# Work Systems in Underwater ROV Operations: Educational Insights for Workforce Development in Maritime Engineering

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## Declarations

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### Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

### Competing interests

The authors declare that they have no competing interests.

### Ethics Statement

Not applicable as this study did not involve human participants.

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### Authors' contributions

MY contributed to the investigation, methodology, and formal analysis. KC led the research's conceptualization, contributing to the investigation and methodology. MY and KC shared responsibility for the validation process and contributed equally to the manuscript's writing, review, and editing.

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## Abstract

As an emerging area within ocean engineering, underwater remotely operated vehicle (ROV) operations signify a crucial intersection of technological innovation and practical application, requiring specialized knowledge and skills. Utilizing Work Systems Theory (WST), this study informs engineering educators and workforce development professionals about the unique work systems involved in ROV operations. Through a systematic review of 275 LinkedIn job postings, the study adopts a parallel convergent mixed methods approach, incorporating topic modeling and qualitative content analysis. The analysis identified ten distinct work systems, each characterized by specific features such as industry sectors, seniority levels, job tasks, educational requirements, and essential Knowledge, Skills, Abilities, and Other characteristics (KSAOs). Based on these findings, we offer recommendations for engineering education, emphasizing the importance of customized educational programs that address the changing workforce demands in this fast-evolving field.


**Keywords:** Ocean Engineering, Maritime Engineering, ROV Operation, Job Analysis, Work Systems, Career Pathways, Training, Development

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## Introduction

Ocean engineering, which encompasses a diverse array of activities, including offshore construction, inspection, and subsea exploration, plays a crucial role in addressing global challenges such as the climate crisis while also fostering new avenues for economic growth and scientific discovery (Huvenne et al., 2018; McLean et al., 2018). In particular, underwater robotic teleoperation stands at the forefront of technological innovation, representing a critical intersection between ocean engineering and exploration. This evolution is closely linked to competencies spanning diverse domains and significantly influenced by emerging technologies (Beer & Mulder, 2020; The World Bank, 2019). These competencies exemplify the rapid evolution of this field and emphasize the imperative for workers to be prepared for cutting-edge advancements.

In recent years, there has been a surge in demand for skilled professionals in this domain, characterized by human-robot collaborations and the enhancement of human abilities (CareerExplorer, 2025.; Fact.MR, 2024). This growth is further fueled by the expansion of maritime industries and the need for scientific exploration in underwater environments. In this context, industry sources such as Marine Technology Reporter (2013), which provides insights into maritime technological developments, have projected a 130% annual increase in these roles. While this projection reflects an industry perspective and may be optimistic, it signals the anticipated expansion of human-robot collaborative roles in maritime engineering. Complementing this industry outlook, broader workforce trends also show sustained growth in STEM-related fields. Specifically, STEM occupations are projected to grow by 8% between 2019 and 2029, compared to a 3.8% growth rate for non-STEM fields. Additionally, the median projected income for STEM professionals is $86,980—2.3 times higher than the $38,160 median

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for non-STEM occupations (U.S. Bureau of Labor Statistics, 2022). Consequently, as the field of ocean engineering evolves, understanding the specific work systems and competencies required will be essential to meet the growing workforce demands.

As a form of work, teleoperation in ocean engineering involves the control of Remotely Operated Vehicles (ROVs) or Autonomous Underwater Vehicles (AUVs) as surrogates for work that is completed in another location (Moniruzzaman et al., 2022). For underwater ROV operators, the essence of the work lies in using standard game controllers, video screens, or virtual reality interfaces while integrating sensor data such as current flow, depth, and water temperature from onshore locations or ships to control drone-like robotic vehicle systems. These systems are used to complete maritime tasks such as inspecting, constructing, or repairing infrastructure in shallow water environments (UTM Consultants, 2020).

Notably, the widespread engagement in video gaming among adults, with 53% of the population participating in this activity (Pew Research Center, 2017), suggests a potential latent talent pool for underwater ROV operations. Recent studies indicate that skills developed through video gaming, including those in virtual reality environments, are transferable and positively correlated with career success in related fields (Sapp, 2023; Vinson et al., 2020). This connection between gaming and ROV operation merits deeper exploration, especially within the context of inclusive educational pathways and workforce development in ocean engineering.

Recognizing the current rapid transformations in the global economy, the U.S. National Governors Association (2020), for example, has emphasized the necessity for new collaborations between employers and educational institutions. Ideally, such collaborations aim to identify and construct learning and career pathways, removing barriers and expanding training to meet the new demands of this evolving landscape. Consequently, engineering education has a critical role

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in nearly every aspect of this phenomenon (Moran, 2021), a likely scenario for all emerging STEM fields.

However, despite the growing interest in underwater ROV operations and demand for workforce development, there remains a significant need for empirical research that identifies the competencies required for success, especially given the diverse tasks and work environments involved in ROV operations. For example, our search of the Occupational Information Network (O*NET), which is the premier U.S. occupational information source maintained under the sponsorship of the U.S. Department of Labor/Employment and Training Administration, failed to identify a single, specific occupation for underwater ROV operators using the same search terms applied in our LinkedIn search. Instead, the search returned a list of 20 occupations that included terms like "remotely operated underwater vehicle" OR "ROV" OR "AUV". Of these, only two occupations, *Commercial Divers* and *Fishing and Hunting Workers*, were found to be directly related to the ocean environment.

Notably, O*NET also reports that the occupation of Commercial Diver is expected to grow rapidly in the next several years, resulting in many job openings. However, the absence of a distinct category for underwater ROV operators highlights a significant gap in our understanding of this emerging field. This lack of clarity has resulted in ambiguity regarding the nature of ROV operations and their workforce requirements, leading to a shortage of targeted research in this area. Therefore, addressing this knowledge gap is crucial for advancing the field and effectively developing the skilled workforce needed to meet growing industry demands.

Analyzing job postings is a pivotal approach to identifying the in-demand competencies of the contemporary job market. For example, Ozyurt et al. (2022) highlight the significance of job postings as indicators of industry needs and trends, providing valuable insights into evolving

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competencies required for thriving in the industries. This method allows researchers to inform workforce development professionals about the distinctive aspects of this emerging career field, thereby facilitating the alignment of training programs with industry needs.

In light of these considerations, this study aims to address the gap in empirical research by analyzing job postings and identifying distinct work systems within underwater ROV operations using Work Systems Theory (WST) as a conceptual framework (Alter, 2013). Through this analysis, the study offers valuable insights into the unique combinations of work context, work, and worker characteristics demanded by the maritime industry. The insights can inform engineering education and workforce development programs in ocean engineering related to underwater ROV operations, cultivating a more skilled and qualified workforce. The following research questions guide our inquiry:

1. What are the work context, work, and worker characteristics for underwater ROV operations within ocean engineering?
2. What work systems can be identified from interactions among work context, work, and workers?

## Conceptual Framework

WST is a conceptual framework for examining the interaction between social and technical elements within an organization as the basis for understanding performance and achieving goals (Alter, 2013). Social elements include organizational culture, communication, group dynamics, and motivations, while technical elements include physical tools, equipment, and technologies germane to work activities. By recognizing the relationships and possible dependencies among such elements, the theory offers insights for designing systems that perform better, enhance employee well-being, and are adaptable to changing circumstances. For example,

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early research involving WST emphasized concepts that provided meaning for the term *quality of working life* as the humanization of work and a person's development through work, with a practical focus on transitioning military veterans to civilian life (Mumford, 2006).

The work system, composed of the worker, work, and work context, is the unit of analysis for identifying and understanding systems in organizations. The theory recognizes that workers are not merely passive recipients of technology but active participants in the work system, highlighting the importance of considering human factors in the design and implementation of technology and work processes (Carayon, 2006). In an organization, work is the application of human, informational, physical, and other resources to produce products and services.

In the case of ROV operations, human operators play a crucial role in preparing, maintaining, and controlling the robotic systems, interpreting data, and making decisions, often in real-time. Yet, success also depends on the design of the technological systems, which increasingly involve augmentation through artificial intelligence, communication interfaces, and the organizational structures supporting the missions (de Vries, 2017). WST can be used in defining worker competencies, optimizing workflows, enhancing communication strategies, and improving the integration of capabilities to better serve participants in the system and achieve more efficient and effective performance in challenging conditions (Hettinger et al., 2015). By emphasizing the interconnections between human operators and robotic systems in complex underwater, onshore, and on-ship environments, WST offers the potential for valuable insights (Stanton & Bessell, 2014).

From the WST perspective, identifying the competencies for employment involves uncovering a work system's human and technical elements and their dynamic relationship within an organization's context (Mumford, 2006). Competence is an unobservable construct specific to a domain and inclusive of learnable and transferable abilities and skills that must be inferred from an individual's performance in various situations (Ufer & Neumann, 2018). The technology used during work affords and constrains the work structure, which inherently has social and psychological properties that function as requirements for completing tasks (Cooper & Foster, 1971). Effective job performance is not solely an application of technical skills and personal characteristics but also the social context in which the work occurs. Therefore, identifying competencies for employment requires considering both technical skills and social factors that contribute to job effectiveness and organizational success (Ufer & Neumann, 2018; Weinert, 2001).

## Literature Review

### Research Using Work System Theory

WST has been applied across various industries and domains to enhance organizational performance and effectiveness. For example, in healthcare, researchers have utilized WST to analyze and improve patient safety and healthcare delivery processes (Carayon, 2006; Challenger et al., 2013; Holden et al., 2011). By examining the interplay between social and technical components within healthcare organizations, such as communication systems, medical equipment, and workflow processes, researchers have identified opportunities for redesign to mitigate errors and improve patient outcomes. WST has been employed in manufacturing to optimize production processes and enhance worker productivity (Maware et al., 2022). Researchers and practitioners have implemented changes to streamline operations, reduce waste, and increase efficiency by considering the interaction between human operators, machinery, and organizational structures.

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WST has been instrumental in developing competencies within specific industries or domains by emphasizing the interaction between social and technical components to optimize performance and achieve organizational goals. Teamwork, communication, and patient-centered care competencies have been used to deliver high-quality healthcare services (Challenger et al., 2013; Holden et al., 2011). Identifying the factors influencing the safety records of airlines reveals the significance of pilot salary, fleet age, and various safety parameters for efforts to enhance airline safety and accident prevention (Low & Yang, 2018). For the oil and gas industry, identifying competencies makes hazards more apparent, improving the safety, operability, and maintainability of on and offshore facilities (Chandrasegaran et al., 2020).

**Research on Underwater ROV Operations**

Research on underwater ROV operations has predominantly focused on three main areas: human factors and workload analysis (Elor et al., 2021; Wu et al., 2015), technology effectiveness (Chin et al., 2018; Konishi et al., 2020; Stewart et al., 2016), and task analysis (Teigland et al., 2020; Thieme et al., 2020). For instance, Wu et al. (2015) identified key human, robot, task, and environmental factors influencing semi-Autonomous Underwater Vehicles (sAUVs), emphasizing challenges such as situation awareness, communication, and task complexity. Similarly, Elor et al. (2021) demonstrated that Stereoscopic-VR could enhance operator performance in midwater creature capture tasks compared to Monoscopic-VR and Desktop conditions, addressing the cognitive demands of ROV piloting.

Regarding technology effectiveness, Chin et al. (2018) suggested a cost-effective virtual reality ROV pilot simulator using Unity3D to enhance training fidelity. Additionally, Konishi et al. (2020) investigated haptic shared control for ROVs, revealing its potential to mitigate mental workload and enhance operator concentration. Moreover, studies focusing on task analysis, such

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as Thieme et al. (2020), identified ROV tasks suitable for automation, underscoring the importance of safety and reliability in subsea operations.

Despite these advancements and the growing demand for a qualified workforce, there remains a gap in the literature, a need for research on the crucial competencies required for underwater ROV operations and the essential characteristics of this emerging career. Addressing these gaps is vital to fully understanding and developing the field, ensuring the effective training and deployment of skilled professionals.

**Defining a Profession through the Longitudinal and Systematic Use of Job Analysis**

Over the past 20 years, job analysis has been used systematically in educational technology to define the competencies of educational technologists and instructional designers. This genre of research, described as competency studies, involves using job announcements and, to a lesser degree, interviews with professionals to define “the knowledge, skills, and abilities professionals need in their roles” (Martin & Ritzhaupt, 2021). These attributes are the most frequently studied variables for all published job analyses (Kim & Angnakoon, 2016).

Beginning in the mid-2000s, Ritzhaupt, Martin, and Daniels (2010) used 205 job postings, and Sugar et al. (2011) used 615 job postings to define the competencies for the instructional designer position. These studies were repeated multiple times over the next ten years with different sources, durations, and subsequent sample sizes to add to and refine the statements (e.g.,Kang & Ritzhaupt (2015); North et al. (2021)). The resulting statements of knowledge, skill, and ability have become the practical definition of the profession as well as the outcomes for program development and accreditation. The most recent work has expanded the scope to include the emergent position of *Learning and Development Professional* (Martin et al., 2022). All cases involved qualitative coding, a varying sampling period from one to seven

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months, and the computation of interrater reliability, which again are hallmarks of job analysis and were used in this study (Kim & Angnakoon, 2016).

## Methodology

Job postings, often termed job ads or announcements, are essential resources detailing job responsibilities, required qualifications, and information about hiring organizations (Kim & Angnakoon, 2016). Analyzing these postings allows researchers to glean insights into the Knowledge, Skills, Abilities, and Other characteristics (KSAO) the industry demands. Additionally, it aids in identifying emerging trends, developing competency frameworks, and uncovering practical implications for stakeholders (Ozyurt et al., 2022).

To gain a deeper understanding of the work context, tasks, and worker requirements associated with underwater ROV operations in the maritime industry, a job analysis was conducted using LinkedIn, a widely used professional networking and job recruitment platform. While it is acknowledged that a considerable portion of engineering and specialized roles is filled through non-public channels, such as professional networks, recruitment agencies, or internal referrals, LinkedIn job postings offer valuable insights. Although the platform may not capture the full range of ROV-related employment opportunities, it provides a dataset that reflects industry-recognized competencies and qualifications explicitly sought in publicly advertised roles. Therefore, these postings are expected to serve as a useful indicator of workforce trends.

Our job analysis involved two parts. First, identifying a data corpus through a systematic review of LinkedIn postings, following the PRISMA process's four phases: identification, screening, eligibility, and inclusion (Moher et al., 2009). The resulting dataset was analyzed using parallel convergent mixed methods (Creswell & Creswell, 2017), integrating qualitative and quantitative analyses to understand the advertised roles comprehensively. While this method

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does not account for unadvertised positions, it offers a systematic and transparent approach to identifying key patterns and trends within the publicly available segment of the ROV workforce.

For the identification phase, a search string was constructed using Boolean operators and parentheses: "remotely operated underwater vehicle" OR "autonomous underwater vehicle" OR "underwater robotic vehicle" OR "unmanned underwater vehicle" OR "remotely operated vehicle" OR "ROUV" OR "AUV" OR "URV" OR "UUV" OR "ROV". The data collection period was from 3/10/2023 to 5/7/2023. Initially, a total of 1694 postings were obtained via web scraping using the platform, Octoparse (Octoparse, 2023) (Table 1). The scraped data were exported to an Excel format, where 481 duplicate postings were identified and removed from the dataset. The remaining 1213 postings underwent screening, during which exclusion criteria (Table 2) were applied based on categorical information, resulting in the exclusion of 635 postings. The remaining 671 postings were reviewed based on the job descriptions, culminating in a final dataset of 275 job postings (Figure 1). From these 275 job descriptions, all irrelevant and unnecessary information, such as company details and application procedures, was removed to ensure the clarity and reliability of the data.

Table 1. Scraping Log

| Start | Finish | # of Postings |
|---|---|---|
| 10-Mar | 9-Apr | 737 |
| 10-Apr | 16-Apr | 346 |
| 17-Apr | 23-Apr | 202 |
| 24-Apr | 30-Apr | 200 |
| 1-May | 7-May | 209 |
| **Sum Collected** | | 1694 |
| **Duplicates** | | 481 |
| **Total for Screening** | | 1213 |

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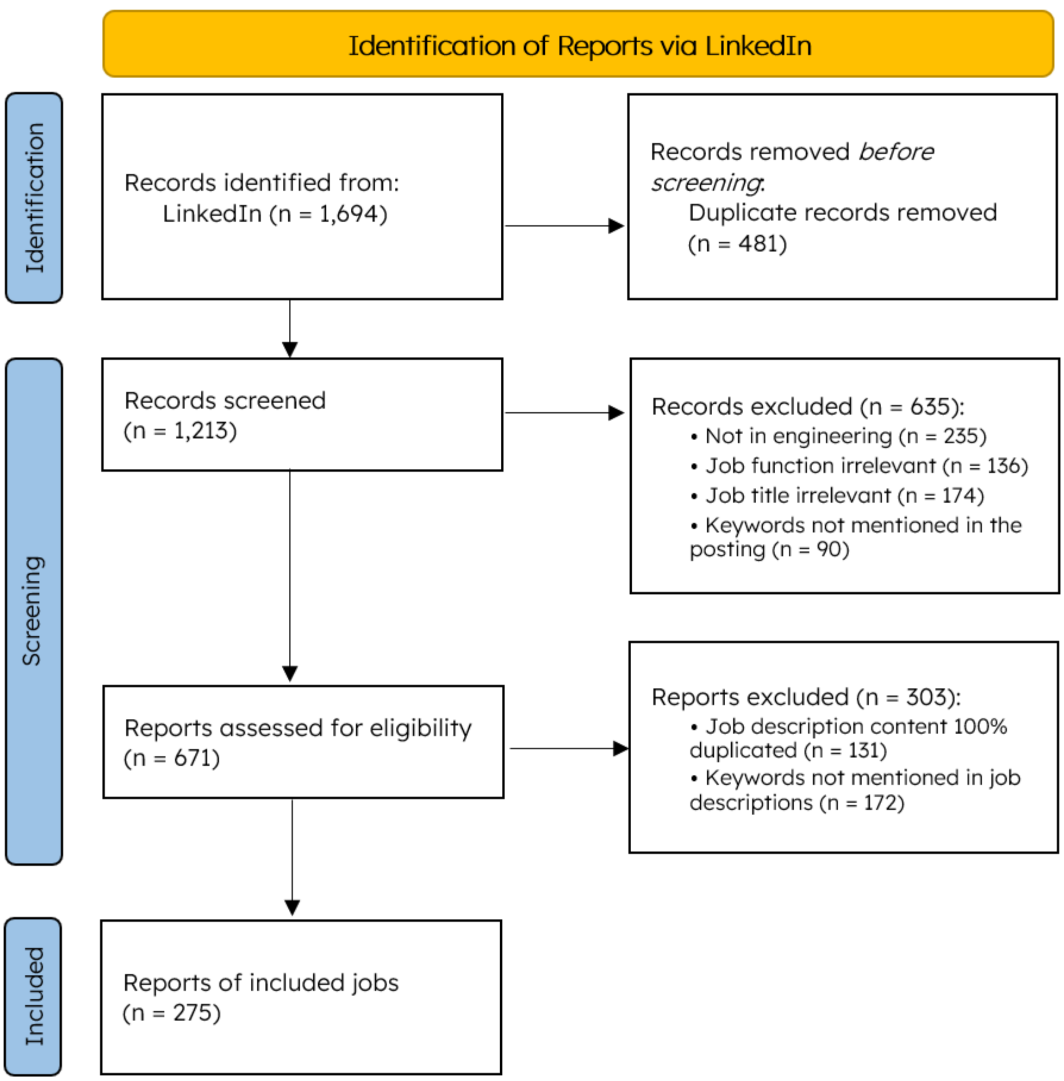
Table 2. Exclusion Criteria

| **Posting Review (n=635)** | **# excluded** |
|---|---|
| Not in engineering | 235 |
| Job function irrelevant | 136 |
| Job title irrelevant | 174 |
| Keywords not mentioned in the posting | 90 |
| **Description Review (n=303)** | **# excluded** |
| Job description content 100% duplicated | 131 |
| Keywords not mentioned in job descriptions | 172 |

Figure 1. PRISMA Review Process Flowchart

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Content analysis through inductive coding was performed utilizing MaxQDA, software for qualitative data analysis, to extract data concerning work context, work, and worker characteristics. Within this analysis, location and industry details were analyzed as elements of work context, while seniority level and job function were identified as the nature of the work. Furthermore, education, experience, and licensure were scrutinized as characteristics of the worker (Krippendorff, 2012). In conjunction with the skills and abilities frameworks from the O*NET content model (United States Department of Labor, 2023), deductive and inductive coding methods were applied to analyze the KSAO statements. Before this analysis, the authors agreed on the coding framework and discussed examples for each code to ensure clarity and consistency.

To achieve methodological rigor and transparency in our coding process, we conducted assessments to ensure intercoder reliability with 10% of the data units, which were randomly chosen to ensure a representative sample given the sample size. This approach adhered to the recommended 10-25% from O'Connor and Joffe (2020). The results demonstrated a Cohen's kappa coefficient of 0.842, indicating nearly perfect agreement following Cohen's criteria (McHugh, 2012).

Concurrently, topic modeling using the Latent Dirichlet Allocation (LDA), a statistical technique rooted in unsupervised Machine Learning (Blei et al., 2003), was implemented using version 8.1.0 of the Text Processor extension in the application Rapidminer (Kotu & Deshpande, 2015). LDA assumes that each indicated text segment consists of exactly one topic, and data pre-processing includes removing numbers, URL's, stop and very short words, and terms by stemming. Using the maximum log-likelihood optimization method (Sbalchiero & Eder, 2020), this approach resulted in the identification of ten distinct topics derived from a compilation of physical work condition descriptions (work context), task statements (work), and qualification descriptions (workers).

The latent patterns require human interpretation (Quinn et al., 2010) and the identified topics were systematically named as work systems and described through a collaborative discussion between the authors (Table 3). This process emphasized the distinctive combination of the nature of work context, work, and worker derived from the original job posting data collected. Names were produced as combinations of work context/work/worker characteristics based on an interpretation of the weighted terms and a review of the associated data fields. For example, topic number three was named *Underwater/System Design/Engineer* due to the frequent occurrence of the term *engineer* in job titles, the emphasis on underwater systems in job descriptions, and the focus on tasks related to designing, testing, and supporting systems that included a requirement for experience and a Bachelor of Science degree in engineering or information technology.

Parallel convergence mixed methods involved simultaneously analyzing the descriptive content analysis results with the topic modeling results. This approach aimed to reveal the interconnections among work context, work, and worker characteristics, which are integral components within each identified work system. Integrating the two methods allowed for a comprehensive understanding of the intricate relationships shaping the dynamics of work systems.

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Table 3. Ten Topics Identified through Topic Analysis and Corresponding System Names Assigned

| System Name (work context/work/worker) | Topic # | Words & Weights | n | % |
|---|---|---|---|---|
| Offshore/ROV Operations/Technician | 1 | oper (318), rov (293), system (183), work (150), ensur (138), mainten (126), safeti (117), compani (112), requir (97), experi (91), dive (87), maintain (82) | 51 | 19% |
| Offshore/ROV Project or System Support/Engineer | 2 | subsea (201), project (186), oper (164), equip (163), client (124), rov (120), ensur (115), offshor (112), vessel (110), technic (105), requir (93), tool (88) | 37 | 13% |
| Underwater/System Design/Engineer | 3 | experi (263), system (222), engin (166), year (139), develop (118), degre (91), vehicl (89), technic (86), program (83), custom (80), relat (77), perform (59) | 35 | 13% |
| Underwater/Software System/Engineer | 4 | test (202), experi (198), system (193), control (107), develop (103), softwar (89), vehicl (70), includ (68), support (62), data (52), year (51), engin (47) | 34 | 12% |
| Industry/Project/Manager | 5 | manag (306), plan (100), product (95), process (93), develop (90), work (88), respons (85), experi (81), team (79), schedul (78), qualiti (78), ensur (71) | 25 | 9% |
| Underwater/Electrical and Mechanical System/Engineer | 6 | experi (142), design (124), engin (93), auv (91), work (81), electr (79), mechan (64), system (57), team (52), robot (46), assembl (42), compon (39) | 23 | 8% |
| Subsea/Product Design/Engineer | 7 | engin (215), design (202), experi (130), project (114), work (109), test (98), requir (77), product (73), year (59), offshor (59), review (57), equip (54) | 22 | 8% |
| Underwater / Survey Data Processing/Analyst | 8 | data (106), survei (84), oper (66), system (42), water (41), knowledg (36), posit (36), field (33), report (33), process (32), requir (32), offshor (31) | 20 | 7% |
| Offshore/ROV Project or System Support/Technician | 9 | system (89), repair (84), mainten (81), certif (46), support (44), experi (41), instal (38), manag (37), maintain (36), rov (35), equip (32), train (30) | 18 | 7% |
| Subsea/Vehicle and Equipment Operation/Technician | 10 | equip (99), system (98), hydraul (74), oper (57), includ (57), repair (47), work (47), electr (46), maintain (45), mechan (44), electron (40), associ (39) | 10 | 4% |
| | | Total | 275 | 100% |

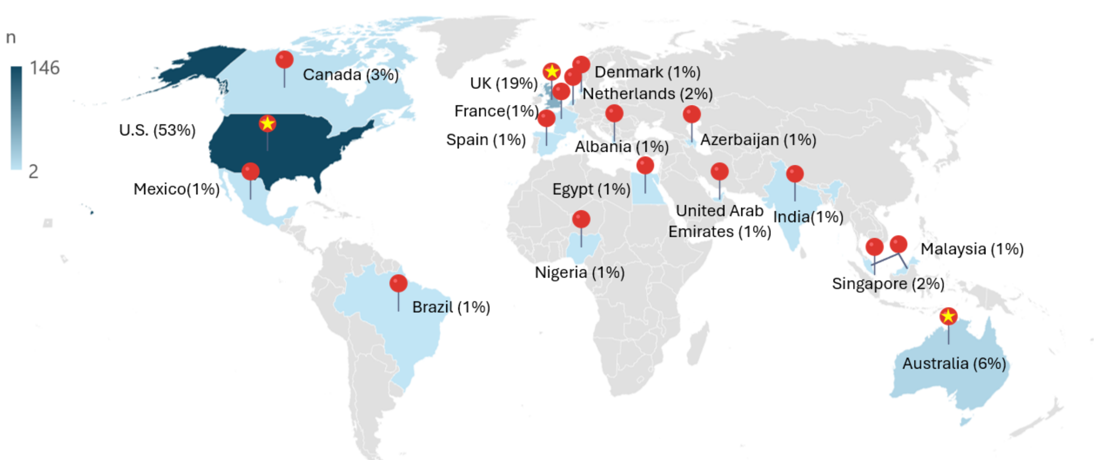
## Results

### Characteristics of the work context, work, and worker

#### *Work Context*

Our analysis of the nature of the work context uncovered a diverse distribution across 29 countries where ROV-related positions are advertised (Figure 2). Notably, while our study focused solely on English-written postings, it is important to acknowledge the global presence of ROV job postings. Predominantly, job opportunities were concentrated in the United States, constituting 53% of the total postings. The United Kingdom and Australia emerged as notable hubs, contributing 19% and 6%, respectively. Other countries, including Canada (3%), the Netherlands (2%), and Singapore (2%), were also identified, highlighting the global significance of ROV-related activities across various regions.

Figure 2. Nature of Work Context: Locations.




| Country and Its Frequency | | | | | | | |
|---|---|---|---|---|---|---|---|
| United States | 146 | Singapore | 5 | United Arab Emirates | 3 | Malaysia | 2 |
| United Kingdom | 52 | Mexico | 4 | Azerbaijan | 3 | Nigeria | 2 |
| Australia | 17 | India | 4 | Egypt | 2 | Albania | 2 |
| Canada | 7 | Denmark | 3 | Brazil | 2 | Other | 11 |
| Netherlands | 5 | France | 3 | Spain | 2 | | |

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The industries associated with ROV operations showed a multifaceted landscape, indicating engagement across diverse sectors (Table 4). The energy sector emerged as the dominant domain, with 26% of job postings linked to oil and gas and renewable energy industries. Manufacturing industries, encompassing defense and space manufacturing and semiconductor manufacturing, constituted 22%, reflecting the intersection of advanced technologies with subsea applications. The professional services, construction, and information technology sectors also exhibited substantial involvement, comprising 28% of the postings. These findings emphasize the interdisciplinary nature of subsea operations and the diverse employment opportunities available across different industries.

Table 4. Nature of Work Context: Industries

| **Industry** | **Example** | **n** | **%** |
|---|---|---|---|
| Energy | Oil and Gas, Renewable Energy, etc. | 71 | 26 |
| Manufacturing | Defense and Space Manufacturing, Semiconductor Manufacturing, etc. | 61 | 22 |
| Multiple | | 39 | 14 |
| Professional services | Staffing and Recruiting, Environmental Services, etc. | 28 | 10 |
| Construction | Civil Engineering, Construction, etc. | 26 | 10 |
| N/A | | 14 | 5 |
| Information Technology | IT services and IT consulting, information and internet, etc. | 13 | 4 |
| Transportation | Maritime Transportation, Truck Transportation, etc. | 10 | 4 |
| Research | Higher Education, Research Services, etc. | 7 | 3 |
| Media and publishing | Internet Publishing, and Book and Periodical Publishing | 5 | 2 |
| Other | Technology, Software Development, etc. | 1 | <1 |
| **Total** | | **275** | **100** |

An examination of companies revealed a mix of established and emerging companies contributing to the ocean engineering field (Table 5). Oceaneering emerged as the predominant employer, accounting for 17% of the total postings analyzed, followed by ClearanceJobs (7%),

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Fugro (6%), and Anduril Industries (5%). This diversity reflects the range of companies involved in subsea operations, from technology providers to career platforms.

Table 5. Nature of Work Context: Companies

| **Company** | **n** | **%** |
|---|---|---|
| Oceaneering | 46 | 17 |
| ClearanceJobs | 19 | 7 |
| Fugro | 16 | 6 |
| Anduril Industries | 13 | 5 |
| Subsea7 | 9 | 3 |
| Atlas Professionals | 7 | 3 |
| L3Harris Technologies | 6 | 2 |
| LSP Renewables | 5 | 2 |
| Leidos | 5 | 2 |
| Techniekwerkt.nl | 4 | 2 |
| Other | 145 | 51 |
| **Total** | **275** | **100** |

### ***Work***

In terms of the nature of the engineering work, the analysis of job titles revealed that the term *Engineer* appeared most frequently, accounting for 41.5% of the positions, followed by Technician (20%) and Technologist (0.36%). Additionally, roles such as *Manager* (8.36%), *Supervisor* (7.63%), and *Analyst* (1.82%) were also identified, which fall under the category of Engineer-Comparable Occupations, positions characterized by collaborative design responsibilities (Magarian & Seering, 2021).

Further examination of seniority levels indicated that nearly half of the postings, accounting for 49%, were categorized as entry-level roles, suggesting opportunities tailored for individuals at the early stages of their careers (Table 6). Following this, mid-senior level positions comprised 39%, and 11% were categorized under not applicable (i.e., N/A), suggesting a lack of explicit delineation of seniority levels in certain job postings. These findings indicate

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the diverse entry points available within the maritime industry, accommodating individuals at different stages of their professional journeys.

Table 6. Nature of Work: Seniority Levels

| **Seniority level** | **n** | **%** |
|---|---|---|
| Entry level | 136 | 49 |
| Mid-Senior level | 106 | 39 |
| Internship | 3 | 1 |
| Director | 1 | <1 |
| N/A | 29 | 11 |
| **Total** | **275** | **100** |

A diverse spectrum of job functions covering various aspects of the maritime industry was revealed (Table 7). Information technology emerged as the predominant job function (39%), underscoring the critical role of technology in subsea operations. Engineering also featured prominently, comprising 33% of the postings. This reflects the technical expertise required for designing, testing, and maintaining subsea equipment and infrastructure. Additionally, management and manufacturing functions accounted for 8% and 7% of the postings, illustrating the managerial and operational aspects of subsea projects and production processes. These findings present the multifaceted nature of work within the maritime industry, involving various technical, managerial, and operational functions essential for success in subsea ROV operations.

Table 7. Nature of Work: Job Functions

| **Job function** | **n** | **%** |
|---|---|---|
| Information Technology | 191 | 39 |
| Engineering | 165 | 33 |
| Management | 41 | 8 |
| Manufacturing | 36 | 7 |
| Project Management | 14 | 3 |
| Quality Assurance | 6 | 1 |
| Other | 29 | 6 |
| N/A | 12 | 2 |

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| | | |
|---|---|---|
| **Total** | **494** | **100** |

Note. Each function was coded separately when more than two were combined.

### *Worker*

Among the educational qualifications, 49% of job postings required a bachelor's degree, 13% specified a high school diploma, and 5% requested an associate degree. Additionally, a small proportion of postings, comprising 3%, indicated a requirement for a master's degree. Notably, 27% of the postings did not specify any particular educational requirement, implying a degree of flexibility or variability in educational prerequisites within the industry.

Regarding experience, the analysis showed that 27% of postings preferred candidates with 1 to 5 years of experience, while 25% required 5 to 10 years of experience. A further 9% preferred candidates with more than 10 years of experience, while 1% specified more than 20 years of experience requirements. 37% of the postings did not specify any specific experience level, indicating potential opportunities for individuals with varied experience levels to enter the maritime industry.

The analysis of safety-related and health/medical-related certifications underscored the emphasis on ensuring personnel are adequately prepared for the challenges of working in the subsea environment (Table 8). Safety-related certifications included maritime safety training certificates such as GWO/STCW/BOSIET and offshore survival certifications like BOSIET/MIST/FOET. Health/medical-related certifications, such as offshore medical and medical fitness certificates, ensure workers meet the health and fitness standards for offshore work.

Skill-related certification analysis highlighted the diverse technical competencies within ocean engineering involving ROV operations (Table 8). Engineering-related certifications

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included forklift certifications, diving-related certificates, and UROV system maintenance certifications, among others. These certifications validate individuals' proficiency in specific technical areas crucial for subsea operations, such as equipment maintenance, inspection, and repair. Licensure requirements within the maritime industry encompass a range of credentials. Driver's and forklift licenses were among the most commonly specified licensure requirements.

In scrutinizing the knowledge areas requisite for roles in ROV operations, it was revealed that a diverse spectrum of expertise is sought (Figure 3, left). Knowledge of ROV technology/equipment/system was the foremost domain, accounting for 17% of the total knowledge. This included familiarity with ROV functionalities, subsea robotics systems, and survey equipment and technologies. Following closely, engineering/technical concepts constituted 13% of the identified knowledge areas, indicating the necessity for a profound understanding of electrical engineering, systems engineering, or oil & gas concepts. Additionally, knowledge about ROV operation (11%) and industry guidelines (9%) were also identified.

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Table 8. Nature of Worker: Certifications and Licensures Excluding Single Occurrences

| **Certifications and Licensures** | **n** |
|---|---|
| Safety-related Licensure/Certifications (n=25) | |
| Maritime Safety Training Certificate (GWO/STCW/BOSIET) | 7 |
| Offshore Survival Certification (BOSIET/MIST/FOET/Etc.) | 7 |
| CPR Certification | 3 |
| STCW Marine Officer Certifications | 3 |
| Basic Safety Training Certification | 3 |
| NEBOSH Certificate | 2 |
| Health/Medical-related Licensure/Certifications (n=17) | |
| Offshore Medical Certificate | 7 |
| Offshore Fitness Certification | 4 |
| Medical Fitness Certificate | 4 |
| Basic Life Support Certificate | 2 |
| Skill-related (n=33) | |
| Forklift Certification | 5 |
| Diving-related Certificate | 5 |
| UROV System Maintenance Certifications | 3 |
| IMCA ROV Certificate | 3 |
| NACE Certification | 3 |
| IPC 610/620 Certification | 2 |
| Water System Operator Certificate | 2 |
| Fluid Power Certificate IV | 2 |
| Electrical Engineering Certification | 2 |
| 3A Hoisting Certification | 2 |
| Technical School Certification | 2 |
| PMP Certification | 2 |
| License (n=19) | |
| Driver's License | 16 |
| Forklift License | 3 |
| **Total** | **94** |

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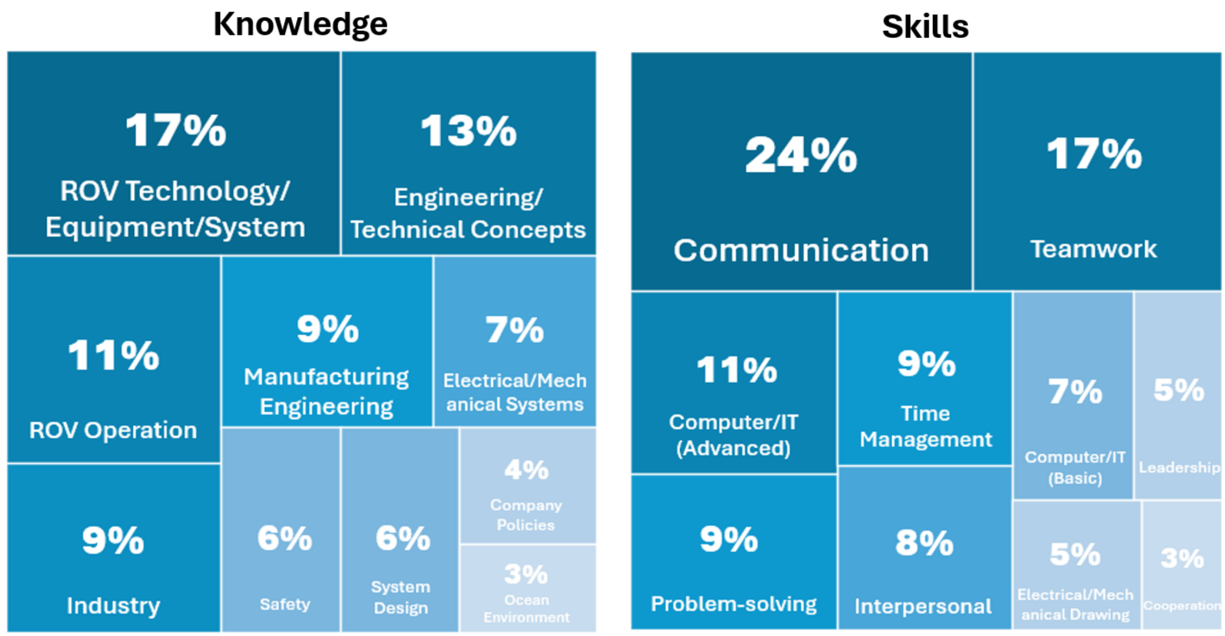
Figure 3. Nature of Worker: Knowledge and Skills




Analyzing the skill domains elucidates the diverse skills employers prefer (Figure 3, right). Communication skills emerged as dominant, representing 24% of the total skill areas. This involved written and oral communication proficiency, technical writing, and presentation skills. Furthermore, teamwork (17%) and interpersonal skills (8%) were also prevalent, emphasizing the importance of collaborative aptitude and interpersonal relationships. Moreover, technical skills, particularly in advanced computer/IT skills such as MathCAD, 3D CAD, Python, Matlab, etc., and basic computer/IT skills like Microsoft Word/Excel, Oracle, Outlook, etc., comprised significant portions, accounting for 11% and 7% of the total skill domains, respectively.

Examining ability areas reveals a spectrum of abilities necessary for navigating the profession's demands (Figure 4, left). Physical ability emerged as predominant, constituting 40% of the identified ability areas. This entails abilities to lift heavy loads, climb heights, or maintain physical endurance. Additionally, the ability to obtain security clearance emerged as crucial, representing 23% of the total ability areas, indicative of the regulatory requirements within the

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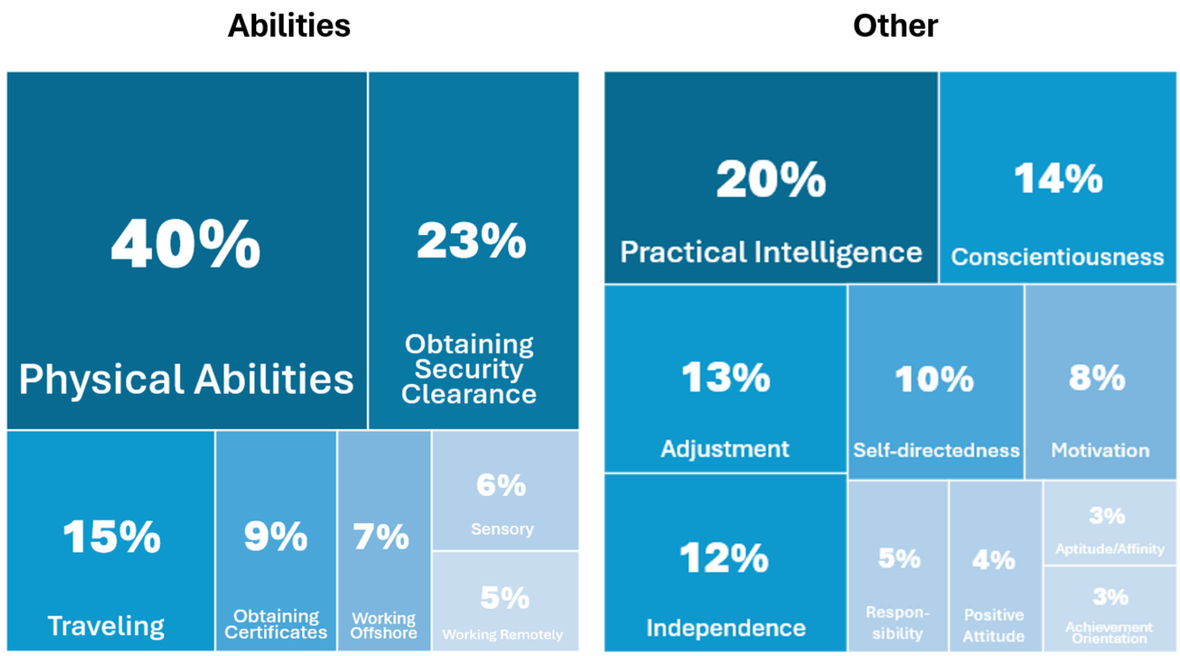
industry. Other significant ability areas included traveling (15%), obtaining certain certificates/licenses (9%), and working offshore/at height (7%).

Figure 4. Nature of Worker: Abilities and Other




Lastly, nuanced attributes are uncovered concerning other characteristics (Figure 4, right). Practical intelligence (20%) emerged as a prominent characteristic, highlighting the importance of analytic intelligence and innovative thinking. Additionally, conscientiousness (14%) and adjustment (13%) were emphasized, demonstrating the significance of integrity and adaptability in navigating the complexities of the subsea domain. Furthermore, independence (12%) and self-directedness (10%) were also identified.

The findings of four distinct analyses concerning KSAOs collectively underscore the multifaceted expertise demanded within ocean engineering involving ROV operations. The findings present the importance of possessing technical knowledge alongside industry-specific insights. Moreover, the results highlight the blend of social and technical skills essential for success as an ROV operator, emphasizing the importance of technical skills and personal

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characteristics. These results also reveal the diverse abilities necessary to thrive in the dynamic and challenging maritime environment.

**Characteristics of the Work Systems in Underwater ROV Operations**

Topic modeling of the 275 job descriptions collected led to the identification of ten distinct work systems derived from descriptions of work conditions (work context), task statements (work), and qualification requirements (workers). Notably, ten specific maritime tasks related to ROV operations within the field of ocean engineering were identified (Figure 5, 3rd row). These tasks encompass a range of activities, including the maintenance, operation, and repair of ROVs and associated equipment, project management, subsea installation and surveying, underwater system development and management, product design and testing, and the processing of survey data. These findings highlight the current maritime tasks using ROVs prevalent in ocean engineering.

In connection with these tasks, the analysis also revealed ten distinct work systems that reflect the diverse range of roles within underwater ROV operations, each characterized by distinct technical responsibilities and competencies. Among these work systems, the most sizable were "Offshore/ROV Operations/Technician" (19%), "Offshore/ROV Project or System Support/Engineer" (13%), and "Underwater/System Design/Engineer" (13%). These work systems, outlined in Table 9 and Figure 5, provide a comprehensive overview of the predominant patterns observed within the dataset.

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Table 9. Overview of the Top Five Work Systems and Their Descriptions

| System Name (work context/work/worker) & Description |
| --- |
| **1. Offshore / ROV Operations / Technician (19%)**<br>Mixed industries, including staffing and recruiting (24%), oil and gas (18%), civil engineering (18%), etc. Operating, maintaining, and repairing ROV systems, ensuring safety. Mixed seniority levels (mid-senior (43%) and entry (43%)). Engineering and IT (61%). BS degree (24%) and HS diploma (18%). 1-5 yrs. (18%) and 5-10 yrs. (12%) experience. IMCA ROV-related certificates and safety-related certificates (GWO, BOSIET, STCW, etc.). |
| **2. Offshore / ROV Project or System Support / Engineer (13%)**<br>Primarily oil and gas (49%). Working with clients and contractors for offshore projects. Managing and evaluating the existing offshore projects/contracts involving maintenance/operation of subsea equipment, subsea installation, surveying, etc. Content focus. Mixed seniority levels (mid-senior (51%) and entry (35%)). Engineering and IT (57%). BS degree (57%) and MS degree (5%). 1-5 yrs. (23%) and 5-6 yrs. (17%) experience. |
| **3. Underwater / System Design / Engineer (13%)**<br>Primarily defense and space (60%). Designing, testing, and supporting underwater/naval systems, including UAV, UUS, AUV, or ROV. Solving underwater/naval system engineering challenges utilizing past experience. Some communication with customers. System-level focus. Mixed seniority levels (mid-senior (46%) and entry (37%)). Engineering and IT (75%). BS degree (80%). Required experience is variable depending on education, but mostly 5-10 yrs. (43%) and 1-5 yrs. (29%) experience. |
| **4. Underwater / Software System / Engineer (12%)**<br>Mixed industries, including defense and space (32%), research (18%), etc. Software testing and development to support underwater systems including vehicle control systems, sensor integration, or automation. Technical focus. Entry level (74%). Engineering and IT (56%). BS degree (59%) and HS degree (9%). 1-5 yrs. (26%), 5-10 yrs. (24%), and 10-20 yrs. (21%) experience. |
| **5. Industry / Project / Manager (9%)**<br>Primarily defense and space (40%) and oil and gas (20%). Project, team, and quality management. Mid-senior level (72%). Mixed job functions, including management and manufacturing (32%), Engineering and IT (20%), and project management and IT (16%). BS degree (60%) and AA degree (20%). 1-5 yrs. (36%) and 5-10 yrs. (20%) experience. |

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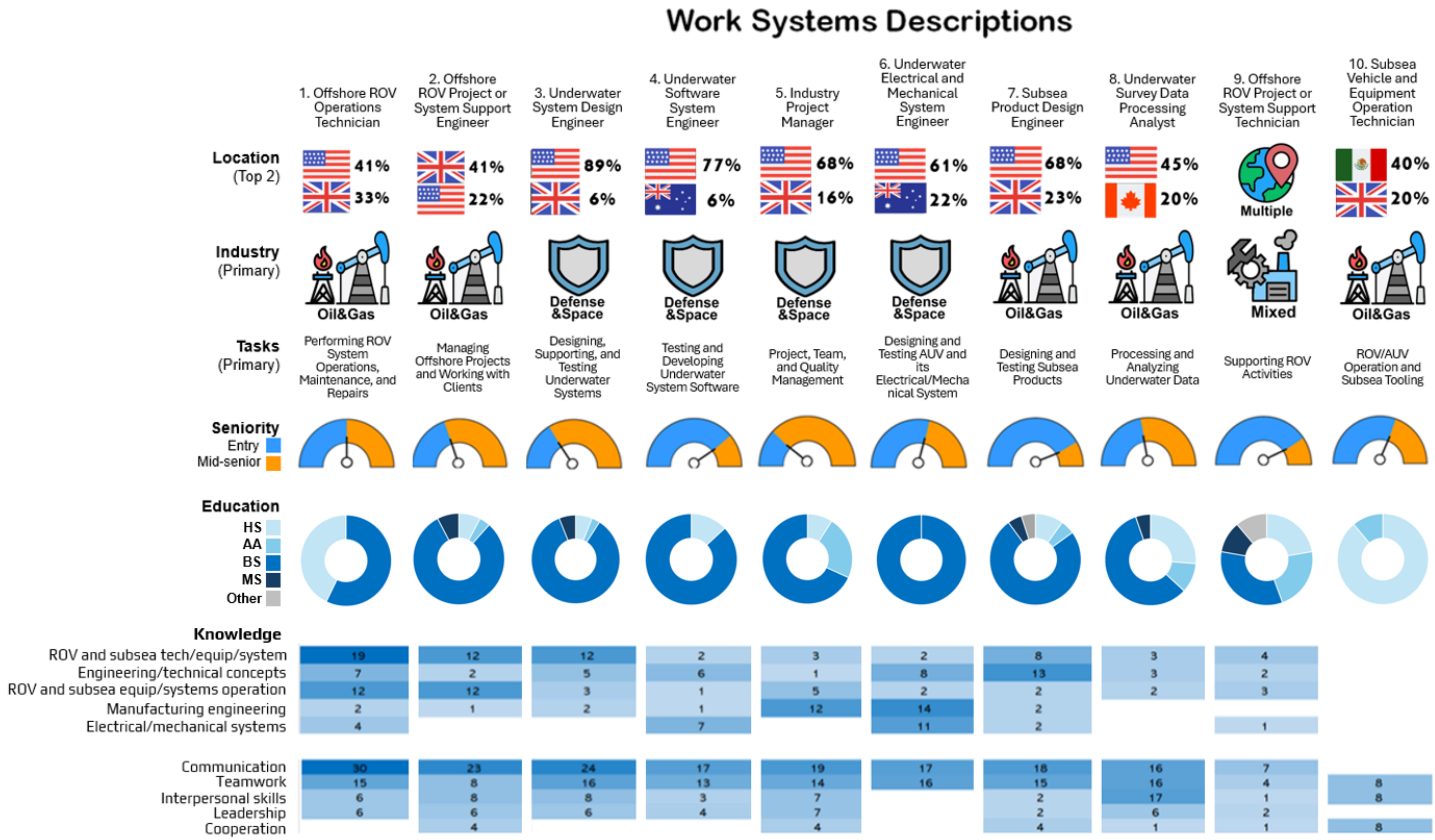
Figure 5. Simplified Work Systems Descriptions

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For example, the first work system, Offshore/ROV Operations/Technician, spans a range of industries, including staffing and recruiting (24%), oil and gas (18%), and civil engineering (18%), with the predominant advertisement in the United States (41%) and the United Kingdom (33%). Positions within this system involve operating, maintaining, and repairing ROV systems while adhering to safety protocols and frequently requiring backgrounds in engineering and IT (61%). Employers typically seek candidates with certifications like IMCA ROV and safety-related certificates. This aligns with Trevelyan and Guzzomi's (2024) framework, which classifies engineering work into technicians, technologists, and engineers, highlighting technicians' focus on hands-on, equipment-oriented tasks and practical technical competencies.

Offshore/ROV Project or System Support/Engineer predominantly operates in the oil and gas sector (49%) across the United Kingdom (41%) and the United States (22%). In this work system, employees collaborate with clients and contractors on offshore projects, overseeing subsea equipment maintenance, operation, and installation. Positions within this system commonly require backgrounds in engineering and IT (57%), accompanied by bachelor's degrees (57%). This system reflects the engineer role conceptualized by Trevelyan and Guzzomi (2024), where technical expertise is integrated with socio-technical interactions, project oversight, and system-level problem-solving.

Similarly, Underwater/System Design/Engineer finds prominence in defense and space industries (60%), primarily in the United States (89%) and the United Kingdom (6%). Employers in this system seek individuals engaged in designing, testing, and supporting underwater/naval systems, addressing engineering challenges, and liaising with clients. Most positions necessitate engineering and IT backgrounds (75%) with bachelor's degrees (80%). Experience requirements vary, ranging from 5-10 years (43%) to 1-5 years (29%). Considering the emphasis on technical

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proficiency and socio-technical collaboration, this system also aligns with Trevelyan and Guzzomi's (2024) classification of engineers.

Underwater/Software System/Engineer spans various industries, including defense (32%) and research (18%), with a concentration in the United States (77%), Australia (6%), and the Netherlands (6%). Within this work system, roles entail developing and testing software for underwater systems, focusing on technical proficiency. These positions are predominantly offered at entry-level positions (74%), requiring candidates to hold bachelor's degrees (59%). Experience requirements vary, with 26% of positions mandating 1-5 years of experience, 24% requiring 5-10 years of experience, and 21% seeking 10-20 years of experience. Interestingly, while 79% of job postings use the term engineer in their title, the described tasks often align more closely with technician responsibilities, focusing on software development and testing rather than broader system design and socio-technical integration. This inconsistency underscores the loose application of the term engineer in some industry contexts, raising questions about role definitions and expectations within engineering education.

Industry/Project/Manager is prevalent in defense (40%), space (20%), and oil and gas (20%) sectors, mainly in the United States (68%) and the United Kingdom (16%). Positions within this system involve overseeing project, team, and quality management functions. A significant portion (72%) of positions is at mid-senior levels, requiring either a bachelor's (60%) or an associate's degree (20%). Experience requirements typically range from 1-5 years (36%) to 5-10 years (20%). Although only 12% of postings within this system include *Engineer* in the job title, the majority (76%) are titled *Manager* or *Superintendent*, emphasizing project management, technical consulting, and leadership. This observation aligns with Magarian and Seering's (2021) conceptualization of engineer-comparable occupations, which encompass roles that, while not

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strictly engineering, require a deep understanding of engineering principles combined with management and strategic oversight.

These findings highlight the diverse and complex landscape of underwater ROV operations. The identified work systems provide valuable insights into the technical responsibilities, core competencies, and qualifications required in this field. These findings have notable implications for engineering education, particularly in curriculum development and the design of workforce development programs. By understanding these work systems, engineering educators and workforce development professionals can design more targeted and relevant coursework and programs that closely align with industry demands, ultimately better preparing graduates for the evolving requirements of careers in ocean engineering.

## Discussion

This study reveals critical insights into the sociotechnical system of underwater ROV operations in maritime engineering, highlighting complex interactions between work context, work, and worker characteristics. The findings contribute to theoretical understanding and practical implications for engineering education and workforce development, while also providing a foundation for future research in this domain.

Our analysis identified several core competencies essential across all work systems, including teamwork, time management, problem-solving skills, and analytical and innovative forms of practical intelligence. These insights contribute to a more nuanced understanding of the nature of the occupation, enhancing clarity within the field. The desire for skills such as general problem-solving, process monitoring, and teamwork are consistent with those influenced by video game play (Mayer, 2019; Sala et al., 2018). This connection presents an intriguing opportunity for engineering educators to explore innovative teaching methods that leverage gaming principles. For instance, the gamification of ROV operation simulations could be integrated into engineering curricula, potentially enhancing student engagement and skill development. However, while video game experience may provide a foundation, it is important for engineering education programs to recognize that ROV operations require a broader range of competencies. This includes physical capabilities, such as lifting 25 pounds, and specialized technical knowledge of ROV equipment and concepts. Engineering curricula should, therefore, balance evolving industry needs with hands-on experience that replicates real-world ROV operation conditions.

Furthermore, the gap between leisure activities and the professional requirements of ROV operation underscores the essential need for targeted workforce development programs. Engineering education professionals could address this by offering certificate programs for individuals from other fields or integrating ROV operation modules into existing programs. These initiatives would provide a broader and more structured pathway for those entering the field of underwater ROV operation. By combining theoretical knowledge with practical skills training, these programs have the potential to help aspiring ROV operators acquire the competencies necessary to succeed in this specialized profession.

The complexity introduced by diverse industry contexts and specific operational conditions further emphasizes the need for adaptable and industry-informed engineering education. To address this, engineering programs could consider incorporating case studies or problem-based learning scenarios that reflect the varied work contexts of ROV operations or establishing partnerships with industries to ensure curriculum relevance and provide students with exposure to current practices and technologies.

Within the work systems identified in this study, our findings echo Trevelyan & Guzzomi (2024) classification of engineering occupations: technicians, technologists, and engineers. However, the inconsistent application of the term engineer within ROV operations is noteworthy. This is especially evident in the *Underwater/Software System/Engineer* work system, where 79% of the job postings indicate engineer roles in their titles. Yet, the tasks align more closely with technician responsibilities. This discrepancy has important implications for engineering education, highlighting the need to critically evaluate how engineering roles are defined and how curricula are structured to prepare graduates effectively for these positions.

Moreover, the prominence of *Industry/Project/Manager* roles supports Magarian & Seering (2021) conceptualization of engineer-comparable occupations, which involve traditional engineering competencies and project management, technical consulting, and leadership skills. This highlights the need for engineering programs to broaden their scope, incorporating diverse occupational categories to better align educational outcomes with industry demands. By doing so, engineering education can more effectively prepare graduates for a wide range of career trajectories in ocean engineering.

Building on this, recognizing the distinct requirements of different occupational paths can inform targeted curriculum design. Professional engineers, often responsible for system-level safety and design approvals (Trevelyan & Guzzomi, 2024), may benefit from advanced engineering system-related coursework, coupled with training in project management and sociotechnical collaboration. Technologists, who frequently engage with modeling software, automated control systems, and data analytics (Trevelyan & Guzzomi, 2024), would benefit from specialized modules in advanced programming, system integration, and computational simulations of ROV operations. Technicians, who work directly with physical ROV equipment

(Trevelyan & Guzzomi, 2024), would require hands-on training focused on mechanical and electrical maintenance, equipment testing, safety procedures, and fundamental troubleshooting skills. These differentiated pathways address current industry demands and open avenues for future research to explore the design and effectiveness of specialized programs in meeting occupational needs across these categories.

In response to these varying needs, developing short-course certificate programs, microcredentials, or in-company training initiatives can efficiently integrate specialized ROV content into existing curricula without displacing core engineering fundamentals. For example, community colleges could offer ROV Technician certification credentials or programs. In contrast, university engineering programs might collaborate with industry partners to provide specialized electives or capstone projects focused on subsea robotics. Embedding these tailored educational pathways will help ensure that engineering education aligns more closely with the realities of ROV operations across diverse industry contexts. Furthermore, these initiatives can provide a foundation for future research exploring the design and long-term impact of specialized training on career progression, professional competencies, and workforce development within maritime engineering.

When refining these curricular and programmatic approaches, engaging stakeholders, including industry stakeholders, educational institutions, practitioners, or recent graduates, is essential to ensuring alignment with industry needs. To support this process, frameworks such as the *Define Your Discipline Stakeholder Consultation Process* (Dowling & Hadgraft, 2013) can facilitate a comprehensive, collaborative approach to curriculum development by incorporating diverse perspectives and expertise. Future research could build on the findings of this study by involving these stakeholders in collaborative efforts to refine educational interventions, thereby ensuring that curricula remain responsive to the dynamic requirements of the industry.

This research further highlights a narrow career landscape, as the top work system accounts for 20% of job postings, and the top five systems combined encompass 66%. However, the complex relationships among the three components of work systems provide valuable insights into workforce development and potential career trajectories. For instance, individuals with a high school education, technical proficiency, communication skills, and an interest in ROV technology and systems may find suitable entry points in roles like Offshore/ROV Operations/Technician (Figure 5, first column). Similarly, undergraduates looking for a job in the U.S. with a background in the defense and space industry, coupled with expertise in manufacturing engineering and teamwork skills, may identify appropriate entry points in positions like Underwater/Electrical and Mechanical System/Engineer (Figure 5, sixth column). These insights lay the groundwork for tailored career and technical education programs that foster inclusive pathways into the ocean engineering industry.

However, it is important to acknowledge potential barriers to inclusivity. These may include disparities in educational access, geographic limitations, and industry-specific prerequisites that disproportionately affect traditionally underrepresented people (Grindstaff, 2022). Addressing these barriers necessitates a holistic approach, encompassing targeted recruitment initiatives, educational outreach efforts, and measures to mitigate systemic biases within the industry.

Additional challenges center on physical and medical requirements and frequent travel to remote offshore sites. The analysis of job descriptions underscores the need for safety-related and health/medical certifications to ensure personnel are adequately prepared for the demanding conditions of offshore work. For instance, maritime safety training certificates and offshore survival certifications are essential for equipping workers with the knowledge and skills to handle emergencies and maintain safety standards. Additionally, health-related certifications, including offshore medical and fitness certifications, ensure workers meet the rigorous health and fitness standards required for offshore operations. Physical abilities also emerged as a potential barrier in this field, with 40% of the required abilities involving lifting heavy loads, climbing heights, and maintaining physical endurance. Travel constraints further compound these challenges, as 15% of the roles necessitate frequent travel, often to remote offshore locations, which can be physically and logistically demanding.

To address these challenges, engineering curricula could integrate industry-recognized certifications in maritime safety and offshore survival, enhancing graduate employability. Collaborations with safety organizations can also help provide on-campus certification programs. Furthermore, physical fitness programs tailored to the demands of ROV operations could be developed in partnership with university fitness centers. These initiatives ensure that graduates are technically proficient and physically prepared for the demanding conditions of offshore work.

Although these general approaches are crucial, it's also important to note that emerging technologies in the field of ocean engineering present significant potential to mitigate these barriers. For example, Xia et al. (2023) demonstrate how VR and haptic feedback technology can lower the barriers to ROV operation by enabling remote control, improving safety through better situational awareness, and reducing the physical and mental demands on operators. Consequently, such advancements are anticipated to make ROV operation more accessible, safer, and more efficient, especially in challenging offshore and subsea environments. As such technologies continue to evolve, they are expected to further increase the accessibility of these roles to a broader range of individuals while enhancing safety and operational efficiency, highlighting the need for active research in this area. By incorporating the evolving nature of ROV operations and emerging technologies into educational programs, engineering education can stay aligned with industry advancements and workforce needs.

## Limitations and Future Research

While this study provides valuable insights into the sociotechnical system of underwater ROV operations, several limitations that may impact the generalizability and robustness of the findings must be acknowledged. The study is limited by its exclusive reliance on publicly available job postings from a single recruitment platform. This approach excludes positions filled through non-public channels, such as professional networks, recruitment agencies, or internal referrals, potentially omitting a considerable portion of the ROV job market. In addition, the use of self-reported job postings introduces the potential for social desirability bias. Companies that provide job openings will likely present themselves or their opportunities more favorably to attract potential applicants. This bias can influence the accuracy of the information provided, which could, in turn, impact the interpretation of our findings. To address this concern, extensive data cleaning was implemented, with particular attention given to removing sections of company advertisements where such bias may be most prominent.

The focus on English-written postings may inadvertently exclude non-English-speaking regions, limiting the comprehensiveness of the dataset and potentially overlooking significant trends and patterns prevalent in diverse linguistic contexts. Finally, limitations arise from the nature of the data itself. Incomplete or insufficiently detailed information within job postings may have introduced uncertainty and undermined the reliability of the study's findings. The identified limitations highlight the importance of a cautious interpretation of the results and signal avenues for future research toward a more comprehensive understanding of the sociotechnical dynamics within the maritime industry.

Further research endeavors should focus on several key areas to deepen our understanding of the nature of the maritime occupation involving ROV operations. First, studies should explore alternative online recruitment platforms beyond LinkedIn to ensure a more comprehensive representation of job opportunities within the maritime industry. Second, there is a need for deeper investigations into the competencies in this study, coupled with longitudinal examinations of shifts within the ROV job market, to uncover evolving trends. Third, evaluating the integration of these competencies into training programs is essential to assess their effectiveness in preparing the workforce to meet real-world demands. Finally, research should explore the potential impact of emerging technologies on ROV operations, examining how these technologies might redefine the work systems. By pursuing these research avenues, we can further enrich workforce development initiatives within ocean engineering, particularly in underwater ROV operations, fostering a more skilled, adaptable, and efficient workforce in this critical sector.

## Conclusion

This study systematically analyzes job postings related to underwater ROV operations, revealing how work context, work, and worker characteristics interconnect within ten distinct work systems. Utilizing the Work Systems Theory framework alongside qualitative content analysis and topic modeling, our findings show the core technical and professional competencies currently in demand within the maritime industry and the diverse range of engineering roles embedded within these systems.

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The findings provide several key contributions to the field of ocean engineering. First, this study identifies essential maritime tasks related to ROV operations, offering insights into the field's operational landscape. Second, it unveils emerging industry trends, workforce demands, and potential barriers to entry, emphasizing the professional qualifications and skills required by the maritime industry. Third, this study delivers detailed insights into ten distinct work systems, covering not only the technical aspects of ROV operations but also the broader contextual factors and competencies that influence workforce requirements.

A significant insight from this research is the consistent emphasis across all work systems on essential professional competencies, such as teamwork, problem-solving, time management, technical proficiency, communication skills, and practical intelligence. This highlights the urgent need for engineering curricula to incorporate these professional skills alongside technical content to better equip students for real-world challenges. Furthermore, the analysis reveals the maritime industry's ambiguous use of the term engineer, stressing the importance of creating clearer distinctions between engineers, technicians, and technologists to ensure role clarity and alignment with industry expectations.

In conclusion, this study offers a comprehensive snapshot of the evolving workforce demands in underwater ROV operations, emphasizing the essential technical and professional competencies needed across various engineering roles. Our findings highlight the necessity of targeted educational programs that blend technical expertise with professional skills to better equip graduates for industry challenges. By aligning academic curricula with the dynamic needs of the maritime industry, educational institutions are anticipated to enhance the talent pipeline and improve graduate employability within this specialized field.

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