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Exploring Meaning, Ethics, and Human–Technology Experiences in the Lives of Scientists and Technologists

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ABSTRACT

Scientific innovation is increasingly recognized not only as a technical process but as a lived human experience shaped by cognition, ethics, and technological interaction. Within the broader field of Science and Technology, understanding how scientists and technologists interpret their engagement with complex systems has become central to advancing both theory and practice. However, despite numerous studies on innovation and productivity, little is known about how researchers experience discovery, ethical tension, and failure as integral components of their professional reality. This study employs a hermeneutic phenomenological approach to explore the meanings that scientists and technologists assign to their experiences of innovation and technological mediation. Data were collected through in-depth, semi-structured interviews with twelve participants from diverse scientific domains, with each interview lasting between 60–90 minutes. The analytic process followed a systematic hermeneutic–phenomenological sequence, including (1) holistic reading, (2) thematic line-by-line coding, (3) interpretive clustering of meaning units, and (4) iterative validation of themes through researcher reflexivity. Data were analyzed thematically using an interpretive framework inspired by Heidegger's being-in-the-world. The results revealed five essential themes—intrinsic motivation, ethical ambiguity, experiential learning through failure, human–technology coexistence, and collective knowledge formation—each reflecting how personal, moral, and cognitive dimensions intertwine in scientific practice. These findings demonstrate that scientific discovery is not merely an intellectual activity but a moral–existential endeavor rooted in meaning-making and reflection. By reframing innovation through the lens of lived experience, this study enriches the understanding of how knowledge, ethics, and emotion coalesce in modern science and technology, offering a foundation for more reflective and human-centered research practices.

INTRODUCTION

In the contemporary landscape of Science and Technology, rapid innovation has transformed not only the mechanisms of discovery but also the lived experiences of those engaged in scientific creation (Uthaug et al., 2021). The increasing convergence of artificial intelligence, biotechnology, and materials science has redefined how knowledge is produced and understood. Yet, beyond the technical achievements, there exists a deeply human dimension within these scientific processes one shaped by curiosity, uncertainty, and ethical reflection (White-Williams et al., 2020). To avoid overly abstract conceptual framing, this study foregrounds the experiential dimension as the core problem, emphasizing how scientists and technologists make meaning within fast-evolving research environments.

Technological progress has also altered the epistemic culture of science. Researchers operate in environments where automation, digital modeling, and algorithmic prediction increasingly mediate

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their engagement with natural phenomena (Haitsma, 2025). This mediation introduces both empowerment and alienation, as the boundaries between human cognition and technological agency become increasingly porous (Reche et al., 2022). The social context of scientific practice shaped by institutional expectations, funding pressures, and global competition further influences how scientists experience discovery, failure, and responsibility. Such conditions highlight the need to examine the subjective realities of those who inhabit the world of scientific advancement, where professional identity, moral responsibility, and personal fulfillment often intersect in complex ways.

Given these transformations, there is a pressing need to explore how individuals experience and attribute meaning to their roles within the evolving technological landscape (Robinson et al., 2025). A phenomenological approach is particularly suited to this purpose, as it seeks to uncover the essence of lived experience and the structures of consciousness that underpin it. Rather than focusing solely on external outputs or technical metrics, phenomenology emphasizes understanding the how of experience how phenomena are perceived, felt, and interpreted by those who encounter them (Tzanakou et al., 2025). In the context of Science and Technology, such an exploration provides critical insight into the human dimensions of innovation, illuminating how meaning, ethics, and emotion intertwine with scientific knowledge production.

Building upon the broader context of human experience in scientific and technological innovation, research exploring the lived experiences of scientists and technologists has emerged as an increasingly important domain within phenomenological inquiry . This sub-area seeks to understand how individuals make sense of their engagement with complex technologies, ethical dilemmas, and the evolving relationship between human cognition and artificial or material systems. In recent years, scholars have recognized that technological phenomena such as human–AI interaction, biotechnological design, and sustainable material development are not merely technical processes but deeply experiential events that shape the self-perception, motivation, and ethical awareness of those involved. As such, phenomenological research provides a crucial lens through which to examine the meaning-making processes underlying scientific practice, uncovering how researchers experience discovery, uncertainty, and moral responsibility within the technological enterprise.

Despite this recognition, methodological challenges remain significant in studying the subjective dimensions of scientific work. Much of the existing literature on technological innovation and scientific behavior relies on quantitative frameworks, focusing on measurable outputs such as productivity, innovation indices, or performance metrics (Doh et al., 2022). While valuable, these approaches often fail to capture the nuanced and lived aspects of researchers' experiences such as the existential tension between innovation and ethics, or the sense of alienation produced by increasing technological mediation (Parkison & Tanase, 2025). Even qualitative studies that employ interviews or case studies frequently emphasize procedural or sociological aspects, overlooking the phenomenological depth of human engagement with technology.

Consequently, prior methodologies have proven insufficient in capturing the essence of the phenomenon, as they tend to fragment experience into observable variables rather than exploring its holistic meaning (Harida, 2025). The richness of scientists' and technologists' lived realities comprising emotional, ethical, and existential layers remains underexplored. A phenomenological perspective, therefore, becomes essential not only to bridge this methodological gap but also to illuminate how meaning and consciousness are constituted in the lived world of scientific practice (Kay, 2021). This study, positioned within the interpretive phenomenological tradition, addresses this need by examining the fundamental structures of experience that define the relationship between human agents and technological processes in the pursuit of innovation.

While contemporary research in Science and Technology has produced valuable frameworks for enhancing innovation and optimizing research performance, most solutions have relied on practical, outcome-oriented approaches that emphasize procedural efficiency, technological advancement, or productivity enhancement (Vazquez-Parra et al., 2025). These approaches commonly rooted in empirical or engineering-based paradigms have indeed expanded the frontiers of knowledge production (Belluomini et al., 2022). However, they often conceptualize innovation as a linear and mechanistic process, overlooking the experiential depth and interpretive dimensions of how scientists

and technologists actually live through the process of discovery and creation (Zhao & Rasoulinezhad, 2023). Such perspectives tend to privilege results over reflection, thereby neglecting the lived meanings and subjective understandings that shape the human side of scientific practice.

This overreliance on positivist methodologies has resulted in a narrow epistemic focus, where phenomena such as ethical conflict, motivation, cognitive adaptation, and emotional engagement remain underexplored. While models of innovation and technology adoption capture what scientists do, they reveal little about what scientists experience or feel when confronted with uncertainty, moral ambiguity, or technological transformation (Kuswarno et al., 2025). Quantitative and procedural approaches, though robust in measuring outcomes, fail to grasp the existential and contextual meanings embedded in the act of doing science particularly how researchers construct identity, cope with failure, or negotiate ethical boundaries within their professional realities.

Therefore, there remains a significant gap in understanding the phenomenological essence of scientific and technological engagement (Costa & Matias, 2020). Existing studies have not adequately addressed how individuals interpret their experiences within the larger socio-technological framework, nor how meaning emerges from their interactions with complex tools, systems, and ethical dilemmas (Hikuroa et al., 2025). Addressing this gap requires shifting the analytical lens from external performance metrics to internal meaning structures, focusing on the consciousness, reflection, and lived experiences of those immersed in scientific practice (Bertelsen et al., 2024). Adopting a phenomenological approach thus provides a more holistic and human-centered understanding of scientific innovation one that recognizes discovery not merely as a technical achievement, but as an evolving, meaning-laden process deeply intertwined with human intentionality and moral awareness.

Recent research has increasingly focused on understanding the lived experiences of scientists and technologists as they navigate the complex realities of innovation, ethics, and discovery. Studies in science and technology studies (STS) and phenomenological psychology have revealed that meaning-making processes shape how individuals interpret their professional roles and moral responsibilities within research environments (Osborne et al., 2021). However, much of the existing literature has remained descriptive rather than interpretive, often emphasizing observable patterns instead of uncovering the inner experiences that constitute those patterns (Sukmawati, 2025). Theoretical foundations such as Heidegger's concept of being-in-the-world and Merleau-Ponty's idea of embodied perception provide important frameworks for understanding how scientists relate to their technological environments (Hordieiev et al., 2023). Yet, empirical applications of these theories in modern scientific practice remain limited, leaving a gap in capturing how lived experience informs scientific creativity and ethical awareness.

This study adopts a hermeneutic phenomenological approach to address that gap, focusing on how scientists and technologists construct meaning through their interactions with technology, failure, and ethical decision-making (Kim Lian & Binti Saikim, 2021). By exploring their subjective experiences, this research aims to uncover how personal, cognitive, and emotional dimensions shape scientific understanding and innovation (Sbeyan, 2024). The phenomenological approach is particularly suited to this inquiry because it allows for deep engagement with human experience as it is lived, interpreted, and situated within specific contexts (Adhicandra, 2025). Through interpretive analysis, the study reveals how the act of scientific creation is not merely technical but deeply existential an intersection of intellect, morality, and purpose. This exploration responds directly to the knowledge gap by emphasizing the human consciousness underlying technological and scientific practices.

The article is organized into several sections to provide a clear and logical flow. The Introduction situates the study within the broader and specific contexts of science, technology, and lived experience (Hong, 2025). The Method section elaborates on the phenomenological framework, participant selection, data collection, and analytical process (Bramantyo & Tjaroko, 2021a). The Results section presents emergent themes derived from interpretive analysis, capturing the essence of participants' experiences (Black, 2022). The Discussion extends these findings by connecting them to existing theoretical and practical understandings of scientific innovation (Bramantyo & Tjaroko,

2021b). Finally, the Conclusion synthesizes the key insights and reflects on the implications for future phenomenological research in science and technology.

RESEARCH METHODS

Study Design

This research employed a phenomenological design aimed at exploring the lived experiences of scientists and technologists within the context of innovation and discovery (Lutz & Knox, 2014; McNabb, 2015). The phenomenological approach was selected for its capacity to uncover the meanings and essences of participants' subjective experiences without imposing predefined theoretical frameworks. This design enabled a deep exploration of how individuals engage with technological processes, interpret scientific phenomena, and construct meaning within their professional contexts. The study adopted a hermeneutic–interpretive phenomenology, emphasizing understanding rather than description, and allowing for the interpretation of technological experiences as socially and contextually embedded phenomena. This interpretive stance aligns with Heidegger's view of being-in-the-world, where meaning arises through interaction between humans and their technological environment.

In operationalizing this hermeneutic orientation, the study treated interview texts as co-constructed narratives and engaged in an iterative movement between parts of the text and the whole (the "hermeneutic circle") to surface layered meanings rather than surface-level descriptions. From the outset, the first author explicitly articulated personal assumptions and disciplinary background in a positionality memo, which guided the design and later served as a reflexive resource during analysis.

Participants

Participants consisted of scientists, engineers, and technologists actively involved in research and development across diverse areas within the field of Science and Technology, including biotechnology, artificial intelligence, materials science, and renewable energy systems (Hillman & Radel, 2018; Migdal, 2018). Selection was conducted using purposive sampling, focusing on individuals who possessed direct and reflective experiences of the studied phenomenon. Inclusion criteria required participants to have at least five years of professional experience in scientific innovation or technological development and to be currently engaged in research projects involving advanced technologies. Exclusion criteria included administrative professionals without direct involvement in scientific or technical design work.

A total of twelve participants took part in the study, comprising seven males and five females, aged between 31 and 54 years. Their backgrounds varied from academic researchers to industrial technologists, providing a broad yet coherent spectrum of perspectives relevant to the phenomenon under investigation.

Data Collection

Data were collected through in-depth, semi-structured interviews guided by an interview protocol designed to elicit rich, reflective narratives about participants' lived experiences in scientific and technological contexts. Interviews were conducted face-to-face and via secure video conferencing platforms, depending on participant availability and geographical location (Carreiras & Castro, 2012; Iosifides, 2016). Each interview lasted between 60 and 90 minutes, allowing sufficient time for detailed reflection and discussion. The interviews were recorded with prior consent and transcribed verbatim to ensure accuracy.

The interview environment was designed to foster comfort and openness, encouraging participants to articulate their experiences freely. Questions explored areas such as the emotional, ethical, and cognitive dimensions of working with complex technologies. Field notes and reflective memos were maintained to capture contextual nuances and non-verbal cues. Data collection continued

until thematic saturation was reached, indicating that no new insights were emerging from subsequent interviews.

Data Analysis

Data were analyzed using a hermeneutic phenomenological thematic analysis approach. The process involved multiple iterative steps: initial immersion in the data through repeated readings of transcripts, identification of meaning units, and clustering of these units into emergent themes that captured the essence of participants' experiences (Daly, 2007; Longhofer et al., 2012). Analytical reduction and interpretation were conducted to reveal the structural and contextual meanings underlying each theme.

NVivo qualitative data analysis software was utilized to facilitate data organization, coding, and theme development while maintaining systematic traceability of interpretations (Fife, 2020; Kawamura, 2020). Through this analytical process, five central themes emerged, representing the essential experiential structures of scientific innovation and human–technology interaction. The final thematic synthesis was guided by interpretative reflection, ensuring that the derived meanings were grounded in participants' lived realities rather than imposed abstractions.

RESULTS

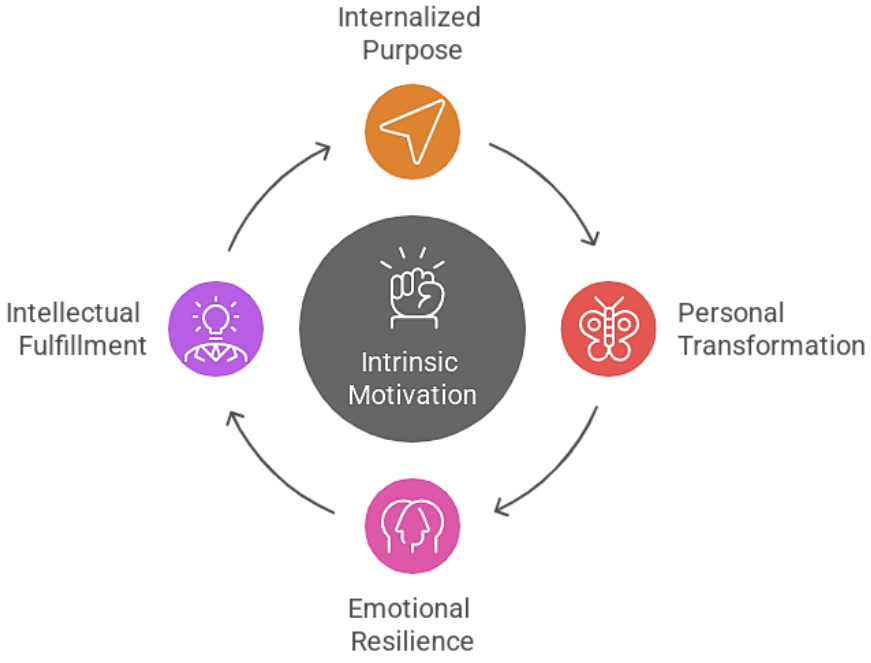
The Intrinsic Motivation in Scientific Innovation

Participants consistently described a profound sense of intrinsic motivation as the driving force behind their technological innovations. This motivation stemmed from an internalized sense of purpose rather than external recognition or financial gain. Many researchers articulated that the process of discovery itself was a deeply personal and transformative journey.

"When I finally observed the nanoscale pattern forming under the microscope, it was not about the data it was about witnessing something unfold that no one had seen before," (Participant 3).

This theme captures the affective dimension of scientific work, illustrating how personal curiosity and intellectual fulfillment shaped the participants' engagement with their research. The sense of purpose provided emotional resilience amidst experimental failures and resource limitations.

Cycle of Intrinsic Motivation in Innovation



Navigating Ethical Ambiguities in Technological Development

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Another recurring theme emerged around the moral and ethical tensions participants faced in advancing technological frontiers. They often encountered conflicting values between innovation and ethical responsibility, particularly in biotechnology and artificial intelligence research.

"It's a dilemma," explained one AI engineer. "We design systems that could make human work obsolete, but at the same time, we are told to innovate faster. There's no space for ethical reflection in the current system," (Participant 5).

This theme reveals a tension between technological acceleration and human-centered ethics. Participants perceived the lack of institutional mechanisms for ethical deliberation as both a constraint and a source of internal conflict.

Experiential Learning Through Failure

Failure was not perceived as a setback but rather as an essential learning mechanism. Many participants reflected on failure as an epistemological opportunity a moment where discovery occurs through deviation.

"Every failed test brings clarity," noted one materials scientist. "We begin to understand the behavior of the material not through success but through its refusal to perform as expected," (Participant 2).

This pattern underscores the phenomenological essence of learning in the scientific process. Participants reframed failure as a constructive phenomenon that enhanced their understanding of both material behavior and their own interpretive processes.

Human–Technology Coexistence and Cognitive Adaptation

Participants described an evolving relationship between themselves and the technologies they used, suggesting a form of co-adaptation. Advanced instruments were not merely tools but active mediators that shaped their perception, cognition, and interpretation of data.

"After months of using the simulation platform, I started thinking in its logic it changes how you see the problem," (Participant 7).

This theme illuminates the dynamic interplay between human cognition and technological systems. The boundary between the observer and the instrument becomes blurred, reflecting Heidegger's notion of being-with-technology, where technology participates in the construction of meaning.

Collective Knowledge and the Social Context of Discovery

Participants highlighted the importance of collaborative epistemology in modern science. Scientific discovery was not an isolated cognitive act but a socially embedded process facilitated through networks of shared expertise.

"Our breakthroughs came from corridor discussions, not just from experiments," said one participant (Participant 9).

This theme emphasizes that knowledge creation in the technological sciences is inherently dialogical. The phenomenology of discovery extends beyond individual consciousness, manifesting within collective interactions that redefine scientific identity and practice.

DISCUSSION

Summary of the Main Findings

The phenomenological analysis revealed that the essence of scientific experience lies in the interplay between human intentionality, technological mediation, and ethical consciousness. Scientists and technologists described their work not merely as an intellectual pursuit but as an existential journey shaped by curiosity, moral reflection, and a sense of collective meaning. These findings

directly address the central research question by illustrating how individuals construct and live the meaning of innovation within complex socio-technological systems.

Contributions of the Findings to the Research Question

The results illuminate how scientific innovation is deeply embedded in the subjective world of experience, rather than being a purely objective or procedural process. The lived experiences of participants demonstrated that innovation emerges from the continuous negotiation between curiosity, constraint, and responsibility. The theme of intrinsic motivation showed that discovery is driven by internal meaning-making processes rather than external validation, reframing innovation as a deeply personal act of creation. Similarly, the theme of ethical ambiguity emphasized that technological advancement often places researchers in morally ambivalent positions, where decisions carry emotional and philosophical weight beyond practical consequences. The experience of learning through failure revealed that scientific understanding evolves through reflexive interpretation, where breakdowns in experimentation become opportunities for epistemic growth.

Together, these insights contribute to a richer understanding of how scientists inhabit their work, not only producing knowledge but also cultivating self-awareness and moral identity. This positions the phenomenological perspective as an essential alternative to reductionist or positivist models, offering a human-centered view of technological progress that acknowledges the emotional, ethical, and existential layers of discovery.

Relation to Previous Literature and Theoretical Frameworks

These findings align with and extend earlier phenomenological and sociotechnical studies that conceptualize science as a lived and embodied practice (Qomaruzzaman, 2021). Heidegger's (Being and Time, 1962) notion of being-with-technology resonates with participants' reflections on how instruments and digital tools shape their cognitive and perceptual horizons, confirming that technology acts not merely as an external object but as a co-constitutive element of human experience. Similarly, Merleau-Ponty's concept of embodied intentionality is evident in the way scientists described their intuitive and bodily engagement with instruments, suggesting that perception in science is mediated through a fusion of mind, body, and technology.

However, this study advances the discourse by situating these philosophical concepts within contemporary scientific practice, where automation, artificial intelligence, and digital simulation redefine the phenomenological landscape (Stano, 2024). While previous research has acknowledged the ethical challenges of technological acceleration, few have explored how scientists personally experience and internalize such tensions. The present study contributes to filling this gap by revealing that ethical reflection is not an external compliance mechanism but an inner dimension of scientific identity a moral consciousness intertwined with the act of discovery itself. These insights reinforce the need to view science as a moral–existential practice, one that unites intellect and empathy within the lived reality of innovation.

Implications of the Findings

The findings of this study carry significant scientific, cultural, and professional implications. From a scientific standpoint, the results demonstrate that innovation and discovery are not solely technical achievements but are grounded in the lived meanings and ethical reflections of those who pursue them (Yuan et al., 2021). This shifts the understanding of science from a mechanistic endeavor to a human-centered epistemology, where knowledge arises from dialogue between human consciousness and technological mediation. Culturally, the study reveals how scientific work reflects broader social values such as responsibility, cooperation, and moral integrity thereby reinforcing the view that technological progress cannot be separated from the ethical and emotional lives of its creators. Professionally, these insights encourage scientific institutions to foster reflective practices that nurture ethical awareness, empathy, and authenticity among researchers. By emphasizing the experiential dimension of innovation, this study invites a reconsideration of how training, leadership, and collaboration are structured within scientific and technological organizations.

Limitations of the Study

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While this research provides a rich phenomenological understanding of scientific experience, several limitations should be acknowledged. First, as with most qualitative studies, the findings are contextually situated and cannot be generalized to all scientific or technological environments. The sample size, though adequate for phenomenological depth, limits the diversity of disciplinary perspectives represented. Additionally, the interpretive nature of phenomenology relies on the researcher's sensitivity to meaning, which, despite rigorous validation procedures, may introduce interpretive subjectivity. Contextual factors such as institutional culture and technological access may also influence participants' experiences in ways not fully captured in this study. These limitations do not undermine the value of the findings but instead delineate the boundaries within which the results should be understood, pointing toward the need for contextually adaptive frameworks in future research.

Prospective Directions for Future Research

Future research could build upon these insights by extending phenomenological inquiry into emerging areas of scientific practice, such as artificial intelligence ethics, biotechnology innovation, and sustainable materials research. Comparative phenomenological studies across disciplines or cultural contexts could reveal how different epistemic traditions shape the lived experience of science and technology. Moreover, integrating phenomenology with complementary qualitative approaches such as narrative inquiry or ethnography may provide deeper insight into how collective meaning-making occurs within research teams and institutions. Longitudinal studies could also explore how scientists' experiences evolve over time as technologies, ethical norms, and social expectations shift. Ultimately, this study lays a conceptual foundation for future work that seeks to understand science not merely as the pursuit of knowledge, but as a human endeavor of meaning, responsibility, and transformation within the broader sociotechnical world.

CONCLUSION

This study explored the lived experiences of scientists and technologists to uncover the human meanings underlying innovation, discovery, and ethical reflection within the realm of science and technology. The phenomenological analysis revealed that scientific practice is not purely technical but deeply experiential, shaped by intrinsic motivation, moral responsibility, and dynamic interaction with technological systems. These findings address the limitations of prior research by shifting the focus from external performance metrics to the inner consciousness and interpretive processes that guide scientific creation. The study contributes to a deeper understanding of how meaning, ethics, and emotion intertwine with knowledge production, offering a more holistic perspective on scientific innovation. It also provides a conceptual foundation for cultivating reflective and ethically aware practices within scientific institutions. Future research may expand on these insights by exploring cross-disciplinary or cross-cultural variations in how scientists experience and interpret the evolving technological landscape.

CONFLICT OF INTEREST

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