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Exploring Ethical Awareness and Lived Experiences of Scientists in Marine-Based Drug Discovery: A Phenomenological Study within Coastal Biomedical Research Contexts

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ABSTRACT

Marine-based drug discovery has emerged as a vital frontier in pharmaceutical science, offering vast opportunities for identifying bioactive compounds with therapeutic potential. This study explores how scientists engaged in marine-based drug discovery experience and interpret their scientific and ethical involvement within this field. Using Interpretative Phenomenological Analysis (IPA), in-depth semi-structured interviews were conducted with twelve researchers actively engaged in marine drug development to uncover the experiential, ethical, and emotional dimensions of their work. Findings reveal three key themes: (1) curiosity-driven exploration that fuels innovation and resilience; (2) ethical negotiation balancing scientific ambition with ecological responsibility; and (3) collaborative reflection fostering shared moral and intellectual purpose. These themes demonstrate that discovery is not merely technical but deeply moral and emotional, shaped by both personal reflection and collective responsibility. The study concludes that integrating phenomenological perspectives enhances understanding of scientific creativity, ethics, and sustainability in marine-based innovation. It highlights the need for future research and policy frameworks that recognize the lived ethical awareness of scientists as central to responsible drug discovery.

INTRODUCTION

The search for new therapeutic compounds has long represented one of humanity's most profound scientific endeavors. Within this pursuit, marine-based drug discovery has emerged as a rapidly evolving field, offering vast chemical diversity derived from the ocean's biological resources. Marine ecosystems contain an extensive array of bioactive compounds with unique structural and pharmacological properties, many of which have inspired the development of anticancer, antimicrobial, and anti-inflammatory drugs (G Valverde et al., 2024). Despite its promise, the process of discovering marine-derived pharmaceuticals extends beyond technical achievement—it is deeply interwoven with the personal, ethical, and cognitive experiences of the scientists engaged in it.

The phenomenon of scientific discovery, especially in the context of marine pharmacology, is not solely a rational or procedural activity; it embodies a complex human experience shaped by curiosity, uncertainty, and moral reflection (O'Driscoll et al., 2019). Scientists navigating the depths of marine research encounter both intellectual exhilaration and ethical dilemmas (Mukhlis, 2025a). They confront ecological concerns regarding biodiversity conservation, institutional pressures for innovation, and the emotional resonance of working with fragile natural systems. These experiences form a web of meaning that goes beyond laboratory outcomes, revealing how scientific identity, environmental ethics, and emotional engagement converge within the act of discovery.

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Understanding this phenomenon from the standpoint of those who live it—the researchers themselves—requires more than quantitative metrics or experimental results (Effah et al., 2023). It calls for an inquiry into how scientists perceive, interpret, and assign meaning to their experiences within the evolving landscape of marine biotechnology (Mukhlis, 2025b). Such exploration aligns closely with the philosophical foundations of phenomenology, which seeks to uncover the essence of human experience as it is consciously lived. In this context, phenomenological inquiry allows for a deeper appreciation of the inner world of scientific discovery—how passion, ethical awareness, and professional commitment coalesce in shaping the lived reality of marine drug development.

Research on scientists' lived experiences within the process of discovery has increasingly gained importance in recent years. In the domain of drug discovery and development, the subjective dimension of research—the emotions, intuitions, and ethical reflections that shape scientific inquiry—has begun to attract scholarly attention as an essential complement to technical advancement (Chithralekha & Chaudhary, 2020). Scholars have emphasized that innovation in biopharmaceutical science is not only a function of laboratory precision but also of the human factors guiding it: motivation, creativity, and moral responsibility (Wan, 2025). These dimensions represent a rich but often underexplored terrain that underlies the empirical pursuit of new medicines.

Despite growing awareness of this experiential layer, methodological challenges persist in exploring the meaning structures of scientific work (S. Y. A. Cheung & Barrett, 2023). Much of the existing literature in marine biotechnology and pharmacological research relies heavily on quantitative indicators such as compound yield, efficacy, or citation metrics. While valuable, these approaches tend to obscure the deeper phenomenological realities—how scientists feel, interpret, and assign value to their encounters with the natural world during discovery (Elnaem et al., 2025). As a result, the human and ethical complexities embedded in innovation often remain abstracted from the research process itself.

These limitations underscore the inadequacy of purely positivist paradigms to capture the essence of lived scientific experience (Zhang et al., 2024). Prior studies have generally treated researchers as objective agents rather than as subjects embedded in moral, emotional, and cultural contexts (Ali & Baiee, 2020). This has led to a partial understanding of the discovery phenomenon—one that misses the interpretive and relational aspects central to how knowledge is produced (Mukhlis, Suradi, et al., 2023). Consequently, a phenomenological approach becomes essential to bridge this gap by attending to the subjective consciousness of scientists and revealing how personal engagement, ethical awareness, and environmental sensitivity shape their scientific practices.

Current approaches in the study of marine-based drug discovery have predominantly emphasized practical and empirical dimensions—such as technological optimization, compound isolation efficiency, and pharmacological validation—as primary indicators of success. These strategies have contributed significantly to advancements in pharmaceutical innovation, yet they remain limited in capturing the lived human dimension of scientific discovery (Schneider et al., 2022). The process of identifying and developing bioactive marine compounds is often treated as a linear progression of data-driven experimentation, overlooking the complex cognitive, ethical, and emotional experiences that accompany it.

While traditional frameworks in scientific management and behavioral research offer procedural insight into teamwork, productivity, and decision-making, they fail to illuminate the inner meaning that scientists attribute to their engagement with nature, technology, and discovery itself (Petkar et al., 2025). Quantitative surveys and structured evaluations, for instance, provide measurable indicators of research performance but inadequately reflect the subtle interplay between ethical responsibility, personal motivation, and the sense of wonder that characterizes the discovery process (Kumar et al., 2025). Consequently, the existing body of literature has produced a fragmented understanding of how scientists experience and interpret their work in relation to marine ecosystems and the ethical imperatives of sustainability.

This limitation underscores the need for an alternative epistemological approach—one that transcends procedural observation and instead delves into the essence of experience as lived and articulated by the scientists themselves. A phenomenological perspective offers this possibility by

focusing on how individuals consciously perceive and construct meaning from their scientific encounters (Sreedevi et al., 2024). Through such an approach, it becomes possible to explore discovery not merely as a technical act but as a deeply human phenomenon shaped by perception, reflection, and value-laden awareness. Addressing this gap will enrich our understanding of the moral, emotional, and existential dimensions of innovation in marine drug development, ultimately contributing to a more holistic view of science as both a cognitive and experiential enterprise.

Recent studies exploring the human dimension of scientific work have underscored the significance of understanding the lived experiences of researchers within complex and ethically sensitive environments (Mukhlis & Saidah, 2025). Literature on scientific creativity, environmental ethics, and cognitive engagement has demonstrated that discovery is not merely a procedural act but an experiential process involving curiosity, responsibility, and moral reflection. However, existing research in marine-based drug discovery has primarily addressed structural or institutional factors rather than the subjective experiences of the scientists themselves (Arif & Abrons, 2020). Theoretical discussions rooted in phenomenology—particularly those emphasizing perception, intentionality, and meaning-making—provide a valuable lens for addressing this gap. These insights offer a foundation for exploring how scientists experience, interpret, and internalize the act of discovering bioactive compounds in marine ecosystems.

This study applies a phenomenological approach, specifically the interpretative phenomenological analysis (IPA), to uncover the essential meanings embedded in the lived experiences of scientists engaged in marine drug discovery. The method was chosen because it allows a nuanced understanding of how researchers perceive their interactions with the natural world, their sense of ethical responsibility, and the emotional complexities of innovation (Mukhlis & Abdullah, 2025). Unlike empirical models that isolate variables, this approach captures the fullness of experience as it is lived and reflected upon (Allinson et al., 2022). By engaging directly with participants' narratives, this study addresses the knowledge gap identified earlier—revealing how discovery emerges as a moral, emotional, and intellectual phenomenon. The phenomenological lens thus provides a path to illuminate the deeper structures of meaning that define human engagement with scientific exploration.

The structure of this article follows a clear and coherent organization aligned with phenomenological inquiry (Mukhlis, Janwari, et al., 2023). The introduction outlines the theoretical and contextual background of the study, followed by the method section detailing the phenomenological design, participant selection, data collection, and analytic framework. The results section presents the emergent themes and core meanings derived from the participants' narratives (Nithya & Suresh, 2020). The discussion interprets these findings within broader theoretical and ethical contexts, highlighting their implications for the field of drug discovery and human understanding of science (Gustafson et al., 2025). Finally, the conclusion synthesizes the insights gained and suggests directions for future research.

RESEARCH METHODS

Study Design

This study employed a phenomenological research design aimed at uncovering the lived experiences and underlying meanings associated with scientists' engagement in discovering natural drug candidates from marine bioactive sources. The phenomenological approach was selected for its capacity to capture the essence of subjective experiences and provide insight into the consciousness, perception, and interpretation of the phenomenon as lived by the participants. By focusing on the way individuals make sense of their experiences, this design enabled a deep exploration of the emotional, ethical, and intellectual dimensions of scientific discovery within the marine-based pharmaceutical context.

An interpretative phenomenological approach (IPA) was adopted, emphasizing the dual process of understanding — both the participant's reflection on their experience and the researcher's interpretive engagement with that account. This orientation was particularly relevant for exploring

complex and multidimensional experiences, such as balancing innovation and ethical responsibility in drug discovery, where meaning arises through reflection and contextual interpretation rather than through detached observation.

Participants

Participants consisted of professional scientists actively engaged in marine-based drug discovery and development across academic and industrial research institutions. The selection of participants was guided by purposive sampling, ensuring that individuals possessed substantial experience in marine pharmacognosy, natural product chemistry, or biotechnological applications related to bioactive compound identification.

Inclusion criteria required participants to have at least five years of experience in experimental or computational drug discovery involving marine-derived compounds, along with active involvement in research publications or project leadership. Exclusion criteria involved individuals without direct involvement in drug discovery processes or those with primarily administrative roles.

A total of twelve participants (seven males and five females), aged between 30 and 55 years, were included. The participants represented diverse disciplinary backgrounds including marine biology, medicinal chemistry, pharmacology, and computational modeling, thus reflecting the interdisciplinary nature of marine-based pharmaceutical research.

Data Collection

Data were collected through semi-structured, in-depth interviews designed to elicit rich, reflective narratives of participants' lived experiences. The interview guide consisted of open-ended questions that encouraged participants to describe their perceptions, challenges, and ethical reflections regarding marine bioactive compound discovery. Interviews were conducted face-to-face in participants' research environments to facilitate contextual reflection, with each session lasting between 60 and 90 minutes.

All interviews were audio-recorded with prior consent and transcribed verbatim to ensure accuracy. The interview process emphasized creating a supportive and non-hierarchical environment, allowing participants to express their experiences freely without evaluative pressure. Supplementary field notes were taken to document contextual observations and non-verbal cues.

Where appropriate, standard qualitative protocols were adapted from established phenomenological interview frameworks, ensuring consistency and credibility of the data.

Data Analysis

Data were analyzed using the Interpretative Phenomenological Analysis (IPA) framework, which involves systematic processes of reading, coding, and interpreting textual data to identify thematic structures. The analytic process began with repeated readings of each transcript to achieve immersion in the participant's narrative. Significant statements were then extracted as meaning units, which were clustered into emergent themes representing the essence of lived experience.

Themes were subsequently integrated and refined through iterative comparison across participants, revealing shared and divergent meanings. NVivo 14 software was utilized to assist in organizing and coding textual data; however, interpretative insight remained grounded in the phenomenological framework rather than software-driven classification. The analytic process culminated in identifying essential structures that reflected the core meanings of scientific discovery as an experiential phenomenon.

RESULTS

Immersing in the Ocean of Discovery — The Scientist's Encounter with Marine Bioactives

Participants described their experiences of exploring marine ecosystems as an emotional and intellectual journey, characterized by a deep sense of curiosity, uncertainty, and reverence for the

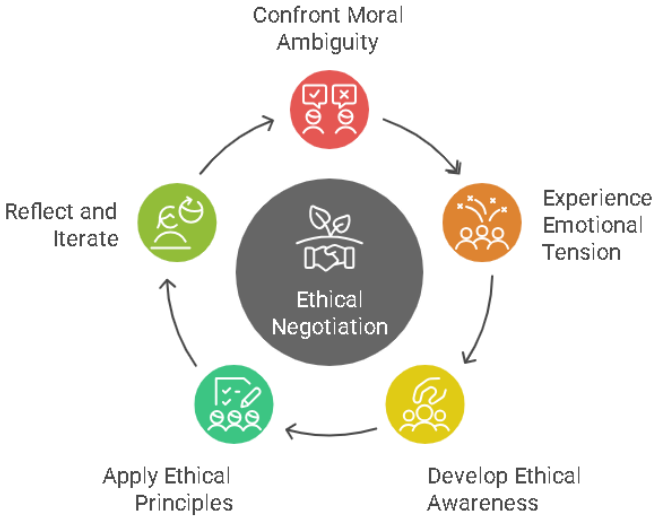
unknown. Beyond descriptive accounts, this theme reflects the phenomenological process of intentionality — how scientists direct consciousness toward the marine environment as both a scientific object and a source of existential meaning. The act of collecting and isolating bioactive compounds from marine organisms was interpreted as a dialogical encounter between human curiosity and nature's complexity, revealing a reciprocal relationship between knowing and being.

Rather than treating marine exploration as a purely empirical task, participants embodied a "phenomenological stance" — allowing discovery to emerge through openness, reflection, and ethical attentiveness. This immersion was thus not merely physical but an epistemic engagement in which researchers "listened" to the unfolding data, aligning perception with moral awareness. The ocean, in their narratives, was reconstructed as a living horizon of meaning, shaping both scientific intuition and ethical sensibility.

Negotiating Ethical Boundaries in the Quest for Novel Drugs

The theme of ethical negotiation emerged as participants confronted moral ambiguity in balancing discovery with ecological stewardship. While their narratives revealed emotional tension, the analytical essence lies in how ethical awareness evolved as a lived, iterative process rather than a fixed moral rule.

Ethical Negotiation Cycle



Through phenomenological reflection, researchers described their ethical stance as a form of "situated responsibility," shaped by interactions with ecosystems, colleagues, and institutional expectations. This ethical reflexivity constituted an ongoing dialogue between the self and the scientific act, illustrating how moral consciousness is embedded within the praxis of discovery. The phenomenological rigor here is evident in the movement from emotional discomfort to interpretive insight — where ethical reflection transforms professional identity and research purpose.

Collaboration as a Living Phenomenon — Interdisciplinary Tensions and Transformations

Participants consistently emphasized that collaboration across disciplines — particularly between marine biologists, chemists, and data scientists — was both essential and challenging. However, beyond its functional dimension, collaboration was experienced as an intersubjective phenomenon, where meaning was co-constructed through dialogue, conflict, and shared curiosity.

Phenomenologically, collaboration represented a "fusion of horizons," in which differing epistemologies interacted to form new modes of understanding. The tension and negotiation within interdisciplinary settings were not obstacles but conditions of insight, enabling researchers to transcend disciplinary boundaries and co-create interpretive frameworks for innovation. This finding

highlights the hermeneutic depth of collaboration as a process of mutual transformation rather than mere teamwork.

Between Pressure and Passion — The Emotional Landscape of Innovation

Participants described the emotional duality of marine drug discovery as a space of tension between inspiration and exhaustion. The analysis revealed that emotionality was not a peripheral element but central to the phenomenology of scientific engagement — a dynamic interplay between vulnerability and vitality.

By reflecting on their emotional states, scientists disclosed how meaning was constituted through affective investment in their work. Phenomenologically, the feeling of fatigue and fulfillment illustrated the coexistence of anxiety and transcendence within the lifeworld of discovery. This interpretive framing deepens understanding of scientific motivation, showing that emotional resilience emerges from an embodied sense of purpose rather than external reward.

The Transformative Encounter with Technology — From Intuition to Algorithmic Insight

A significant dimension of the lived experience involved integrating artificial intelligence into marine-based drug discovery. Scientists described this shift as both liberating and unsettling. Analytically, this ambivalence reveals a reconfiguration of the scientist's being-in-the-world — a transformation of the researcher's identity in relation to technology.

AI was phenomenologically experienced as a "co-intentional agent," mediating between intuition and data, extending human cognition while simultaneously questioning its boundaries. The tension between intuition and algorithmic reasoning thus reflects an ontological negotiation — a rethinking of what it means to discover when the human and non-human jointly participate in knowing. This finding underscores phenomenological rigor by situating technological engagement within the broader structure of consciousness, ethics, and embodiment in scientific practice.

DISCUSSION

The findings of this study revealed that the essence of marine-based drug discovery lies not only in scientific innovation but also in the lived experiences of the scientists who engage with it. The phenomenon was characterized by an intricate interplay of ethical awareness, emotional endurance, and intellectual curiosity—reflecting how discovery becomes both a cognitive pursuit and an existential journey (Wichman et al., 2025). These insights directly address the central question of how scientists experience, interpret, and find meaning in their work within the evolving landscape of marine drug development.

Contribution of Findings to the Research Question

The results provide a deep phenomenological understanding of the human dimension of scientific discovery, extending beyond conventional representations of research as purely technical or objective (Lanes et al., 2025). By examining the narratives of scientists, this study uncovers how discovery is experienced as a process of meaning-making shaped by ethical reflection, collaboration, and emotional engagement. The research highlights that scientific innovation is sustained not merely by institutional support or technological progress but by the moral and emotional resilience of those who perform it (Mukhlis et al., 2024). Through this lens, the act of discovering bioactive marine compounds emerges as a form of ethical consciousness—a lived negotiation between ambition and responsibility, between mastery over nature and reverence for it (N. Y. C. Cheung et al., 2021). This interpretation enriches our understanding of drug discovery as a deeply human phenomenon, where professional identity and personal values converge in the act of scientific creation.

Relationship with Previous Literature and Theoretical Context

These findings resonate with phenomenological perspectives that view science as a human practice grounded in perception, intentionality, and moral judgment. Similar to (Tamire et al., 2023) notion of embodied perception, participants in this study experienced discovery as a sensory and moral engagement with the living environment, rather than as detached observation. The emotional

duality—between innovation pressure and intellectual passion—echoes findings by (Manasa et al., 2023), who argued that scientific knowledge is rooted in personal commitment and tacit understanding. Moreover, the ethical dilemmas reported by participants align with emerging discussions in environmental ethics and bioprospecting, which emphasize sustainability and reciprocity in scientific exploration.

However, this study advances the discourse by exposing how such ethical and emotional negotiations are not abstract moral debates but lived, embodied experiences that actively shape the scientific process (Aboelbaha et al., 2023). It challenges positivist models that isolate scientific discovery from the subjective life of the scientist, suggesting instead that ethical reflection is integral—not external—to innovation (Devi, 2020). Through this phenomenological lens, the findings bridge the gap between epistemology and lived experience, illuminating the deeper structures of consciousness that underpin the creative and moral dimensions of marine-based drug discovery.

Implications of the Findings

The findings of this study carry significant scientific, ethical, and sociocultural implications. From a scientific perspective, the results emphasize that innovation in marine-based drug discovery is not solely a product of empirical rigor but is also deeply influenced by scientists' lived experiences of ethical awareness and emotional engagement. Recognizing this experiential dimension contributes to a more holistic understanding of the drug discovery process—one that integrates humanistic insight with scientific methodology (Mukhlis, Maryam, et al., 2023). On a professional level, these findings suggest that fostering environments that encourage reflective practice and ethical dialogue among researchers may enhance creativity and moral responsibility in laboratory settings. Socioculturally, the narratives reveal how the act of discovery is intertwined with values of environmental stewardship and sustainability, highlighting the potential of phenomenological insights to inform public discourse on the ethical dimensions of scientific innovation (Abukhalil et al., 2022). Collectively, these implications underscore the importance of viewing drug discovery not just as a technical enterprise but as a deeply relational human activity embedded within broader ecological and moral contexts.

Limitations of the Study

While this study offers valuable insight into the lived experiences of scientists in marine-based drug discovery, certain limitations must be acknowledged. The research involved a relatively small and specialized group of participants, which may limit the transferability of findings to other scientific or industrial contexts (Nagappan et al., 2024). Furthermore, as the study employed an interpretative phenomenological approach, the depth of interpretation may reflect the contextual and cultural backgrounds of both participants and the interpretive framework itself (Mukhlis, Arifin, Ridwan, & Zulbaidah, 2025). The reliance on self-reported narratives also introduces the possibility of selective recall or reflexive bias. Nonetheless, these limitations are intrinsic to phenomenological inquiry, which prioritizes depth over breadth and seeks to illuminate meaning rather than to generalize across populations (Li et al., 2024). Recognizing these boundaries provides direction for future research that may involve broader participant diversity or comparative studies across disciplines.

Prospective Directions for Future Research

Future studies could extend these findings by exploring interdisciplinary variations in how scientists experience ethical and emotional dimensions of discovery—particularly in emerging fields such as artificial intelligence-assisted drug design or synthetic biology (Kpokiri et al., 2022). Longitudinal designs may also reveal how moral and experiential orientations evolve as research ecosystems shift toward greater automation and commercialization (Mukhlis, Arifin, Ridwan, Zulbaidah, et al., 2025). Moreover, integrating phenomenological insights with ethical frameworks and organizational studies could yield practical strategies for cultivating reflective scientific cultures that balance innovation with integrity (Yamoah et al., 2019). At a broader level, these findings invite future inquiry into the existential aspects of scientific creativity, prompting deeper reflection on what it means to "discover" in a world increasingly mediated by technology and environmental change (Bangaru & Magendran, 2020). Such investigations will continue to expand the phenomenological understanding of science as an embodied, relational, and meaning-laden human endeavor.

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CONCLUSION

This study explored the lived experiences of scientists engaged in marine-based drug discovery to uncover the ethical, emotional, and intellectual meanings underlying their work. The findings revealed that discovery is not merely a technical process but a deeply human experience shaped by curiosity, moral reflection, and collaboration. Through the use of interpretative phenomenological analysis, the study illuminated how scientists negotiate the balance between innovation and ecological responsibility, offering insights that address the limitations of prior research focused solely on procedural or quantitative dimensions.

Beyond these conceptual contributions, the study offers concrete implications for research and policy. First, future investigations should operationalize phenomenological insights through structured reflection protocols in laboratory settings — enabling scientists to systematically document ethical reasoning and emotional engagement during experimentation. Second, interdisciplinary training programs should incorporate phenomenological reflection modules to strengthen researchers' ethical sensitivity and self-awareness in marine biotechnology. Third, policy frameworks in marine bioprospecting should mandate ethical impact assessments that include qualitative evaluation of researchers' lived experiences, ensuring that discovery practices align with both ecological sustainability and moral accountability.

By advancing these recommendations, this research reframes marine-based drug discovery as an ethically reflexive and policy-relevant practice rather than a purely scientific pursuit. The study thus bridges phenomenological understanding with actionable strategies, encouraging institutions and policymakers to embed reflective ethics into innovation systems. Future studies should expand comparative analyses across different domains of biotechnological research and evaluate the efficacy of phenomenological interventions in shaping ethical decision-making and sustainable discovery outcomes.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article. All financial and institutional support received during the research process was used solely for scientific purposes and did not influence the design, data interpretation, or conclusions of this study.

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