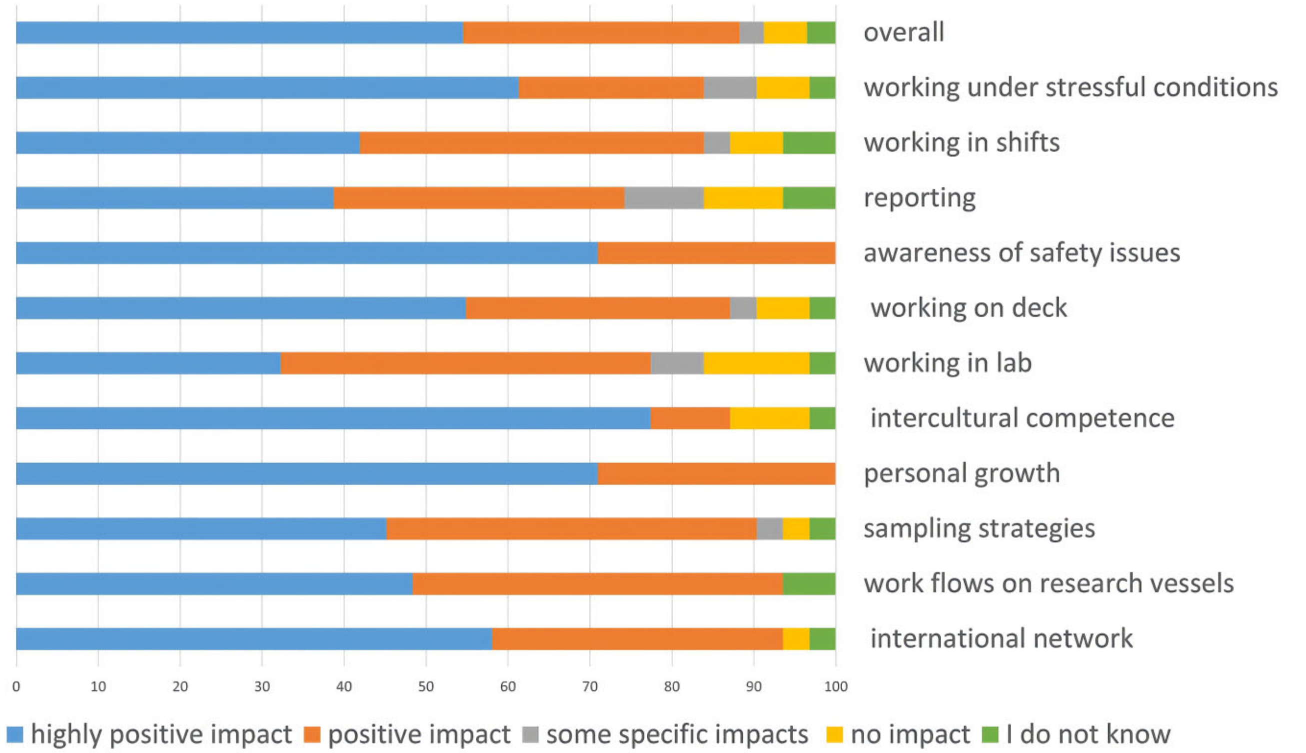

Figure 4. Evaluation of the shipboard training (voluntary participation one year after successful completion of the shipboard training, n = 31); Answers to the question: "How would you judge the impact on your professional and personal development?" The scholars distinguished between the answering options the shipboard training had a highly positive impact, a positive impact, a specific impact (specific modules), or no impacts or that they do not know. Especially the categories "personal growth" and "awareness of safety issues" were positively named.

tional, NGO and private initiatives such as the Nansen Programme by the FAO (Groeneveld and Koranteng 2017), or the West African Science Service Center on Climate Change and Adapted Land Use (WASCAL) focus on specific geographical regions (Olusegun et al. 2017).

In the past 10–15 years large European initiatives such as Eurofleets have been very successful in using research vessels for training voyages and for specialized on-/inshore marine training which mainly focus on single persons or small groups joining expeditions as trainees. One benefit of shipboard training in groups is the opportunity for the participants to build a network amongst peers (Krug et al. 2025; Satterthwaite et al. 2022). The All-Atlantic Ocean Capacity Development and Training Platform has indicated training at sea as critical for preparing the new generations of Early Career Ocean Professionals (ECOPs). By bringing existing initiatives and programmes together to strengthen further trainings the All-Atlantic Floating University Network was created (@SEAnetwork).

However, few of these programmes have published the methodologies and educational curricula used, or the success rates of this training. The UN Ocean Decade declared sustainable capacity building as one goal and fostered activities on capacity exchange, gender equality and inclusive approaches (Ryabinin et al. 2019).

Educational concepts aiming for gender equality, internationality, and anti-discrimination, as well as on trans- and interdisciplinarity are essential (Wisz et al. 2020). This urgency for fair, cross-disciplinary research is high (Wisz et al. 2020). Even recently launched projects addressing the imbalance in scientific resources between the countries of high economic income and countries with low economic income still show inequality in norms, perception and a lack of inclusion (Mahajan et al. 2022).

Overall, with an increasing number of marine experts being educated worldwide, the demand for usage time on research vessels for practical training on ships increases as well has hardly improved (Ryabinin et al. 2019). Indeed, although in the marine sciences, training on research vessels is an essential pillar of science education (Urban and Seeyave 2021), the opportunities for scholars are still rare exceptions. Due to the high demand of ship time for research it takes immense efforts and dedicated programmes, as well as personnel to develop and run such training programmes. Notably, ships are increasingly rarely operated by educational institutions. Additionally, the modern bachelor/master curricula are so tightly packed, that it is even more difficult for students to participate in research expeditions (Winter and Anger 2010, Winter et al. 2012).

The Polarstern Atlantic transect training (PSATT) has shown to be an extremely successful and flexible international ocean training, which can be used as an educational blueprint for any shipboard training on medium to large research vessels.

The importance of outreach and dissemination of the objectives and the scientific results cannot be overestimated. The scholars coming from different regions of the world are key communicators towards their local communities and peer groups. Several scholars have given talks in local schools and universities or were featured in local print media (Krug et al. 2025). This aligns with the Sustainable development goals (SDG) report (United Nations, 2017a) which emphasize the

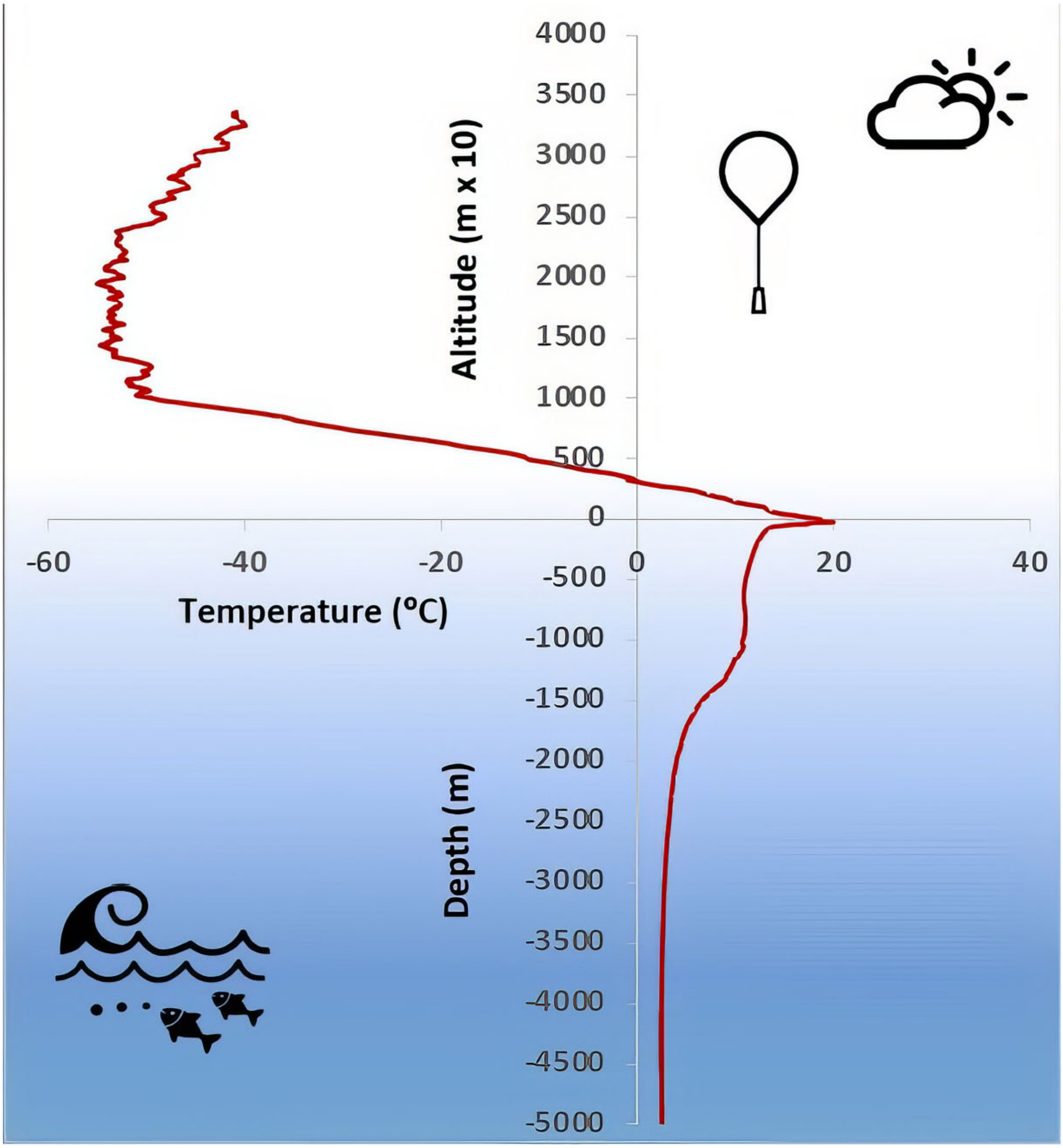

Figure 5. Example of an infographic depicting in 2D the temperature change from the bottom of the sea to the top of the atmosphere from measurements taken on a sampling day on board. The corresponding X (twitter) post from 09.09.2022 was "Deep Oceans: still a cold environment. Far below the ocean's surface, at 5000 m deep, the temperature is 2.5°C. In comparison, at 5000 m altitude, it is −11°C. In the troposphere at 30 km, our weather balloon indicated −40°C. Are the deep oceans getting warmer? That is the question.."

importance of activities to educate and reach data users. This report clearly separates the use of different media for different target groups. Higher-income countries favoured the use of newer, more innovative approaches, such as social media, publication programmes targeted to specific user groups, live chat sessions and podcasts, whereas low- and lower-middle-income countries preferred the traditional media appearances. The communication strategies of PSATT targeted traditional as well as newer communication platforms to disseminate the results and the objectives.

By embedding shipboard training into a basin scale meridional transect, PSATT allows the students to directly assess the role such transects have in the Global Ocean Observing System, and this contributes towards Challenge 7 (Sustainably expand the Global Ocean Observing System) of the United Nations Ocean Decade. The skills and knowledge acquired by the students during PSATT, also contributes directly towards Challenge 9 (skills, knowledge, technology and participation for all). Similarly, students involved in PSATT, become advocates, influencers and enablers for Challenge 10 (Restore society's relationship with the ocean), through the onboard outreach program during the expedition and upon the students return to their home countries when they discuss and talk about their experiences with other ECOPs, family members and the general public. Shipboard mini-projects undertaken by the students also often focus on aspects of the UN SDG

Table 7. Educational outreach activities during the expedition especially towards children and young adults.

Number of schools involved	Expedition	Schools Country	Estimated number of participants	Age group
4	PS102, PS120, PS132	Germany	92	8–15
8	PS102, PS132	UK	132	8–12
2	PS102, PS120	Ireland	55	6–12
2	PS102, PS120	Brazil	45	6–15
1	PS102	Japan	11	6–11
1	PS132	Spain	15	8–13
1	PS95, PS132	South Africa	18	8–14
Universities				
Expedition		*Country*	*Estimated number of participants*	*Age group*
PS102		New Zealand	20	Young adults
PS102, PS120		Ireland	30	Young adults
Conferences				
Name	*Expedition*	*Country*	*Estimated number of participants*	*Age group*
Klimakonferenz Wir.Machen.Klima. Leipzig	PS120	Germany	300	9–18 years
Presentation at the sustainability week of the island of Sylt	PS132	Germany	240	6–99
International climate symposium (From Copenhagen to Katowice—what has been done so far) at Klimahouse Conference, Bremerhaven	PS102	Germany	250	12–99
Live conversation with German-ESA Astronaut Alexander Gerst	PS120		350	25–65
Commocean 2016	PS102	Bruges, Belgium	500	25–66

Goal 14: Life Below Water related to their home countries or to activities they are doing as part of the expedition.

Shipboard training plays a pivotal role in marine science education, offering students invaluable hands-on experience in real-world marine environments an opportunity not replicable within classrooms or laboratories. This practical training is particularly vital for young scientists from countries with emerging economies, enabling them to acquire skills tailored to their regional marine ecosystems (Satterthwaite et al. 2025) . Several reasons emphasize the importance of shipboard training, especially for these young scientists:

1. Exposure to Marine Environments and Ocean Technologies: Shipboard training immerses students in marine environments, allowing them to comprehend the intricacies and diversity of marine ecosystems. It fosters understanding of challenges such as climate change, pollution, and overfishing. They experience handling with ocean technologies, deploying and retrieving instrumentation. They learn the application and constrains of devices.
2. Practical Experience: Students gain practical expertise in collecting, processing, and analysing ocean data, essential for conducting meaningful research in marine science. This hands-on experience enhances their understanding of complex interactions between marine organisms and their surroundings.
3. Collaboration Opportunities: Shipboard training encourages collaboration with scientists worldwide. Interacting with peers and experts not only enriches their knowledge but also establishes professional relationships in the field.
4. Multi-disciplinary Learning: Shipboard training exposes students to various fields, including oceanography, marine biology, marine geology, and marine engineering. This interdisciplinary learning is crucial for a comprehensive understanding of marine science.
5. Career Development: Shipboard training equips young scientists with the skills, knowledge and experience needed for a successful career in marine science. It opens doors to employment opportunities, networking and research collaborations in the field.

In summary, addressing gaps in ocean and coastal observational data requires increased investments, technological advancements, improved data sharing, capacity building, and international cooperation. By implementing these strategies, we can ensure a robust and comprehensive understanding of our oceans, facilitating informed decision-making and sustainable management practices.

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Data availability

Environmental data are archived, published and disseminated according to international standards by the World Data Center PANGAEA Data Publisher for Earth & Environmental Science (https://www.pangaea.de) within two years after the end of the cruise at the latest. By default, the CC-BY license will be applied. The data underlying this article were accessed from RV Polarstern (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung (2017) Polar Research and Supply Vessel POLARSTERN Operated by the Alfred-Wegener-Institute. Journal of large-scale research facilities, 3, A119. http://dx.doi.org/10.17815/jlsrf-3-163.).

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