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Transactional Systems of Exploration and Learning: The *Okeanos Explorer*

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Abstract

The Okeanos Explorer, a NOAA ship, operates a robotic vehicle outfitted with cameras, instruments, and sampling arm, enabling scientists to explore the depths of the Earth's oceans in multiple-week expeditions without leaving their homes. An ethnographic study conducted onboard oriented to the question, "What accounts for the quality of the scientific work?" Contra the cliché of "robotic mediation," the functional instrumentality of the exploration system is distributed as different roles, tools, and protocol-regulated activities, involving scientists, engineers tele-operating the robotic system, and the ship's crew. This sociotechnical "collaboration system" is depicted as a dependent hierarchy of responsibilities, with nested transactional activities. The emergent multidisciplinary coordination is a kind of dance that pursues intellectual interests within the technical operating constraints of the technology and the physical safety of the ship. The design promotes conversation and influencing how the investigation proceeds, facilitating learning among the scientists, students, and the public.

Keywords: Ethnographic Fieldwork, Activity Theory, Telescience Operations, Robotic Exploration, Sociotechnical System, Collaboration System, Oceanographic Expedition, Work System Design, Transactionalism

Background: An Ethnographic Study of a Sociotechnical System

In 2017, I had the opportunity to observe operations onboard the *Okeanos Explorer* (*OE*), a National Oceanographic and Atmospheric Administration (NOAA) ship that uses a robotic vehicle to explore new regions of the ocean. The *OE*'s multiple-week expeditions are a form of exploratory science, influenced by the interests of the United States Department of Commerce, in which NOAA resides. My study began with Shirley Pomponi, a renowned oceanographer at Florida's Harbor Branch Oceanographic Institute, who became concerned that NOAA was shifting research funding from HBOI's submersibles and ships to shared robotic systems that would transmit video back to scientists at home. The agency believed that telepresence would be more productive and cost effective. Pomponi wondered, "How can oceanographers explore without going to sea?" (indeed, without going to see).

On learning about my studies of the scientists using the Mars Exploration Rover (Clancey 2012), Pomponi realized there might be a parallel, given that, as I explain in *Working on Mars*, we can do field science on Mars without being there. And not being able to go into space isn't discouraging students from becoming planetary scientists. Consequently, Pomponi secured funding to conduct ethnographic studies of this new work practice at HBOI's Exploration Command Center (ECC). Our investigation asked, "What are the limitations or even advantages of the *Okeanos Explorer* system, compared to not being on a ship or undersea in person?"

In this chapter, I provide an overview of the *Okeanos* exploration system, characterizing it as a transactional system constituted by activities of different groups (ship crew, engineers, scientists) having different focal concerns and employed by different organizations with their own ranks, roles, tools, schedules, and responsibilities. Working together, a new exploration capability resulted, ameliorating the scientists' original concerns conceived in inter-actional terms: the distancing of observer from observed in "robotic mediation." To characterize the success of the Okeanos exploration system, we shift stance, viewing expedition operations as "an organism-in-environment-as-a-whole" (Dewey & Bentley 1949: 133). This perspective fits our observations that diverse commercial, political, technical, and scientific interests and capacities constitute a coherent practice, with intricate cooperative actions at various times and places onboard: "no one of its constituents can be adequately specified as fact apart from the specification of other constituents of the full subject matter" (p. 137). This transactional notion is familiar in ethnographic studies (e.g., Hutchins 1991; Clancey 2006; Mindell 2015).

The design of the exploration system is of special interest in how it facilitates learning among the scientists, students, and the public, who are together studying the sea floor with a robotic system. In this broader view, I show how the layout of the control room onboard fits the transactional character of the work. The scientific and educational aspects are not related as producer and consumer, but one exploration activity, reified by a professional cinematographer sitting alongside the engineers: "Act and product belong broadly together, with product, as proceeds, always in action, and with action always process" (Dewey & Bentley 1949: 155).

The *Okeanos* Exploration System

Figure 4.1 provides an overview of the *Okeanos* exploration system, which NOAA refers to as telepresence-enabled ocean exploration. Only two scientists are onboard the ship, a biologist and geologist. They communicate with scientists onshore via an open telephone line and chat room; this remote team may work at university offices, home, or one of NOAA's seven ECCs.

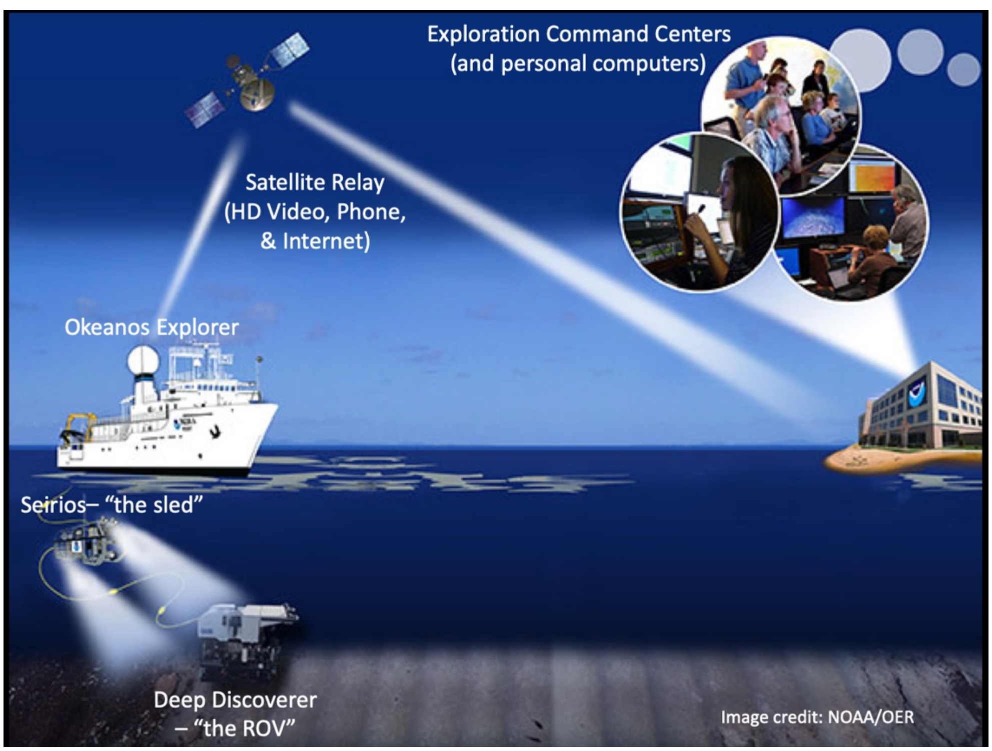

Figure 4.1. *Okeanos* exploration system—telepresence-enabled ocean exploration. Adapted from image courtesy of the NOAA Office of Ocean Exploration and Research.

Engineers onboard the *OE* operate two robotic systems. The Seirios camera sled essentially hangs from the ship on a steel cable, rated for operations nearly four miles (6 km) deep. The robotic system, Deep Discoverer, also D2 or just “the ROV” is connected to Seirios on a 30 m soft tether. The scientists onboard interact with the remote science team by telecon and a chat room. Everyone is viewing the high-definition video from D2 and Seirios.

The ECCs are outfitted with multiple high-resolution displays depicting the two camera views and a quadrant display showing the dive status (e.g., depth and orientation of the ROV, bathymetric map, the control room). The public website, available on a personal computer, provides somewhat lower resolution camera views, with about a 30 second delay.

The *Okeanos* exploration system is a second-generation version of a design by Robert Ballard (perhaps best known for his collaboration with James Cameron in finding and exploring the Titanic with an ROV). D2 weighs about 4000 kg, with dimensions of approximately 3 m length x 2 m width x 2.5 m height. It incorporates over 900 m of electrical wiring, twenty LED lights, and nine video cameras (Rogers 2016). The system is maneuverable by remote control of hydraulic motors at pressures almost 600 times sea level. Using robotic arms, geological and biological samples can be cached in boxes and returned to the surface.

The zoom lens (ZEUS Plus by Insite Pacific, a High Definition broadcast standard 3-CCD color camera with 2/3-inch 2,200,000-pixel 1080i IT CCDs, with a horizontal resolution of 1,000 TV lines) provides almost microscopic imagery, which is often the most exciting part of a dive. Seirios’ lights and cameras are controlled to keep the ROV in continuous view.

Both Seirios and D2 are deployed daily on roughly an 8 am to 5 pm schedule, called a “dive,” during which D2 is dropped and “flown” to the lowest part of the path planned for the day, called a “traverse.” A dive traverses hundreds of meters moving up from the lowest point.

Dives are planned several weeks in advance by oceanographers who register to be part of the science team. A more detailed dive plan is often laid out the day before, based on bathymetric maps which are essentially topographic charts that the *OE* creates in each region as the expedition proceeds.

Public Views of the Scientific Work

In June 2016 I worked for several weeks with Chris Kelley at the University of Hawaii’s ECC in Manoa (Honolulu, Oahu). Kelley was then the science lead for a three-year NOAA investigation of U.S. marine protected areas in the Pacific. We watched D2’s video on a magnificent high-definition wall display. We were often alone in the room but were communicating with the scientists onboard and several dozen others in the chat room and via an open teleconference. After several years working this way, the scientists in different countries have gotten to know each other and their expertise. They exchange personal greetings, prompt each other with questions, and document the animal life they encounter. Figure 4.2 shows some examples of what remote scientists and the public can see.

I was surprised by the varied geology and that everything we saw alive was an animal—there are no plants below several hundred meters (photosynthesis requires light). Besides retrieving rocks and biological samples, the robotic arm can be used to deploy a temperature probe as shown in the figure.

I was especially intrigued by the video shown periodically of the control center on board. I could see the two scientists sitting behind three engineers controlling the ROV and Seirios. I could sometimes hear them talking in the public broadcast, but what was really going on behind the scenes? How did the engineers operate the robotic systems? Were the scientists onboard working closely with them? I had to get onboard to find out.

Figure 4.2. Examples of images publicly available during a dive, illustrating (clockwise from upper left) varied geology, control room onboard *Okeanos Explorer*, animal life, and using temperature probe with ROV robotic arm.

I had the opportunity to visit NOAA's Headquarters near Washington D.C. in 2016 and presented my proposal to do an ethnographic study of the work on board, formulated around these questions:

- What accounts for the quality of the scientific work using the telepresence-enabled exploration system—including people, roles, computer and robotic systems, procedures, schedules, facilities, etc.?
- What are the work practices in the ECCs and onboard the *OE* during expeditions involving the D2 remotely operated vehicle?
- In particular, how does the exploration system affect the remote scientists' participation and collaboration in collecting data, making interpretations, and ongoing engagement in the exploration process?

These study objectives adopted a perspective similar to my study of the Mars Exploration Rovers, focusing on how the quality of scientific field work is affected by the dramatic change in historical practices, namely working remotely through robotic surrogates in large teams.

In actuality, these new collaborations, plus the advent of high-definition close-up cinematography on an ROV operated far below where submersibles can go, have turned out to be highly successful for NOAA, increasing the regions of the sea floor that can be explored and bringing to bear international expertise during every dive.

The *Okeanos Explorer* American Samoa Expedition

The story of the ship and life onboard would merit a book in itself. Perhaps the most important fact is that the entire expedition operated with forty-six people onboard, a village to ourselves, managing daily operations and even changing our destinations without needing to consult with NOAA headquarters—a surprise given my experience during NASA missions.

During the expedition a crew of twenty-four operated the ship, including eight NOAA officers who serve in NOAA's Commissioned Officer Corps (a service of the US military) and sixteen "wage mariners" who belonged to a union, consisting of engineers, technicians, and stewards.

There were also twenty-two people called "augmentators," which included the NOAA coordinator who managed the entire expedition, two science leads, and two mapping leads (employed by NOAA's Office of Ocean Exploration and Research, OER) and a science data manager (a scientist contracted for the expedition), plus nine ROV engineers and six video specialists employed by the Global Foundation for Ocean Exploration (GFOE). Officially, my role was designated as VIP, a title used for unpaid guests.

The ship left from American Samoa in the South Pacific, and during two weeks at sea, February 16 to March 2, 2107, carried out dives at thirteen seamounts. The route of the expedition was developed with input from American Samoa management agencies, a call for proposals from any interested scientist, and regional workshops. The Rose Atoll Marine National Monument and National Marine Sanctuaries suggested natural biological areas to explore.

Unexpected squalls from a tropical cyclone on the fourth day required an emergency retrieval of Seirios and D2 and then high-tailing it to the north. The coordinator and two scientists developed a new traverse plan, which was reviewed by the remote scientists. We returned to the south on the eleventh day to pick up the lost site, then completed the expedition at the port of Apia in Samoa, on the other side of the date line.

At the end of the voyage, we experienced two Friday sunsets and two Saturday sunrises. We had encountered a kind of transactional time warp in crossing the international dateline—an Excel chart was required to keep track of it; electronic photo and video time stamps were all confused.

A Transactional Perspective of the *Okeanos* Exploration Subsystems

Teamwork onboard during the expedition transcends organizational boundaries: The NOAA officers, wage mariners, and ROV contract engineers work as a single team to carry out the dives safely, guided by the interests of the scientists. For example, one may find ROV engineers working directly with wage mariners in physically deploying and retrieving Seirios and D2. Similarly, the NOAA Commanding Officer (CO), OER coordinator, and mapping lead, and scientists collaborate to schedule daily dives and re-planned the route as necessary. During the 9 am daily briefing on the bridge, the CO and NOAA OER members reviewed weather charts and considered how condition of the seas might affect carrying out the planned traverse. Briefings generally required only five or ten minutes, everyone standing except the CO. After polling for issues, he would call, "Break!" and pairs or small groups would converse to work out the identified issues (e.g., how proximity to a sanctuary affected ship operations). The efficient meetings reflect how completely ship, ROV, and science activities were distributed, coordinated, and generally routine.

To represent functional relations among the diverse activity systems during an expedition, I adapt Wilden's (1987) notation and analysis using a *dependent hierarchy* (Figure 4.3). This diagram shows the overall exploration system as consisting of multiple subsystems with their own integrity—different institutionalized practices constituted by roles, activities, technologies, procedures, etc. training, funding, and career paths—working together as a single team during the expedition, most visibly and intensely during a dive.

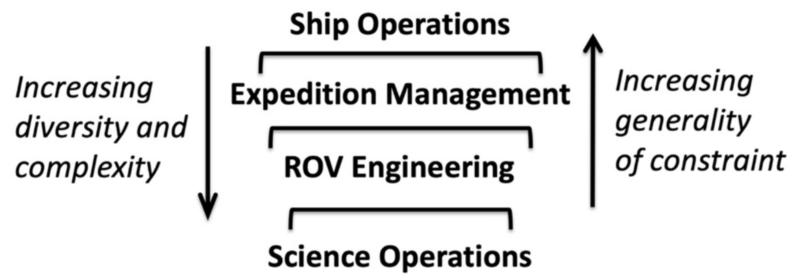

Figure 4.3. *Okeanos* exploration system dependent hierarchy.

To verify the validity of an analysis, Wilden uses the *Extinction Rule*: "To test for the orientation of a dependent hierarchy, mentally abolish each level (or order) in turn, and note which other level(s), or orders(s), will necessarily become extinct if it becomes extinct" (p. 74). Each "subsystem level" provides an environment for those below to exist, that is, to carry out their activities during the expedition:

- Without the ship and its infrastructure, these tele-presence scientific expeditions would not exist (e.g., the satellite dish enables real-time interactions with the remote scientists).
- Without the expedition management provided by NOAA's OER, the ROV engineering team and the two scientists would not be collaborating onboard, and the remote science team's organization, logging tools, and practices would not exist.

The term "existence" refers specifically to the organization and character of each subsystem in activities during expeditions, not its origin, history, or future. In particular, *OE* was constructed to collect underwater acoustical data in support of anti-submarine warfare operations; its ownership and use could change again. NOAA's OER operates ten research vessels, with many other forms of data collection and services, including National Weather Service satellites. Even the relatively specialized GFOE non-profit organization serves other activities, such as undersea filmmaking and shipwreck archaeology. Scientists typically work on several projects with different sources of funding; they are usually volunteers, not employed by NOAA. Thus the individuals and groups participating in the activities shown in Figure 4.3 have obligations and concerns apart from *Okeanos* expeditions, which underscores the question, how do they constitute a coherent exploration system, with practices that developed, but mostly persist, over a decade of expeditions, with different people playing the roles?

Such a complicated activity may suggest a hierarchical command structure, but who or what group is at the top in control? The scientists do not have authority over ship operations; and although the ship's crew and the NOAA OER expedition leader can veto operations when the constraints they manage require (e.g., safety, politics), neither may decide D2's path or sampling. Although one could imagine a dependency tree, with science operations at the top (inverting the diagram), it would suggest that the other activities are subservient or only exist for the sake of the more complex system, a form of reductionism. For example, other functions of ship operations and expedition management (e.g., to serve mining interests by scanning the seafloor overnight) would be obscured by only viewing them through the interests of oceanography in a dependency tree. This point is illustrated further in the section "Imaginary Oppositions."

Rather than breaking the expedition into parts and wondering how it "comes together" (an inter-actional view) or identifying some authority that controls the others (a form of "self-action"), we use Figure 4.3 as a way of "seeing functions together," with the levels corresponding to groups having different formal organization, roles, and activities, acting within the environment provided by those represented higher in the dependent hierarchy. Crucially, *each subgroup's expedition activities exist physically and temporally, and have meaning, only within the larger whole*—the exploration system in action. Although most salient during dives, the work system depicted by Figure 4.3 has extended and developed over a decade of expeditions, incorporating new sensors, online tools, and purposes (see section "A Broader View of the Dependent Hierarchy of the Okeanos Exploration System").

We say that the relationships of the activities among the subsystems are *transactional* because the constraints flow in both directions and pervade the entire exploration system. Nevertheless, the "higher" levels are more general and flexible. The ship's function is primarily to go from point A to point B, whatever the expedition requires, while keeping everyone alive with food, water, and basic utilities. Aside from challenges of the weather and aging ship, for the crew every day is much like the rest. ROV launches and recoveries are also routine and by the clock, though on the seafloor they are co-operating with the scientists. Expedition management relates logistic and technical activities, primarily in organizing expeditions and advising during abnormal situations, but never strictly supervising or directing the subgroups. The scientific work is a more diverse, opportunistic activity, as it involves different disciplines investigating the varied seafloor and biosphere, relating interests, theories, and projects. During an expedition a plethora of specific requests and constraints affecting dive sites, traverse paths, and how to use D2 to collect data ripple through the entire system.

In a work system, one group's activities constitute an "environment" for others by providing the services they require. Thus responsibilities and expectations develop and reinforce local actions into the coherent practice of a single team. For example, ROV engineers expect ship operations to be predictable after the bridge's acceptance of their movement requests (unless notified of difficulties). The scientists expect that GFOE will maneuver the ROVs to satisfy the agreed upon daily plan and keep them operable for the full expedition. Figure 4.3 thus provides a way of seeing the different group–activity systems as an "extensional-durational" whole: "Our own procedure is the transactional, in which is asserted the right to see together, extensionally and durationally, much that is talked about conventionally as if it were composed of irreconcilable separates" (Dewey & Bentley, 1949: 120; see also Andersson, Garrison, & Östman 2018).

Although the operations of the *Okeanos* exploration consist of cooperating and often collaborating institutionalized organizations (e.g., NOAA/OER, GFOE, universities), typically levels in a work system are not formally distinct corporations, agencies, etc. More generally, Wilden says the different activity levels are "goal-seeking systems" (e.g., ship operations seek to preserve the infrastructure while satisfying the interests of NOAA and the scientists).

In a broad exposition of his analytical framework, *System and Structure*, Wilden ([1972] 1980) characterizes *structure* as consisting of frameworks, channels, coding—more generally "types of relationships between subsystems." *System* consists of processes, transmissions, messages—more abstractly, "how regularities are used" and "relations between relations." The essential point, which I elaborate subsequently, is that although for design and accounting purposes we commonly view subsystems as distinct, independently existing entities, this labeled separation—making a whole process into named things—exists only in our conceptual activity of describing and notating, characterized by Wilden as "in the imagination." To understand how the exploration system succeeds, it must be "seen together," as activities extended in space and time (Ryan 2011; Garrison 2001: 285 ff.).

The Functional Trans-Actions of a Dive

A ship is a perfect work site for an ethnographic study—places, roles, and activities are all well-defined and repeat daily. I spent most of my time sitting next to the scientists in the control room (Figure 4.4). You see here the operations at the start of the day as Seirios is to be deployed off the stern using the A-Frame crane; D2 is deployed portside with another crane.

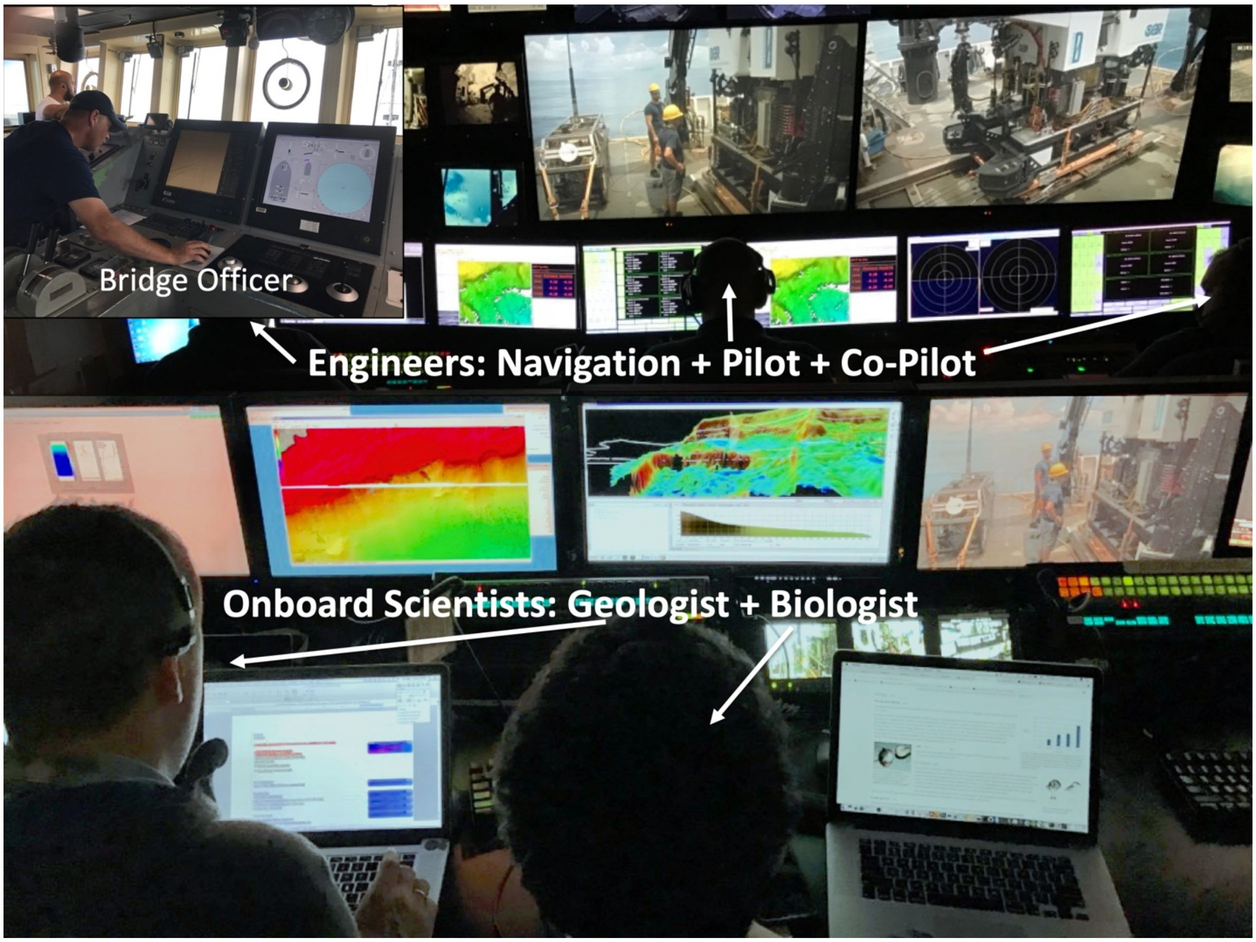

Figure 4.4. *Okeanos Explorer* Control Room, showing morning deployment of Seirios (top middle), ROV (top right), inset of Bridge Deck Officer (top left), ROV engineers, and scientists sitting in the back.

Seated up front in the control room, the engineer on the left is the ROV navigator (ROV NAV), who communicates with the bridge to keep the ship aligned with Seirios and D2. The ROV Pilot flies D2 using hydraulic thrusters, and the ROV Co-pilot aims Seirios cameras and assists in operating D2 when retrieving samples. To the right, off this image, the cinematographer controls the zoom camera on D2. The two scientists (called "Watch Leads") and I sat in the back. Everyone has a choice of over forty video and graphic displays that enable tracking the status of the rovers and provide views through cameras on Seirios, D2, and onboard.

The NOAA bridge deck officer works within the broader maritime environment to make ROV operations possible. Using software to control the robotic ship, he is constrained by the topside physical environment (weather, sea conditions), resources and capacities (fuel, propulsion, life support), and crew assignments. The videos broadcast to the ECCs and through a browser provide stereo sound, with the engineers and scientists on different channels. Thus, we can hear (and see indirectly) how the engineers coordinate with each other, the bridge, the cinematographer, and the scientists sitting behind them. Like television celebrities hosting a holiday parade, the narration from the scientists is continuous during the dive, explaining what we are seeing and doing to the unseen audience of remote scientists and the public. At times, a remote scientist will call on the shared phone line, which is broadcast in the narration channel, usually providing information relevant to what we are seeing—identifying it, characterizing its habitat or significance, and relating it to other species. Usually the remote scientists use the chat room for most of these remarks, which at least one of the watch leads is monitoring.

Figure 4.5 shows the recurrent lines of communication during a dive. By protocol, each person only speaks with certain other people. For example, the Watch Leads only address the ROV Pilot; they never make a request directly to the cinematographer. And in this group, only the ROV NAV communicates with the NOAA bridge deck officer. Different voice loops are dedicated to different subgroups.

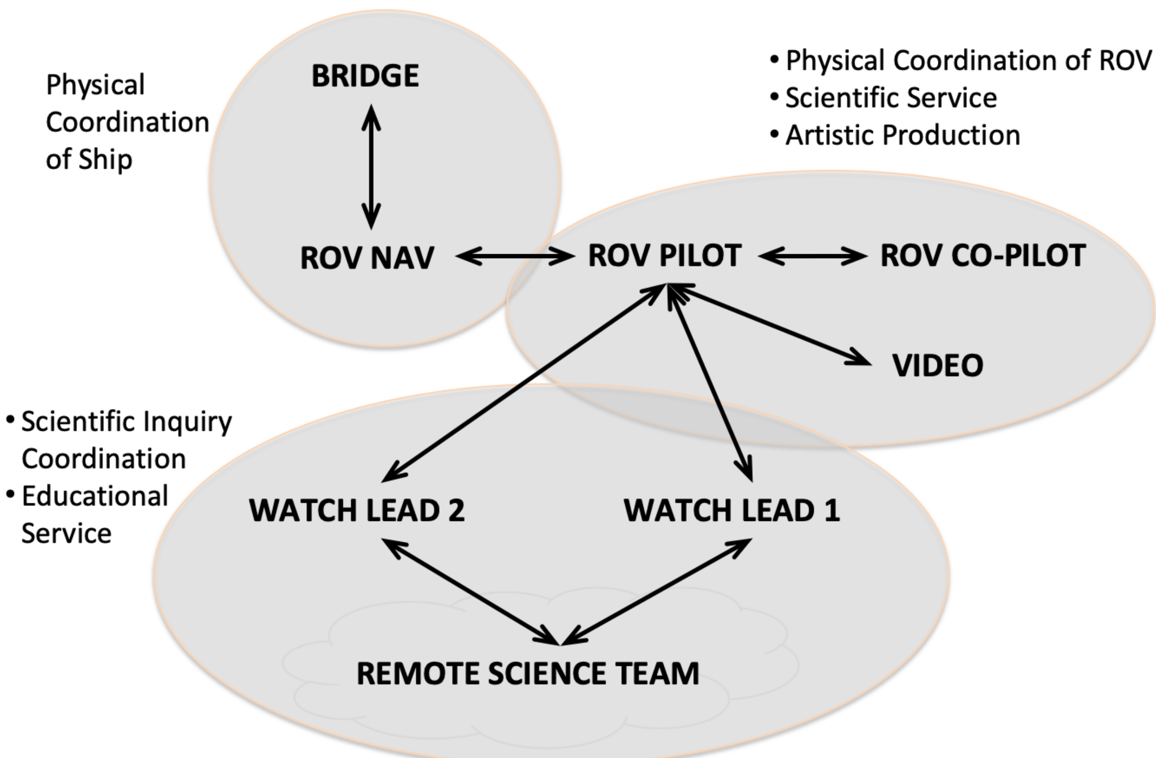

Figure 4.5. Lines of communication during a dive.

At one point, we see the ROV NAV glance over several displays, including one overhead, and then turn to the ROV Pilot, saying, "You should have another five minutes…." The ROV NAV's remark indicates that he is monitoring the relative locations of the ship and D2; he knows that a sampling activity is underway that prevents moving D2. As D2 moves forward, he will contact the bridge to move the ship forward in accord with the planned path and pace of the scientists' investigation. Each request specifies a certain heading, speed, and distance. If the ship is currently executing such a path, D2 will need at some point to move along so Seirios doesn't get ahead of it.

Responsibilities during a dive are fixed and relatively role-specific, associated with actions only particular individuals or groups may take, such as moving the ship, maneuvering D2, zooming the video, controlling the arm (ROV Co-Pilot's role), and logging the dive in a shared online tool (SeaScribe, accessible to any member of the science team). Responsibilities are with respect to some activity/subsystem, in service to other people. These relations correspond to the lines of communication; for example, the ROV Pilot is responsible to VIDEO for providing sufficient time to "image" a sample with the zoom lens, creating a close-up for the scientific database.

At one point, we hear the geologist say, "Chris Kelley is going to like this," revealing how he conceives his service to the remote science team, and his expectation that Kelley is watching or will be interested to examine the recorded data later. More broadly the entire team onboard is providing a service to students, future scientists using the dive's database, commercial fishing interests, and environmental protection agencies.

The design of the work system nicely illustrates the claim that "Knowing is co-operative and is integral with communication" (Dewey & Bentley, 1949: 97). Referring to Figure 4.5, people within each oval are *collaborating* in a specific activity, with broader durational-extensional *coordination* occurring among them. Thus, ROV NAV/Bridge activity is *coupled* to the engineer's activity, which is *coupled* with the scientists' activity. The whole system is like a collection of elastic bands tugging at each other, as they negotiate physical and intellectual constraints. A striking characteristic of this overall system is that we can't easily identify anyone as being completely in control of the dive operations: Control of D2's location and orientation is transactionally distributed with varying authority throughout the exploration system, including the remote scientists, who may call in with a request or whose narration requires holding D2 in place a while longer.

Furthermore, D2 is effectively a sensory-motor extension of our bodies—we see through the zoom lens, we manipulate and retrieve samples through the arm. Everyone moves with and through D2, up along the traverse path—a physical–intellectual choreography.

As mentioned, a wide variety of tools are used for communicating during a dive—visual, verbal, and written; some are shared, some private. These include the videos, the status displays, scientists' narration and audible communications with the engineers; the open telephone line; the formal species identifications in SeaScribe; and the chat room. Negotiation of interests and actions occurs throughout in visible reporting and requesting.

An example sequence in the chat room illustrates a common type of conversational exchange:

MJ: As a geologist, I ask a dumb question: I understand that the nautilus is a cephalopod, like the squid and octopus?
BM @AS: The eggs are laid singly, attached to bottom ... Nautilus are long-lived, slow-maturing … compared to other cephalopods.
AS @BM: Thank you! very interesting!
BM @MV: You are better qualified to answer MJ's question than am I.
MV: yes. Nautilus is a cephalopod, but …

Here the geologist (MJ) explicitly refers to his discipline and expresses deference to those with other expertise. But his remark may also be interpreted as signifying his awareness of needing to demonstrate competence as a selected, distinguished representative of the scientists onboard. (The answer comes from BM, partly in response to a prior question from AS, followed by BM deferring to MV as more knowledgeable to speak about cephalopods.) "Being scientific" is an ongoing accomplishment of individuals, the science team, and on through activities of the engineers and NOAA Officer Corps. New technologies for gathering and interpreting data, including especially robotic observation and communication methods, require new work practices, and thus reinventing what *being scientific* means (for elaboration, see Clancey [2012]). Accordingly, the "reality" of the ocean (as we know it) is inter-dependent with how we "come to know." The exploration methods and practices (activities of *knowing*) affect what is examined, described, and measured (aspects of the ocean claimed to be *known*); and vice versa, as known interests, needs, and opportunities shape tools, organizations, and operations.

Figure 4.6 is another way of representing graphically how one activity area provides an environment for another.

TEAM	SCIENCE		ENGINEERING			SHIP
POSITION	Remote Scientists	WLs	ROVP & ROVC	VIDEO	ROVN	BRDG
CONCURRENT REAL-TIME ACTIVITIES	**Science** Telecon, Chat room, & SeaScribe logging—shared focus on identifying what we are seeing. [Collaboration]		**Cinematography** Tight choreography relating ROV position and camera—shared focus on clarity and quality of video [Collaboration]		**Operating Ship** ROVN calls for repositioning ship; Bridge reports on weather effects—shared focus on relation of ship to Seirios/ROV [Cooperation]	
	Data Interpretation Chat & Phone Interaction [Collaboration]	**Gathering Scientific Data** Request view, close-up, sample—shared focus on satisfying scientific interest [Cooperation]				
			Operating ROV ROVN advising pilots about operations—shared focus on safety of ROV & tethers [Collaboration]			
PUBLIC VIEW	**Shared ROV main camera and Seirios main camera looking at ROV**					

Figure 4.6. Robotically mediated work system design.

Each subgroup—designated as in Figure 4.3 as science, engineering, ship— is responsible for the quality of a different aspect of the dive: Scientific guidance and interpretation; D2/Seirios operation and video recording (cinematography); and movement and stability of the *OE*. But some activities overlap, such as gathering biological and geological samples, as well as operating the ship during a dive (in which ROV NAV gives specific movement directions to the bridge deck officer).

The activities functionally compose to create a scientifically coherent investigation of the region, while preserving safety of the ROVs and ship. The overlap among groups reveals how relationships are forged through and within activities. In this graphic, *collaboration* is defined as working together as peers on a common project (e.g., scientific research; operating ROVs); *co-operation* involves people engaged in an activity but with different intentions, perhaps functionally related, often across organizations. In particular, gathering scientific data involves cooperation between the university scientists and GFOE engineers—the former to specify interests and the latter to determine what is possible and execute operations. The *OE* bridge is not involved in science or operating D2 directly, but co-operates with those activities, tacitly aware of D2 and knowing something about the planned traverse route and duration. ROV NAV collaborates with the Bridge Deck Officer in moving the ship, but of course the officer has responsibility and authority for all ship movements and how they are carried out. It is common to talk about "shared goals" in activities, but the notion can be subtle, with different aspects of "sharing." The ROV Pilot and Co-Pilot share the goal with the Watch Leads of gathering scientific data, but they have distinctly different roles and subgoals. The scientists select sample candidates according to their interests, while the ROV engineers decide whether a candidate sample is retrievable and have their own subgoals and methods for grabbing and storing it.

Finally, the diagram helps us realize that "robotically mediated" refers to much more than the robotic system, D2. The mediation—the functional instrumentality of the exploration system—is distributed throughout the system of roles, technology, and protocol-regulated activities.

Student Activities in an Exploration Control Center

My ethnographic study of the *Okeanos* exploration system actually began by observing university classes at the Harbor Branch Oceanographic Institute's ECC during 2015. My interest was to help Pomponi and other teachers understand how the ECC functions as a learning environment and how teachers might facilitate the students' experiences while observing dives together.

During one expedition the students and teachers were watching and talking about a series of dives during a week, while the students were charged with creating a taxonomic catalog of the life encountered. A lecturer provided a broad overview of oceanographic field science, illustrated by physical samples HBOI had collected during past decades. Afterwards, the teachers sat among the students and participated in searching on the internet for information and photos, commenting on what they were seeing, and (infrequently) posting remarks and questions in the chat room. Three high-resolution screens on the front wall displayed the chat room, the main video from D2, and either a context video from Seirios or the quad-display with status of the ROVs.

The group often listened intently to the onboard scientists' narrations, which was broadcast loudly in the room. Inevitably their conversations would overstep the narration, as they became engaged among themselves and ignored the broadcast audio. The students and teachers were observing the same vistas as the science team at nearly the same time and effectively constructed their own scientific narration, as in this exchange:

ECC teacher: Look how long that's been there, how clean it is.
(Watch Lead): (Yeah) that's what I was thinking.
ECC graduate student: That's exactly what he was thinking.
ECC class student: How was something like that formed?
ECC graduate student: That's a really good question … [explains]

The graduate student was observing the class and expedition, often standing in the back of the room. When the onboard scientist made a remark that circumstantially fit what a teacher in the classroom had said, the graduate student snapped back in a joke, "That's exactly what he was thinking." Everyone laughed, implicitly acknowledging the discordance—even though everyone in the ECC heard what the scientists and engineers broadcast, nobody outside the room could hear what the students and teachers were saying.

In an ECC we are observing the observers, but we are also a constituent part of the exploration system. The ECCs are being "played to" as part of the audience of the narrated streaming video and products later posted on the web. The scientists onboard, ROV team, and bridge deck officer, as well as the scientists who call in or post, are at least tacitly aware that their actions and remarks are public and being recorded. But students and facilitators in the ECC are also able to post remarks or questions in the chat room; when this occurred, scientists onboard responded to HBOI postings during their narration.

The chat room enables students to observe what the participating scientists are seeing and thinking and learning from each other. Everyone is seeing this world together for the first time, and the scientists' guidance, interests, surprises, and questions are visible for all to reflect on. Indeed, we might say that for all participants: "observer and observed are held in close organization" (Dewey & Bentley 1949: 131).

The *Okeanos* Exploration System is Designed for Learning

In summary, NOAA has created a sociotechnical exploration system for collaborative learning among the scientists, students, and the public. We can view D2 itself as being a tool for collaborative inquiry, just as Mars rovers are multidisciplinary collaboration tools for field science. Together with the software tools for planning, programming/control, and visualization of operations, these robotic systems provide a sense of presence, in which we project ourselves into the viewpoint of the rover as it moves, sees, and manipulates life and objects on the sea floor. In learning the practice of observing, imagining action, and its execution, we become present through the robot, not as spectators, but transacting directly with the sea environment (cf. Clancey 2012, Chapter 6, "Being the Rover"). This common embodiment in the physical place of the seafloor (and Mars surface) brings engineers, scientists, students, and the public together in a special, powerful way. The *Okeanos* exploration system is particularly effective because tele-operated control enables real-time contributions by everyone. All experience some form of personal agency in the exploration. (Mars operations are carried out in "batch mode," using fully programmable instruments; data is returned about a day after a restricted science team formulates requests).

More generally, we can view the exploration system as being designed for learning, pervading every aspect of the work system: planning, cinematography, sampling, and narrative. In the ethnographic report to NOAA following my participation during the American Samoa Expedition, I suggested how learning opportunities might be facilitated or elaborated:

- **Exploration Command Centers**: The ECC at the NOAA Daniel K. Inouye Regional Center in Pearl Harbor, HI benefits from being placed immediately outside the cafeteria where people encounter it daily. A NOAA employee is present during dives to explain what is occurring, as well as to welcome school and other visiting groups. Such facilitators serve as mediators between the narrated, visible dive operations and the people present, enabling feedback to the onboard scientists. To be available to the public, the ECCs require more volunteer facilitators.
- **Online Educational Materials**: Previously, NOAA's web site has naturally focused on the facts of each expedition and the oceanography. The *Okeanos* system also provides an excellent opportunity to explain how engineers use technology during scientific investigation (e.g., radar). Recently posted logs are revealing technical aspects of the exploration system and the diverse activities of scientists, engineers, and NOAA officers.

- **Open Remote Science Teams**: The telecons and shared media make data gathering and interpretation open to everyone during the mission. Making the sample curating after the dive and subsequent analysis public would reveal to students that “scientific discovery” involves much more than looking and sampling during a dive’s traverse.

Imaginary Oppositions: System Levels in a Dependent Hierarchy

To better understand the intent of the dependent hierarchy presentation, it is useful to know that Wilden’s analysis was partly motivated to dispel what he called *imaginary oppositions*, such as the familiar mind–body dichotomy (Figure 4.7). For example, technology is created and used within less constrained orders such as social systems, on which its existence and proper functioning depends. What we call the biological “self” has different boundaries from the “psychic self or social role.” Epistemological boundaries exist in the imagination of an observer, not nature itself (Wilden ([1972] 1980): 220–221).

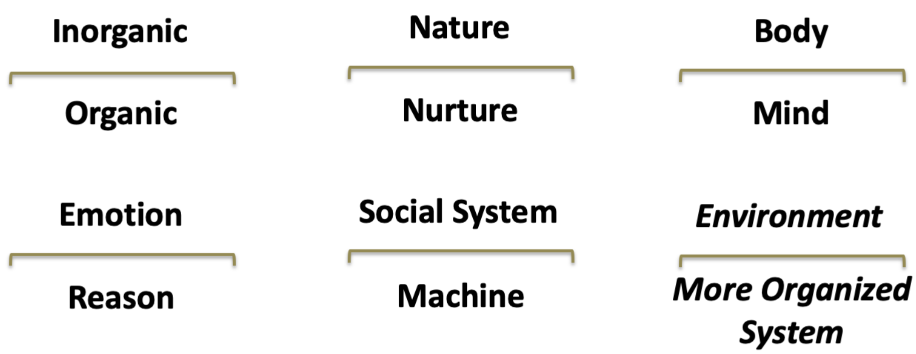

Figure 4.7. Imaginary oppositions shown as dependent hierarchies, most generally showing a designed or natural system/organism in an environment. (Concept adapted from Wilden, 1987, p. 82).

Wilden’s summary is helpful: “Only in the imaginary—of common folk and scientific parlance—can these categories be seen as symmetrical, binary opposites rather than as relations between levels of a larger system. The higher term (e.g., body) is the environment that the other term (e.g., mind) depends on for subsistence and survival” (Wilden 1987: 82). One might refer again to Dewey and Bentley’s (1949: 120) remark about “seeing together” what is typically decomposed into “irreconcilable separates.”

Perhaps the most useful, general principle is shifting from *either–or* analyses to understanding systems contextually with *both–and* development and reciprocity (including simultaneity). Different organizations or systems within a functional whole (e.g., the layers in Figure 4.3, as well as biological subsystems in an organism) are in “a reciprocal and co-constitutive exchange” (Wikipedia 2019), such as how emotional experience orients and shapes a conceptualization of “being in a situation.” Garrison (2011) stated this similarly: “Transactional thinking requires us to comprehend the organism-in-environment-as-a-whole; the same holds for mind-(or self)-in-social-environment-as-a-whole” (p. 311). Every more organized system (the lower systems in the Figure 4.7 dyads) may be viewed as being in a dynamic “organism-environment” relation with a less-constrained context that makes its existence possible, providing a source of problematic situations, challenges, and opportunities, and also providing resources for their resolution as the more organized system develops.

But we must be careful in how we adopt the transactional perspective in characterizing a system. It is tempting to suggest that the transactional perspective is "best," viz, "…all human exchange is best understood as a set of transactions within a reciprocal and co-constitutive whole" (Wikipedia 2019). Our understanding of an "either–or" mentality should lead us to take pause. Transactional and interactional descriptions of a system adopt different modeling perspectives/viewpoints. Their value depends on the context and our purpose. Analytic methodology can fruitfully incorporate *both* TP (transactional perspective) *and* IA (interactional analysis). In particular, in designing a work system, we can model automated system flows by an interactional analysis (as in a dataflow diagram), while understanding and considering that the relation of people to each other and automation will emerge in the practice, a transactional perspective (the automation may also adapt in response to people's behavior and the environment).

In short, the opposition of IA and TP exists only in the imagination; implying that TP is superior or "truer to reality" adopts a false dualism. TP is not more objectively the "correct" way of describing a work system in particular or always the "best" perspective, but it may be more useful for certain purposes, bringing out different aspects of the system, such as its resilient, adaptive, and dynamic qualities. Indeed, another well-known remark by Dewey and Bentley (1949), suggests that we may start with an interactional perspective and refine it after we have identified subsystems, roles, protocols, and practices: "Transaction…represents that late level in inquiry in which observation and presentation could be carried on without attribution of the aspects and phases of action to independent self-actors, or to independently inter-acting elements or relations" (p. 136).

Inquiry is usually iterative; our appreciation of relations develops over time and as new aspects are revealed by events and their patterns. Our descriptive language changes and interesting nuances are realized that may be useful for our purposes, which may involve teaching, redesigning a work system, inventing new kinds of automation, providing guidance to long-term planners, and so on. I conclude with such a broader transactional perspective of the exploration system.

A Broader View of the Dependent Hierarchy of the *Okeanos* Exploration System

Figure 4.8 broadens out from the ship–oriented perspective shown in Figure 4.3 to include the physical–biological and political–economic environments. These are less-organized systems than the ship's operation and the expedition policies and management of NOAA's OER (for simplicity, the ship subsystem not shown; it is implicitly included here in the OER management of exploration and research). Again, these are not like layers in a cake, but coupled systems: Influences flow in both directions throughout the system and aren't isolated to levels; for example, political-economic interests and policies of commerce and the government influence expedition routes and what the scientists study.

NOAA, including the OER, is part of the United States Department of Commerce and thus must serve business interests, for example, studying the ecology of fisheries in the North Atlantic. Scientific motives transcend what we might call "pure science"—scientists may select sites that they believe should be set aside as preserves in which fishing might be prohibited. Some oceanographers may want to reveal and document how trawling for shrimp by dragging nets destroys everything in their path, as has occurred along the continental shelf of Florida. Consequently, *Okeanos* expeditions may be *both* scientific *and* political, as well as economically and pedagogically oriented.

Each level of the exploration system co-exists and is in a reciprocal relation to others, establishing a broader system of mutual conditions. Because these are open systems, effects may be expressed throughout the overall system. Perhaps most obviously, technological capability and scientific inquiry are co-developing; for example, expeditions reveal to scientists what instruments might be useful, just as the pace and location of traverses reveal to engineers what map and radar instruments and displays, planning programs, and mobility are useful during expeditions. For example, success in using the thermal probe in one location may prompt studying another area, but also modifying its capabilities and/or how it is deployed.

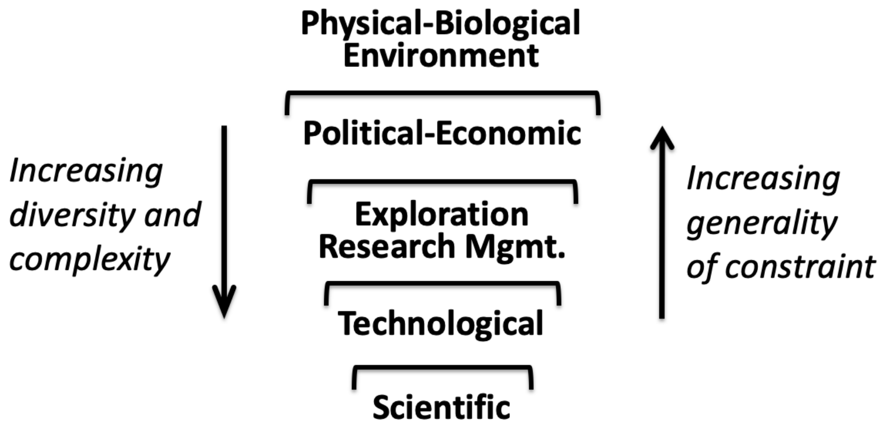

Figure 4.8. Broader view of the dependent hierarchy of the *Okeanos* exploration system.

Political and economic interests and policies may be influenced by climate changes to ocean properties (especially temperature) and hence affecting biological habitats. Consumer preferences shape economic interests, which may lead to over-fishing and new government regulations.

The term "constraint" in the dependent hierarchy diagram refers to resources, guiding values, beliefs, perceptions, and methods that organize a system in accord with certain functions or qualities of the whole. For example, political beliefs of the US President and Congress affect NOAA's funding and may seek to discourage or even prevent certain forms of scientific inquiry:

> The [Trump] administration has proposed cutting NOAA's budget to about $4.5 billion for fiscal year (FY) 2020, a drop of about 18%, nearly $1 billion, compared with the agency's FY 2019 enacted budget … The proposed budget would terminate most climate research programs … and eliminate climate competitive research funding. Among other cuts, the budget would terminate the National Centers for Coastal Ocean Science, the National Sea Grant College Program, and some Arctic research products; decrease funding for ocean exploration and research efforts; and eliminate coastal zone management grants. (Showstack 2019)

In conclusion, the study of the *Okeanos* exploration system demonstrates how exploration can be understood as an ecology of systems influencing each other. The physical/biological and political/economic constraints are most general, providing an environment in which exploration enterprises (e.g., NOAA expeditions), advanced technology development, and scientific research may exist. These more diverse and complex subsystems of interests, data, models, and guidance then affect policies and (commercial) operations in the government agencies that support exploration. The exchanges throughout may at first be described as interactions in a flow of funding, data, control, and information within exploration system (e.g., Figures 4.5 and 4.6). But when we inquire about the history of scientific work, such as how the origin and locations of expeditions over nearly a decade, we find a transactional perspective fruitful, as it leads us to discover reciprocal relations and mutual influences. We realize in particular that terms such as "collaboration," "sharing," and "mediated," which are often used informally in robotic research, can be more precisely understood by examining the roles and activities of people and automation within a work system. And regarding the scientists who worried about the inter-actional limitations of the new robotic system, although they might not state it this way, their satisfaction with the *Okeanos* exploration system is an expression of its transactional nature.

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https://oceanexplorer.noaa.gov/okeanos/explorations/ex1702/welcome.html

This report was prepared in my personal capacity and represents my own observations and conclusions, which are accurate to the best of my knowledge, and do not necessarily represent the views of NOAA or any other institution.

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