Which Robot When?

Overview

TOPIC: Underwater Robots

FOCUS: Students analyze the varied technical specifications of different exploration vehicles and decide which robot is best suited for real-world ocean exploration scenarios.

GRADE LEVEL: 6-8 Engineering Design, Technology

TIME NEEDED: One or two 45-minute class periods

OBJECTIVES/ LEARNING OUTCOMES:

Students will:

- Become familiar with a variety of exploration vehicles that are used by ocean explorers.
- Analyze a variety of mission scenarios that exploration vehicles might encounter during ocean exploration operations.
- Distinguish shape and structural features among at least three types of exploration vehicles that make each suitable for specific mission scenarios and tasks.
- Discuss, analyze and decide which vehicle is best suited for which situation.
- Participate in group decision-making to reach consensus.

MATERIALS:

Exploration Vehicle Compatibility Activity

- Student Worksheet: Which Robot When (one per student or group)
- Exploration Vehicle Summary Sheets (1-2 exploration vehicle summary sheets per group; there are 10 different vehicles in the set)

Performance Expectations (PEs)
MS-ETS1-1; MS-ETS1-2

Disciplinary Core Ideas (DCIs)
ETS1.A Defining and Delimiting Engineering Problems; ETS1.B Developing Possible Solutions

Crosscutting Concepts (CCs)
Influence of Science, Engineering, and Technology on Society and the Natural World

Science & Engineering Practices (SEPs)
Asking Questions and Defining Problems
Developing and Using Models
Engaging in Argument from Evidence

COMMON CORE CONNECTIONS
RST.6-8.1

OCEAN LITERACY ESSENTIAL PRINCIPLES AND FUNDAMENTAL CONCEPTS
Principle 7: FCs b, d, f

Overview

MATERIALS cont.:

- Mission Scenarios, pg. 6 (one copy of all scenarios per group)
- Collaborative Mission Scenarios, pg. 7 (class copy, project for all students to see)
- Exploration Vehicle Compatibility Survey, pg. 8 (class copy, project or copy on the board for all students to see)

Videos

- Rare Sperm Whale Encounter with ROV (4:24) *Ocean Exploration Trust*
- Gulf of Mexico 2012 Monterrey: Exploring a 19th Century Shipwreck (4:54) *NOAA Ocean Exploration*
- Coordinated Robotics 2 - Wrap Up - FK180119 (5:02) *Schmidt Ocean Institute*
- Coordinated Robotics 2 - Week 01 - FK180119 (2:37) *Schmidt Ocean Institute*

EQUIPMENT:

- Computer and projector for class viewing of videos and class Exploration Vehicle Compatibility Survey
- Optional: Student laptops or tablets for extensions and/or additional research

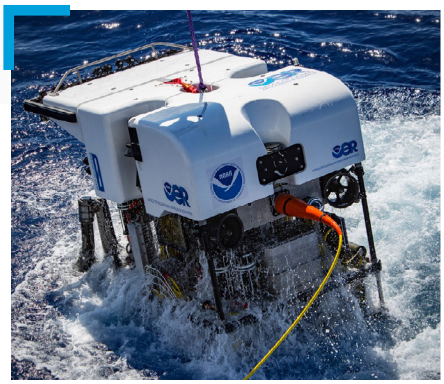
SET-UP INSTRUCTIONS:

- Cue up videos to show the class.
- Exploration Vehicle Summary Sheets:
  - Print enough copies so that each group (maximum of 10) has one assigned exploration vehicle summary sheet. Multiple copies of the same exploration summary sheet can be provided to each group so that all students can read simultaneously. *Smaller classes can be divided into 5 groups and have 2 assigned vehicles.*
  - Fold sheets in half and laminate to make a class set. T**ape or staple closed if you cannot laminate.**
- Project the Exploration Vehicle Compatibility Survey, pg. 8, or copy it on the board so all students can see.
- *Optional for additional scaffolding:*
  - *Only provide a few mission scenarios to each group to simplify for younger students.*
  - *Make copies of the Remotely Operated Vehicle and Autonomous Underwater Vehicle fact sheets and OYLA magazine student article noted below to provide students with additional background information.*

Educator Guide

Background

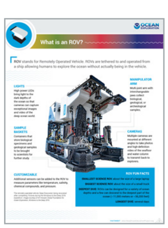
Today's technologies allow us to explore the ocean in increasingly systematic, scientific, and noninvasive ways. Ocean exploration relies on a variety of exploration vehicles, including submersibles like remotely operated vehicles (ROVs) and autonomous underwater vehicles (AUVs), uncrewed surface vessels (USVs), and more to explore and study some of the most remote areas of the ocean. These vehicles come in a variety of shapes, sizes, and configurations that make them suited for many mission objectives. When planning an expedition, ocean explorers must decide which exploration vehicle(s) is best for collecting the data they need (video, samples, measurements, etc) to advance our understanding of the ocean.



ROV *Deep Discoverer* being launched off the back deck of NOAA Ship *Okeanos Explorer. Image courtesy of NOAA Ocean Exploration.*

FOR MORE INFORMATION:

- *What is an ROV?* Fact Sheet



- *What is an AUV?* Fact Sheet

- Ocean Exploration Technology OYLA student magazine article

Educator Guide cont.

Introduction

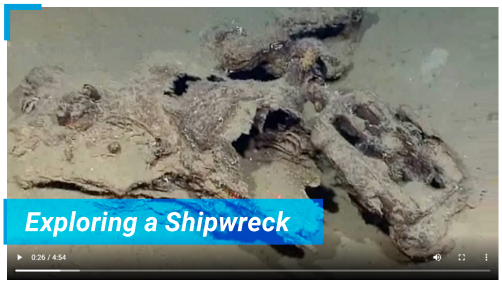
Present the Driving Questions to the class:

How can exploration vehicles help ocean explorers gather data under a variety of ocean conditions?

How do ocean explorers determine which piece of technology is best suited for their mission?

Show one or both of the following videos to get students thinking about the different ways exploration vehicles are used in scientific exploration of the deep ocean.

- Rare Sperm Whale Encounter with ROV (4:24) *Ocean Exploration Trust*
- Gulf of Mexico 2012 Monterrey: Exploring a 19th Century Shipwreck (4:54) *NOAA Ocean Exploration*



Provide a brief review by discussing the following guiding questions:

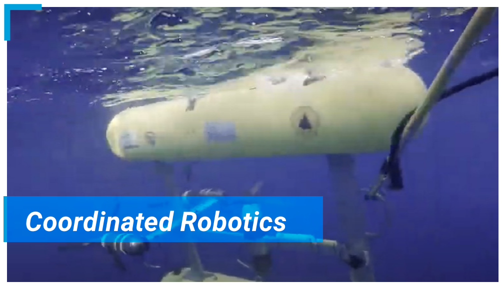
- How can exploration vehicles help ocean explorers gather data for a variety of ocean exploration scenarios?
  - What conditions make ocean exploration challenging, compared to terrestrial (land) exploration?

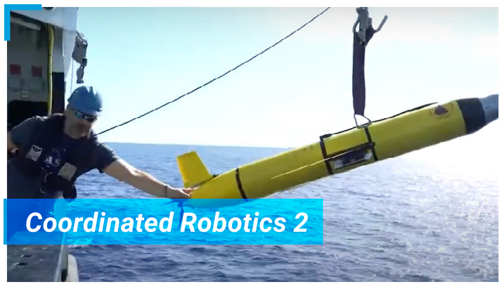
    Possible student answers: remote regions (far from resources on shore); inability to breathe underwater; pressure even at moderate depths; cold temperatures; rough currents; lack of light.
  - What capabilities do exploration vehicles have that exceed those of humans?

    Possible student answers: they never tire; they can withstand a greater range of temperatures; they can be designed to withstand intense pressure; they do not require oxygen.

Show one of these two Coordinated Robotics videos from Schmidt Ocean Institute to help students understand the use of underwater robots in the field.

- Coordinated Robotics 2 - Wrap Up - FK180119 (5:02) *Schmidt Ocean Institute*
- Coordinated Robotics 2 - Week 01 - FK180119 (2:37) *Schmidt Ocean Institute*





Provide a brief review by discussing the following guiding questions.

- Are all exploration vehicles used the same?
- How do ocean explorers determine which piece of technology is best suited for their mission?
  - When selecting a tool for any job, what must you consider?
    Possible student answers: form, function, cost, mission objective.
  - What factors should be considered regarding a vehicle dive mission?
    Possible student answers: maximum depth; size of area to be explored; potential obstacles; time needed on the seafloor.
  - What are the various functions that an exploration vehicle can perform?
    Possible student answers: collection of biological, geological and chemical [water] samples; photography; videography; bathymetric mapping.

For additional scaffolding, provide students with copies of the fact sheets or the OYLA student article in the For More Information section to explore.

Educator Guide cont.

Learning Procedure

Divide the class into as many as 10 groups, each with two or more students.

Tell students today they will be ocean explorers, and together they will model a portion of the expedition planning process by determining the best exploration vehicle for a variety of exploration scenarios. As a class, students will examine ten different exploration vehicles, including uncrewed surface vessels (USVs), remotely operated vehicles (ROVs), autonomous underwater vehicles (AUVs), landers, and hybrid vehicles and a variety of ocean exploration scenarios.

Assign each group one exploration vehicle and distribute the Exploration Vehicle Summary Sheet for the assigned vehicle to each group. *For larger groups, provide more than one copy of the Exploration Vehicle Summary Sheets so that all group members can read simultaneously.*

Distribute the Student Worksheet: Which Robot When to each student (or one per group).

Tell each group that their first job is to become an expert on their assigned exploration vehicle. Together, they will complete **Section One** of their **Student Worksheet: Which Robot When** for their vehicle, noting the unique capabilities and limitations. Give students 10-15 minutes to review their assigned vehicle and complete section one.

Distribute a complete set of Mission Scenarios to each group. *Provide fewer mission scenarios to scaffold for younger students or if time is limited.*

Tell students that as a group, they are to review each of the ocean exploration mission scenarios they've been provided and determine which scenario(s) their assigned exploration vehicle could complete based on the unique specifications, equipment, and features of their vehicle.

Tell student groups to record their answers and reasoning in **Section Two** of their Student Worksheet: Which Robot When. Give students 15-20 minutes to review the scenarios and complete section two of their worksheet.

While students are working on completing their worksheet for their assigned exploration vehicle, **project** a blank copy the **Exploration Vehicle** Compatibility Survey on the board for all students to see.

Ask student groups to select one group member to share their findings with the class. Each student group should identify which exploration vehicle they investigated, share the unique specifications and/or equipment of that vehicle, and identify which exploration scenario(s) their vehicle would be able to complete.

Complete the class **Exploration Vehicle Compatibility Survey** as groups report out.

Putting the Pieces Together

Once the class Exploration Vehicle Compatibility Survey has been completed, **ask** students to share their observations about the completed class **Exploration Vehicle Compatibility Survey**. *Students should notice that some scenarios, such as exploring under ice, only have one vehicle that would work, while others have more than one vehicle that could do the mission.*

Lead a class discussion to select the "best" exploration vehicle for each mission scenario. **Ask** students to share how they think explorers select the "best" exploration vehicle for mission scenarios in situations where more than one vehicle is capable of doing the job? Start with the first mission scenario that has more than one compatible exploration vehicle. **Ask** the student groups who were experts on each of the compatible vehicles to share why their vehicle would be well-suited for the mission. After all groups that have compatible vehicles share, **ask** the class which vehicle they think would be best for each scenario and why? **Encourage** students to respectfully disagree and practice arguing with evidence from the exploration vehicle summary sheets and mission scenarios. Once a class consensus is reached for each mission scenario, circle or highlight the best vehicle on the class **Exploration Vehicle Compatibility Survey**.

Collaborative Mission Scenarios

Now that students have experience selecting the "best" exploration vehicle for a mission scenario, it is time to explore more complex exploration scenarios that require more than one vehicle to complete the mission.

Distribute the two **Collaborative Mission Scenarios** to each group or display one at a time on the board so all students can see.

Ask students to read through each mission scenario and identify specific mission objectives, tasks, or challenges that will help narrow down which vehicle is best for the job.

Ask groups to share whether they think their exploration vehicle could accomplish the mission? What about part of the mission?

Ask the class if they think vehicles can work together on a mission? Once a consensus is reached, ask student groups to share whether they think their vehicle could complete the mission scenario if it worked with another vehicle? Continue the class discussion until all groups agree on what vehicles could work together to complete the mission.

Educator Guide cont.

Extensions

Suggestions for related activities:

Have students craft their own mission scenarios and trade with a partner to determine which ROVs, AUVs, and/or USVs could perform the job.

Have students design a unique ocean exploration vehicle to present to a Shark Tank-style panel of their peers. Have students design and create a model of an ocean exploration vehicle to accomplish specific tasks out of recycled materials.

Have students examine the future potential uses of AUVs in space exploration by reviewing The Rise of *Orpheus* on the Woods Hole Oceanographic Institution's website.

Suggestions related to other disciplines:

Explore how the name of the AUV *Orpheus* and the hadal zone it is designed to explore (6,000-11,000 meters—the deepest part of the ocean) relate to Orpheus and Hades in Greek mythology.

Research famous oceanographers such as Sylvia Earle, Robert Ballard, Jacques Cousteau, and Vagn Ekman to learn what tools they use(d) for underwater exploration.

See how MBARI's marine operations staff and ROV pilots performed an intricate underwater robot ballet 650 meters (2,000 feet) below the surface of Monterey Bay.

Check out how an ROV was used to record an underwater music video for rock band Black Smoke Trigger's *Caught in the Undertow*.

Assessment

Opportunities for formative assessment are embedded throughout the lesson through class discussions. The student explanations that are used to determine which ocean exploration vehicles are the best for each individual mission scenario or which vehicles can work together to complete the collaborative mission scenarios could be used as an opportunity for summative assessment.

LOOK FORS

The following components should be included in students' final explanations:

- Students can distinguish among shape and structural features of different types of underwater vehicles that make each suitable for specific ocean exploration tasks.
- Students use data to make decisions on which exploration vehicle is optimal to meet the criteria of specific situations encountered in ocean exploration.
- Students recognize that complex mission scenarios may require multiple exploration vehicles to complete all tasks for the mission.

Scientific Terms

Autonomous: independent

AUV: Autonomous Underwater Vehicle; a robot that is not tethered to a ship—it can move independently to explore the ocean

Bathymetric: Bathymetry is the study of the "beds" or "floors" of bodies of water. Bathymetric mapping refers to mapping the depths and shapes of underwater terrain

Remotely Operated: controlled from a distance (like a remote-controlled car)

ROV: Remotely Operated Vehicle; unoccupied underwater robots that are tethered to a ship, where human "pilots" on board the ship control their movement and actions

Submersible: a craft designed to operate underwater

Sensor: a device that detects or measures a physical property; a sensor then records or responds to that property (e.g., a sensor to detect chemicals in water)

Tether: a rope or cable to restrict movement; a bundle of cables that connects a ROV to a ship

USV: Uncrewed surface vessel; a small, boat-like vehicle that roams the ocean's surface without an onboard crew, collecting oceanographic and atmospheric data

Mission Scenarios

1 **We are planning an expedition to study an unexplored area off the coast of Alaska with a maximum depth of 1,800 meters (5,906 feet).** Ocean explorers are particularly interested in mapping scarps (a steep slope or cliff, formed by the movement of a geologic fault, a landslide or erosion). We want to investigate the water salinity near the feature. We will also sample organisms that may be living on these formations. One challenge of working in this area during much of the year is bad weather and sea ice.

2 **Our team is studying an unexplored chain of underwater volcanoes. These may be extinct or potentially active.** We want to sample geological formations as well as biological communities. We won't know exactly what types of samples will be needed until we can illuminate and see the area. The bases of these volcanoes are about 4,500 meters (14,764 feet) deep. Their summits (peaks) are around 1,500 meters (4,921 feet) deep. One of our lead researchers is not able to go to sea due to family obligations. They are very interested in participating remotely by watching a livestream video of the exploration.

3 **While a team on a telecommunication ship was installing new cables on the seafloor, they came upon a Spanish galleon shipwreck lying in a deep canyon.** We need a complete, detailed visual survey of the area around the ship. The wreck lies in waters approximately 3,000 meters (9,843 feet) deep. A no-touch investigation will use video and photos of the cargo on board. This may help the team determine from which port the ship may have last sailed. These clues will help archaeologists support a recommendation that the area should be protected from disturbance. This exciting discovery and follow-up investigation were unplanned and therefore the explorers are keen to keep the budget as low as possible.

4 **As plate boundaries collide and subduct, deep trenches are formed. Along these boundaries, subduction can cause large faults and underwater earthquakes.** These large seismic events also cause sediment to fall and accumulate at the trench bottom. Little is known about the processes in these areas. The Java Trench is an area with little previous study. Our team wants to better understand the landslide risk in an area at a depth of 7,400 meters (24,278 feet) in this region. Photos taken from multiple angles will help us to answer some of our questions. To take images throughout the entire trench region will take many days at sea. The mission team will need to minimize their daily costs to maximize the number of days they can explore the region.

5 **Glass sponges are animals that form massive reef colonies. Many thought glass sponges had gone extinct 66 million years ago.** However, since the late 1980s, glass sponge reefs have been discovered in cold waters around the world. We are learning that these 'living fossil' reefs are home to many animals such as fishes, crabs and sea stars. Ocean explorers plan to study the organisms living on a recently discovered glass sponge reef at a depth of 1,400 meters (4,593 feet). We want a complete photographic record of the study area (approximately 10,000 square meters). We also need to collect samples of unknown organisms for identification.

6 **The Murray Fracture Zone is 3,000 kilometers (1,864 miles) long, 90 kilometers (56 miles) at its widest spot, and up to 2,000 meters (6,562 feet) deep.** Our expedition is tasked with creating the first high-resolution map of the entire area. This mapping-focused mission will require continuous data collection over many days.

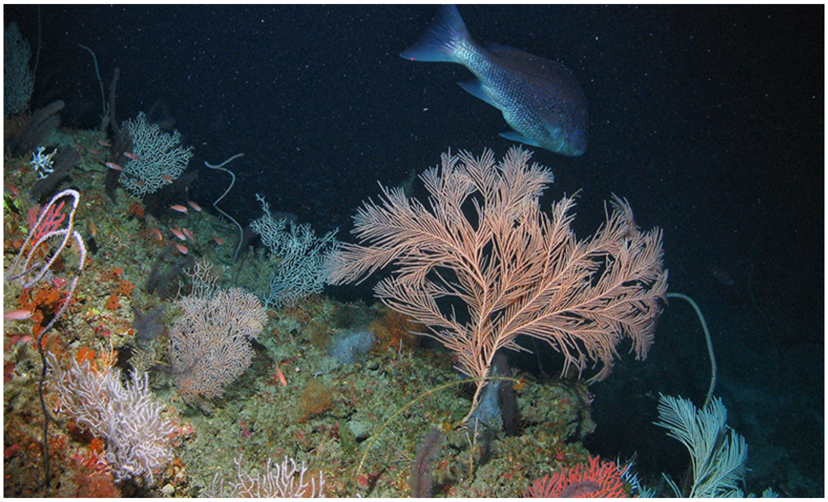
7 **We are returning to American Samoa as part of a long term project mapping Vailulu'u Seamount,** located 32 kilometers (20 miles) east of Táū Island within the American Samoa archipelago. This hotspot volcano has a peak roughly 600 meters (2,000 feet) beneath the ocean surface and is a perfect example of the changing landscapes that make up deep-sea environments. Maps from a series of previous expeditions here (2005 - 2024) reveal dramatic changes over time to the shape of the volcano crater. Our team wants to track the detailed geologic changes to Vailulu'u Seamount, by mapping the top of the seamount with high-resolution multibeam sonar monthly, over a full year. The mapping route will be the same each month, taking about 16 hours each trip to completely map the area to less than 0.5 meter (1.6 feet) resolution.

8 **Deep-sea trenches are locations where one tectonic plate subducts, or slides, beneath another.** The Puerto Rico Trench is the deepest in the Atlantic Ocean Basin. It is located to the north of Puerto Rico and is deeper than 8,400 meters (27,560 feet) beneath the ocean surface in some locations. Our team is planning an expedition to the trench to map the region, and collect water samples at all depths of the trench to identify how the chemical composition of the water and the animals living there vary at different depths. The team does not know where (at what depths) the chemical profiles or biological communities will change. Their sampling options are limited by the number of Niskin bottles (used to collect water samples) on the vehicle. The team will need to be strategic with its water sampling to only collect samples at depths where these factors are actually changing. Maintaining the pressure of the water samples collected at extreme depths as they are brought back up to the surface will also help the team most accurately learn about the conditions within the trench.

Collaborative Mission Scenarios

Collaborative Mission Scenario 1

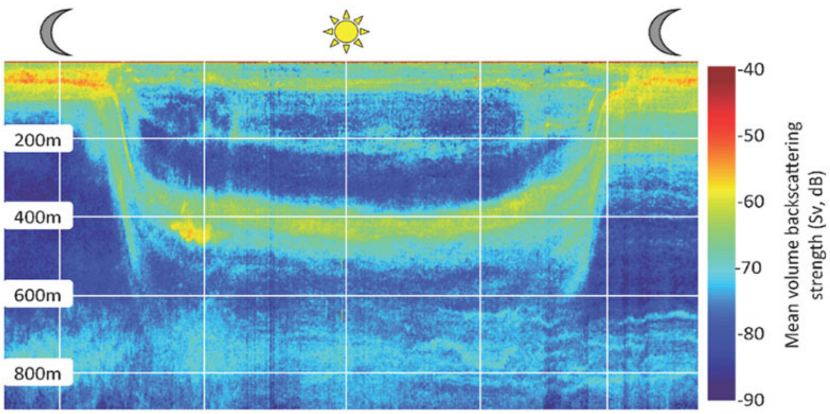
A science team from the Flower Garden Banks National Marine Sanctuary, off the coast of Texas wants to study ish communities around deep water coral reefs in the Gulf of America ranging between 1,500 - 1,700 meters (4,921 - 5,577 feet). We want to understand the biodiversity of the reef. The team needs to make video recordings of fish species in a variety of habitats, particularly under coral ledges near the bottom. We need to collect samples of several fish species without disturbing the reef. This area also contains a series of caves. Each one is approximately 300 meters (984 feet) long. Video images of the interior of these caves will help us plan further explorations. Our team wants to document how underwater micro-climates impact fish populations. The team will monitor the water temperature around the caves and the reef. We will need to take temperature samples every hour for a month.



Mesophotic and deep benthic habitats are vast and complex ecosystems on the ocean loor that are a foundation of Gulf of America food webs. *Image courtesy of NOAA, Marine Applied Research & Exploration.*

Collaborative Mission Scenario 2

Biologists and engineers are working together off the coast of Hawai`i to better understand diel (24 hour) vertical migration (DVM) of small animals. During DVM, billions of tiny animals including zooplankton, fishes, shrimp, and jellies travel up and down in the water column in a pattern that follows day and night. Scientists are usually restricted to taking samples as their equipment moves through the water column, only capturing a "snapshot" of what is happening during DVM. To better understand what organisms are migrating and their behavior during their journey, our team wants to follow a full DVM cycle, staying with the tiny organisms for a full 24 hours. We will need to operate at least two vehicles. One vehicle will operate multibeam sonar systems from the surface to locate and keep track of how deep the organisms are and to communicate with a second vehicle. The second vehicle will be used to dive, record video, take samples and follow the organisms.



This echogram illustrates the ascending and descending phases of the diel vertical migration through the water column. The yellows and reds are indicative of the greatest density of animals. *Image courtesy of DEEP SEARCH - BOEM, USGS, NOAA.*

Exploration Vehicle Compatibility Survey

MISSION SCENARIO	COMPATIBLE VEHICLES FOR THE SCENARIO *Circle/highlight the best vehicle for the job*	KEY CAPABILITIES / ATTRIBUTES FOR THE TASK
1		
2		
3		
4		
5		
6		
7		
8		
COLLABORATIVE SCENARIO 1		
COLLABORATIVE SCENARIO 2		

Exploration Vehicle Compatibility Survey Answers

MISSION SCENARIO	BEST VEHICLE FOR THE MISSION	POSSIBLE ALTERNATIVES
1	HROV *Nereid Under-Ice (NUI)*	ROV *Deep Discoverer (D2)*, ROV *SuBastian*
2	ROV *Deep Discoverer (D2)*	ROV *SuBastian*
3	ROV *Little Hercules*	ROV *Deep Discoverer (D2)*, AUV *Orpheus*, ROV *SuBastian*
4	AUV *Orpheus*	None due to depth of research site
5	ROV *SuBastian*	ROV *Deep Discoverer (D2)*, HROV *Nereid Under-Ice (NUI)*
6	AUV *Sentry*	AUV *Eagle Ray*
7	AUV *Eagle Ray*	AUV *Sentry*, AUV *Orpheus*
8	Deep Autonomous Profiler (DAP) *Lander*	No good alternatives for this depth and autonomous decision making capabilities
Collaborative Scenario 1	ROV *Little Hercules* and DAP *Lander*	HROV *NUI* could be substituted for ROV *Little Hercules* to operate under the shelf. DAP *Lander* would be the best for the long term data collection, but any of AUVs could be deployed for days at a time to collect the data too.
Collaborative Scenario 2	HROV *Mesobot* and USV *DriX*	No good alternatives that work well in tandem without input from the ship.

Which Robot When? Links and Resources

Page 1
- NOAA Ocean Exploration Deep Discoverer (image): https://oceanexplorer.noaa.gov/technology/subs/deep-discoverer/deep-discoverer.html
- Student Worksheet: Which Robot When (pdf): https://oceanexplorer.noaa.gov/edu/materials/which-robot-when-student-worksheet.pdf
- Exploration Vehicle Summary Sheets (pdf): https://oceanexplorer.noaa.gov/edu/materials/exploration-vehicle-summary-sheets.pdf

Page 2
- Rare Sperm Whale Encounter with ROV (video): https://www.youtube.com/watch?v=SkBpummjR5I
- Gulf of Mexico 2012 Monterrey: Exploring a 19th Century Shipwreck (video): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/dailyupdates/media/video/highlights-0426/highlights-0426-960x540.mp4
- Coordinated Robotics 2 - Wrap Up - FK180119 (video): https://www.youtube.com/watch?v=0ggXqbYTFfo&list=PLJGVqQI3okzbqF_JLN2cmLs8Fz56Tsp3O&index=2
- Coordinated Robotics 2 - Week 01 - FK180119 (video): https://www.youtube.com/watch?v=FXcN45rSvVI
- ROV *Deep Discoverer* (image): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1811/logs/nov13/media/img3-hires.jpg
- What is an ROV? Fact Sheet (pdf): https://www.oceanexplorer.noaa.gov/edu/materials/rov-fact-sheet.pdf
- What is an AUV? Fact Sheet (pdf): https://www.oceanexplorer.noaa.gov/edu/materials/auv-fact-sheet.pdf
- Ocean Exploration Technology OYLA student magazine article (pdf): https://oceanexplorer.noaa.gov/explainers/media/tech-aug22/NOAA_Technology_August.pdf

Page 3
- Rare Sperm Whale Encounter with ROV (video): https://www.youtube.com/watch?v=SkBpummjR5I
- Gulf of Mexico 2012 Monterrey: Exploring a 19th Century Shipwreck (video): https://oceanexplorer.noaa.gov/okeanos/explorations/ex1202/dailyupdates/media/video/highlights-0426/highlights-0426-960x540.mp4
- Coordinated Robotics 2 - Wrap Up - FK180119 (video): https://www.youtube.com/watch?v=0ggXqbYTFfo&list=PLJGVqQI3okzbqF_JLN2cmLs8Fz56Tsp3O&index=2
- Coordinated Robotics 2 - Week 01 - FK180119 (video): https://www.youtube.com/watch?v=FXcN45rSvVI

Page 4
- Exploration Vehicle Summary Sheet (pdf): https://oceanexplorer.noaa.gov/edu/materials/exploration-vehicle-summary-sheets.pdf
- Student Worksheet: Which Robot When (pdf): https://oceanexplorer.noaa.gov/edu/materials/which-robot-when-student-worksheet.pdf

Page 5
- The Rise of Orpheus (video): https://www.whoi.edu/news-insights/content/the-rise-of-orpheus-2/
- Intricate underwater robot ballet (video): https://www.youtube.com/watch?v=m-Get7opYt0
- ROV Black Smoke Trigger (video): https://www.boxfishrobotics.com/case_study/underwater-music-video/

Page 7
- Mesophotic and deep benthic habitats (image): https://oceanexplorer.noaa.gov/news/oer-updates/2024/media/mdbc-fish-coral-800.jpg
- Echogram (image): https://oceanexplorer.noaa.gov/explorations/17deepsearch/background/water-column-research/media/fig2-800.jpg

Partners, Information and Feedback

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