Engineers' Perspectives on Ethical Challenges in Emerging Multidisciplinary Technologies: A Qualitative Study

Saman Bagheri[1*]

Citation: Bagheri, S. (2026). Engineers' Perspectives on Ethical Challenges in Emerging Multidisciplinary Technologies: A Qualitative Study. *Multidisciplinary Engineering Science Open,* 3, 1-13.

Abstract

This study aimed to explore engineers' perspectives on the ethical challenges encountered in the design, development, and implementation of emerging multidisciplinary technologies. This qualitative study was conducted using a conventional thematic analysis approach. Participants were 24 engineers working in technology-driven, research-based, and multidisciplinary organizations in Tehran, Iran. Participants were selected through purposive sampling to include engineers with direct experience in emerging technologies such as artificial intelligence, robotics, biomedical engineering, nanotechnology, smart infrastructure, renewable energy systems, and data-driven industrial systems. Data were collected through semi-structured interviews lasting 45–75 minutes. Interviews continued until theoretical saturation was reached after the twenty-first interview, followed by three additional interviews to confirm saturation. All interviews were audio-recorded with informed consent, transcribed verbatim, and analyzed using NVivo software. Coding proceeded through open coding, category development, constant comparison, and theme refinement. Credibility was strengthened through member checking, peer review, and maintaining an audit trail. Thematic analysis generated five main categories: ethical uncertainty and anticipatory responsibility; distributed accountability in multidisciplinary collaboration; privacy, data justice, and algorithmic opacity; tension between public welfare and commercial or institutional pressure; and the need for embedded ethical governance. Participants emphasized that ethical challenges often emerged before technical consequences were fully visible and were intensified by fragmented responsibility across disciplines. Engineers also reported difficulty translating abstract ethical principles into practical design decisions under time, budget, and market pressures. The findings indicate that ethical engineering in emerging multidisciplinary technologies requires more than individual professional morality. It demands anticipatory thinking, interdisciplinary accountability, transparent design processes, stakeholder inclusion, and institutional mechanisms that integrate ethics into the full technology lifecycle. Strengthening ethical governance can help engineers address uncertainty, reduce harm, and support socially responsible innovation.

Keywords: Engineering ethics; emerging technologies; multidisciplinary innovation; responsible innovation; qualitative research; ethical governance; Tehran

---

1. Department of Marine Engineering, Chabahar Maritime University, Chabahar, Iran

*Correspondence: e-mail: saman.bagheri.maritime@gmail.com

1. Introduction

Emerging technologies increasingly develop at the intersection of multiple fields rather than within the boundaries of a single engineering discipline. Artificial intelligence, robotics, biomedical devices, nanotechnology, smart infrastructure, renewable energy systems, autonomous systems, and data-intensive industrial platforms are not merely technical artifacts; they are socio-technical systems shaped by organizational priorities, regulatory expectations, cultural norms, user practices, and public trust. Engineers working in such environments are no longer responsible only for calculating technical feasibility or ensuring mechanical, computational, or structural performance. They are also expected to anticipate social consequences, negotiate conflicting values, manage uncertainty, and contribute to responsible innovation. This shift has created new ethical challenges for engineering practice, particularly where emerging technologies are multidisciplinary, rapidly evolving, and deployed before their long-term effects are fully understood.

Engineering ethics has traditionally emphasized professional responsibility, competence, honesty, safety, and the protection of public welfare. Professional codes such as the National Society of Professional Engineers' Code of Ethics require engineers to hold paramount the safety, health, and welfare of the public. This principle remains central, but emerging multidisciplinary technologies complicate how engineers understand and enact this responsibility. In conventional engineering projects, risks may be relatively visible, bounded, and measurable through established standards. In contrast, emerging technologies often involve uncertain consequences, data-dependent behaviors, opaque computational processes, dual-use possibilities, and distributed chains of responsibility across software developers, domain experts, managers, investors, regulators, and end-users. As a result, engineers may recognize ethical concerns but lack institutional authority, methodological tools, or interdisciplinary language to address them effectively.

The ethical complexity of emerging technology is partly explained by the Collingridge dilemma, which suggests that technology is easier to shape during early development, but its social consequences are harder to predict at that stage; once consequences become clearer, the technology may already be embedded in institutions, markets, and everyday practices, making control more difficult (Collingridge, 1980). This dilemma is highly relevant to multidisciplinary technologies because uncertainty is not only technical but also social, legal, and organizational. For example, an AI-enabled medical device may raise issues of clinical safety, patient autonomy, diagnostic accountability, data privacy, algorithmic bias, and regulatory compliance. A smart-city infrastructure system may simultaneously involve civil engineering, sensor networks, cybersecurity, environmental design, and public governance. Engineers working in such projects may confront ethical questions that cannot be resolved solely through technical optimization.

Responsible innovation provides one influential framework for addressing these challenges. Stilgoe, Owen, and Macnaghten (2013) proposed anticipation, reflexivity, inclusion, and responsiveness as key dimensions of responsible innovation. Anticipation requires systematic reflection on possible futures and unintended consequences. Reflexivity requires engineers and organizations to question their assumptions, values, and limitations. Inclusion emphasizes the involvement of affected stakeholders, while responsiveness requires the capacity to modify innovation trajectories in light of ethical concerns and social feedback. These dimensions are especially important in emerging technologies because ethical risks cannot always be eliminated in advance; rather, they must be continuously identified, discussed, monitored, and governed.

Similarly, anticipatory ethics argues that ethical reflection should begin during the research and development stage, before technologies are widely implemented (Brey, 2012). This approach is important because waiting until harm becomes visible may reduce opportunities for prevention. Van de Poel (2016) further conceptualized the introduction of new technologies into society as a form of social experimentation. From this perspective, emerging technologies should be assessed through principles such as non-maleficence, beneficence, respect for autonomy, and justice. Such a view shifts ethical responsibility from post-hoc reaction to proactive governance. Engineers are not only builders of technical systems but also participants in experiments that may affect human behavior, social relations, environmental sustainability, and institutional trust.

The rise of data-driven technologies has added further ethical concerns. Algorithmic systems can produce consequences that are difficult to explain, contest, or attribute to a single actor. Mittelstadt, Allo, Taddeo, Wachter, and Floridi (2016) argue that algorithmic mediation raises ethical issues related to opacity, bias, discrimination, accountability, and unintended harms. Jobin, Ienca, and Vayena (2019) found convergence across AI ethics guidelines around principles such as transparency, justice and fairness, non-maleficence, responsibility, and privacy, while also showing that there is considerable divergence in how these principles are interpreted and implemented. This gap between principle and practice is especially relevant to engineers, who must translate broad ethical values into design requirements, testing protocols, documentation practices, risk assessments, and operational safeguards.

Value-sensitive design also offers a useful perspective for understanding ethical challenges in engineering. Friedman, Kahn, and Borning (2006) define value-sensitive design as an approach that accounts for human values in a principled and comprehensive manner throughout the design process. This perspective suggests that values such as privacy, autonomy, accessibility, fairness, safety, trust, environmental responsibility, and accountability should not be treated as external considerations added after technical development. Instead, they should be embedded into the conceptual, empirical, and technical stages of design. For engineers, this requires asking not only whether a technology works, but also for whom it works, under what conditions, who may be harmed, who benefits, and whose values are represented in the design process.

Engineering ethics scholars also distinguish between microethics and macroethics. Microethics focuses on individual professional conduct, such as honesty, confidentiality, competence, and conflicts of interest. Macroethics addresses the collective responsibility of the engineering profession toward society, including public policy, sustainability, technological justice, and the distribution of technological risks and benefits (Herkert, 2005). Emerging multidisciplinary technologies require both levels. Individual engineers may face immediate decisions about data handling, safety testing, design shortcuts, or reporting concerns. At the same time, these decisions occur within broader systems shaped by organizational incentives, market competition, regulatory gaps, and public expectations. Therefore, ethical responsibility cannot be reduced to individual conscience; it must also involve organizational structures, professional cultures, and governance mechanisms.

The multidisciplinary nature of emerging technologies creates additional complications. Engineers often work alongside computer scientists, physicians, designers, business managers, legal experts, social scientists, and policymakers. While such collaboration can improve innovation, it can also fragment responsibility. Each discipline may define risk differently, use different evidence standards, and prioritize different outcomes. Technical teams may focus on performance, business teams on market readiness, legal teams on compliance, and users on usability or trust. Ethical problems may fall between these domains, especially when no single actor has complete knowledge of the system. This situation can produce what participants in technology ethics often describe as "responsibility gaps," where many actors contribute to an outcome but no one feels fully accountable.

In developing contexts and rapidly expanding technology markets, these ethical challenges may become more intense. Organizations may adopt advanced technologies faster than ethical guidelines, regulatory frameworks, and professional training systems can adapt. Engineers working in metropolitan innovation centers such as Tehran may encounter global technological models, local regulatory constraints, limited resources, sanctions-related supply challenges, market pressures, and culturally specific expectations about privacy, public welfare, and professional responsibility. Yet empirical studies on how engineers themselves perceive these ethical challenges remain limited, particularly in non-Western contexts. Much of the literature discusses ethical principles at the policy or philosophical level, while fewer studies examine how engineers experience ethical tensions in daily project work.

A qualitative approach is suitable for investigating these experiences because ethical challenges are often complex, context-dependent, and embedded in professional narratives. Interviews can reveal how engineers define ethical problems, how they negotiate competing pressures, how they interpret responsibility, and what forms of support they believe are needed. Understanding engineers' perspectives can help bridge the gap between ethical theory and engineering practice. It can also inform ethics education, organizational governance, professional regulation, and responsible innovation policies.

Therefore, the aim of this study was to explore engineers' perspectives on ethical challenges in emerging multidisciplinary technologies, with particular attention to uncertainty, accountability, data-related risks, public welfare, commercial pressure, and the institutional conditions required for responsible engineering practice.

2. Methods and Materials

This study used a qualitative research design based on conventional thematic analysis. The qualitative approach was selected because the study aimed to explore engineers' lived professional perspectives, meanings, interpretations, and experiences regarding ethical challenges in emerging multidisciplinary technologies. Rather than testing predefined hypotheses, the study sought to generate an interpretive understanding of how engineers identify ethical problems, describe responsibility, and explain the organizational and technical conditions that shape ethical decision-making. Thematic analysis was used because it provides a flexible and systematic method for identifying, analyzing, and reporting patterns within qualitative data (Braun & Clarke, 2006).

Participants were 24 engineers working in Tehran, Iran. Purposive sampling was used to recruit engineers with direct experience in the design, development, testing, implementation, or management of emerging multidisciplinary technologies. Inclusion criteria were: holding at least a bachelor's degree in an engineering discipline; having at least five years of professional experience; working in a project involving emerging or multidisciplinary technology; and willingness to participate in an audio-recorded interview. Engineers were recruited from technology firms, knowledge-based companies, university-affiliated research centers, private engineering consultancies, and semi-public innovation organizations in Tehran.

The final sample included 14 men and 10 women. Participants' ages ranged from 27 to 54 years. In terms of specialization, six participants worked in software engineering, artificial intelligence, or data systems; four in biomedical engineering; four in electrical engineering, robotics, or automation; four in mechanical or industrial engineering; three in chemical, materials, or nanotechnology fields; and three in civil, environmental, or smart infrastructure projects. Regarding professional experience, eight participants had 5–10 years of experience, nine had 11–15 years, and seven had more than 15 years of experience. Participants included project engineers, senior engineers, research and development specialists, technical managers, systems designers, and engineering consultants.

Data were collected only through semi-structured interviews. An interview guide was developed based on the literature on engineering ethics, responsible innovation, value-sensitive design, and emerging technology governance. The interview guide included open-ended questions such as: "What ethical challenges have you encountered in projects involving emerging technologies?" "How do multidisciplinary teams discuss responsibility when ethical risks appear?" "What kinds of ethical risks are most difficult to predict?" "How are privacy, safety, fairness, or public welfare considered in your projects?" and "What organizational supports would help engineers make more ethical decisions?"

Interviews were conducted individually between March and June 2026. Each interview lasted between 45 and 75 minutes. Interviews were conducted in Persian, audio-recorded with participants' consent, and transcribed verbatim. Field notes were written after each interview to record contextual observations, emerging analytic ideas, and researcher reflections. Data collection continued until theoretical saturation was achieved. Saturation was reached after 21 interviews, when no substantially new themes emerged. Three additional interviews were conducted to confirm saturation and strengthen the adequacy of the categories.

Data were analyzed using NVivo software. The analysis followed a thematic procedure involving familiarization, initial coding, category construction, theme development, review, definition, and interpretation. First, transcripts were read several times to obtain an overall understanding of participants' narratives. Second, meaningful units related to ethical challenges, responsibility, uncertainty, data use, safety, public welfare, and organizational governance were coded. Third, similar codes were grouped into preliminary categories. Fourth, categories were compared across interviews to identify similarities, differences, and recurring patterns. Fifth, the research team refined the thematic structure by reviewing whether each category was internally coherent and distinct from other categories.

To enhance trustworthiness, several strategies were used. Credibility was supported through member checking with selected participants and peer debriefing among researchers. Dependability was strengthened by maintaining an audit trail of coding decisions, category revisions, and analytic memos. Confirmability was addressed through reflexive memo-writing to reduce the influence of researcher assumptions. Transferability was supported by providing detailed information about the study context, participant characteristics, and data collection procedures. Ethical considerations included voluntary participation, informed consent, anonymity, the use of participant codes, and secure storage of audio files and transcripts.

3. Findings

A total of 24 engineers participated in the study. Fourteen participants were male (58.3%) and ten were female (41.7%). Participants' ages ranged from 27 to 54 years, with most participants between 31 and 45 years old. Regarding educational level, 11 participants held a bachelor's degree (45.8%), nine held a master's degree (37.5%), and four held a doctoral degree (16.7%). In terms of engineering specialization, six participants worked in software engineering, artificial intelligence, or data systems (25.0%), four in biomedical engineering (16.7%), four in electrical engineering, robotics, or automation (16.7%), four in mechanical or industrial engineering (16.7%), three in chemical, materials, or nanotechnology fields (12.5%), and three in civil, environmental, or smart infrastructure projects (12.5%). Eight participants had 5–10 years of work experience (33.3%), nine had 11–15 years (37.5%), and seven had more than 15 years (29.2%). Participants were employed in private technology firms (n = 9), knowledge-based companies (n = 7), university-affiliated research and development centers (n = 5), and public or semi-public engineering consultancies (n = 3).

The first main category reflected engineers' concern that ethical challenges in emerging technologies often appear before consequences are fully measurable. Participants explained that in multidisciplinary projects, technical teams are frequently required to make design decisions under conditions of uncertainty. Engineers reported that risks related to safety, misuse, user dependency, environmental effects, and social acceptance were difficult to predict during early development. However, they also believed that uncertainty should not be used as an excuse for ethical inaction. One participant stated, "In traditional engineering, we usually know the failure mode, but in AI or smart systems, the failure may appear later, in user behavior or social impact. We cannot say it is not our problem just because we cannot calculate it now" (P07). Another engineer noted, "Sometimes the ethical risk is invisible at the prototype stage. By the time the product reaches users, changing the design becomes costly and politically difficult" (P12). This category included codes such as unpredictable consequences, delayed harms, anticipatory risk assessment, uncertain user behavior, and responsibility before evidence is complete.

The second category concerned the fragmentation of responsibility across multidisciplinary teams. Participants emphasized that emerging technology projects often involve several professional groups, including engineers, programmers, medical specialists, business managers, legal consultants, and external clients. While this collaboration was viewed as necessary, it also created ambiguity about who should be responsible for ethical decisions. Several participants reported that ethical issues were often passed between departments, with each group assuming that another unit had addressed them. One participant explained, "The software team says the medical team approved it; the medical team says the algorithm was written by engineers; management says the client accepted the risk. In the end, responsibility becomes scattered" (P03). Another participant said, "When everyone owns a small part of the system, no one feels they own the ethical consequence of the whole system" (P18). Engineers described this problem as especially serious in projects involving automated decision-making, medical technologies, industrial monitoring, and public infrastructure. Subcategories included responsibility gaps, unclear decision authority, weak interdisciplinary communication, and conflict between technical and non-technical priorities.

The third category addressed ethical challenges related to data collection, privacy, algorithmic transparency, and fairness. Participants working with AI, biomedical devices, industrial sensors, and smart infrastructure described data as both a technical resource and an ethical risk. Engineers reported concerns about excessive data collection, unclear user consent, insecure storage, lack of explainability, and biased datasets. A software engineer stated, "The pressure is always to collect more data because it improves the model, but nobody asks whether we really have the right to collect all of it" (P09). A biomedical engineer added, "When a diagnostic model gives a result, doctors and patients want to know why. But sometimes even the engineering team cannot explain the model in a simple way" (P15). Participants also noted that imported datasets, incomplete local datasets, or poorly labeled data could produce unfair outcomes when systems were applied to Iranian users. This category included codes such as privacy-by-design, informed consent, data minimization, algorithmic bias, explainability, and fairness in local contexts.

The fourth category captured the tension between engineers' professional commitment to public welfare and organizational pressure to deliver products quickly, reduce costs, satisfy clients, or demonstrate innovation. Participants stated that ethical concerns were sometimes treated as obstacles to market entry rather than as essential components of responsible design. Safety testing, environmental assessment, cybersecurity checks, and long-term maintenance planning were identified as areas vulnerable to budget and time constraints. One participant said, "The ethical problem is not always that engineers do not know what is right. Sometimes they know, but the project schedule leaves no room to do it properly" (P21). Another engineer working in automation noted, "A technology designed for efficiency can also be used for surveillance or control. We need to think about dual use before delivery, not after misuse happens" (P05). Participants also emphasized environmental sustainability, especially in energy, materials, and infrastructure projects. Subcategories included safety versus speed, cost pressure, dual-use concerns, cybersecurity vulnerability, environmental responsibility, and public trust.

The fifth category reflected participants' belief that ethical engineering cannot depend only on individual awareness or personal morality. Engineers argued that organizations should create formal mechanisms to integrate ethics into project lifecycles. Suggested mechanisms included ethics review meetings, multidisciplinary risk assessment, documentation of ethical decisions, stakeholder consultation, privacy and safety checklists, post-deployment monitoring, and ethics training tailored to engineering practice. Participants emphasized that ethics should not be limited to general lectures or symbolic codes. One participant stated, "We need ethics inside the workflow, not only on posters. If it is not part of design review, testing, and approval, it will be forgotten under pressure" (P11). Another participant said, "Engineers need a safe way to raise concerns. If speaking about risk is seen as being negative, people stay silent" (P24). This category included codes such as institutional ethics review, ethical documentation, stakeholder involvement, professional training, whistleblowing protection, and lifecycle governance.

4. Discussion

This study explored engineers' perspectives on ethical challenges in emerging multidisciplinary technologies. The findings showed that engineers experience ethical challenges as practical, organizational, and socio-technical problems rather than as abstract philosophical questions. Five main categories were identified: ethical uncertainty and anticipatory responsibility; distributed accountability in multidisciplinary collaboration; privacy, data justice, and algorithmic opacity; public welfare, safety, sustainability, and dual-use risk under commercial pressure; and the need for embedded ethical governance and professional support. Together, these findings suggest that ethical engineering in emerging technologies requires a shift from individual compliance toward systemic, anticipatory, and participatory governance.

The first finding showed that engineers face ethical uncertainty because the consequences of emerging technologies are often unclear during early design stages. This aligns with the Collingridge dilemma, which emphasizes that technologies are easier to influence before they are widely adopted, but their consequences are least predictable at that early stage (Collingridge, 1980). Participants' concern that ethical risks may appear after deployment is also consistent with Brey's (2012) concept of anticipatory ethics, which argues that ethical analysis should begin during research and development rather than after social harm occurs. Similarly, Van de Poel (2016) argues that new technologies can be understood as social experiments, requiring attention to non-maleficence, autonomy, beneficence, and justice. The present findings extend these ideas by showing how engineers themselves experience anticipation as a professional burden: they recognize the need to predict possible harms, yet they often lack tools, time, or organizational support for systematic ethical foresight.

The second finding concerned distributed accountability in multidisciplinary collaboration. Participants described responsibility gaps that emerge when different professional groups contribute to a technological system but no single actor controls or understands the whole system. This finding is consistent with Herkert's (2005) distinction between microethics and macroethics. While microethical responsibility focuses on individual conduct, multidisciplinary technologies require macroethical awareness of collective professional and societal responsibility. In complex projects, ethical responsibility is distributed across technical design, organizational decision-making, regulation, client requirements, and user behavior. Therefore, accountability cannot be assigned only to individual engineers. The findings suggest that multidisciplinary collaboration needs explicit responsibility mapping, shared ethical language, and decision protocols that clarify who is responsible for identifying, evaluating, documenting, and responding to ethical risks.

The third finding highlighted privacy, data justice, and algorithmic opacity as major ethical concerns. This result supports previous work showing that algorithmic systems raise ethical problems related to opacity, bias, discrimination, responsibility, and the difficulty of explaining automated decisions (Mittelstadt et al., 2016). It also aligns with Jobin et al. (2019), who found that transparency, justice and fairness, non-maleficence, responsibility, and privacy are among the most frequently cited principles in AI ethics guidelines. However, the current study shows that engineers experience a gap between these general principles and their operationalization in real projects. Participants reported that pressures to collect more data, improve model accuracy, and accelerate deployment can conflict with data minimization, informed consent, explainability, and fairness. This finding also supports value-sensitive design, which argues that human values should be incorporated throughout design rather than added after technical development (Friedman et al., 2006).

The fourth finding revealed tensions between public welfare, safety, sustainability, dual-use risks, and commercial pressures. This finding is closely related to professional engineering codes requiring engineers to prioritize public safety, health, and welfare. In practice, however, participants reported that market speed, client demands, budget constraints, and institutional reputation may weaken ethical safeguards. This reflects a broader challenge in engineering ethics: professional duties are often exercised within organizations that may reward speed, innovation, and profitability more visibly than precaution, transparency, or long-term social responsibility. The finding also connects with responsible innovation theory, which emphasizes responsiveness and inclusion as necessary dimensions of ethical technology governance (Stilgoe et al., 2013). Engineers in this study did not reject innovation; rather, they called for innovation processes that make room for safety testing, environmental assessment, cybersecurity review, and reflection on dual-use risks.

The fifth finding emphasized the need for embedded ethical governance and professional support. Participants repeatedly argued that ethics should be integrated into engineering workflows, including design reviews, risk assessments, documentation systems, testing procedures, and post-deployment monitoring. This supports responsible research and innovation, which frames innovation as a process that should be conducted "with society" rather than only for markets or technical communities (Owen et al., 2012). It also aligns with the IEEE's Ethically Aligned Design framework, which emphasizes human well-being, rights, and responsible development of autonomous and intelligent systems (IEEE, 2019). Similarly, the NIST AI Risk Management Framework highlights trustworthiness characteristics such as validity, reliability, safety, security, accountability, transparency, explainability, privacy, and fairness (NIST, 2023). The present findings show that engineers value such frameworks but need them translated into practical organizational routines, not merely formal policies.

Overall, the findings suggest that ethical challenges in emerging multidisciplinary technologies are not isolated dilemmas solved by individual moral judgment alone. They are embedded in uncertain innovation trajectories, fragmented professional roles, opaque technical systems, commercial pressures, and incomplete governance structures. This means that engineering ethics education and organizational policy should move beyond general ethical awareness toward applied ethical competence. Engineers need training in anticipatory risk analysis, stakeholder engagement, responsible data practices, explainability, sustainability assessment, and ethical documentation. Organizations also need structures that protect engineers who raise concerns and ensure that ethical review has real influence over project decisions.

The findings also have contextual significance. In Tehran-based technology organizations, engineers may work with global technological models while facing local constraints, including limited access to some international tools, regulatory ambiguity, resource restrictions, and rapidly changing market expectations. These conditions may intensify ethical uncertainty and increase reliance on engineers' personal judgment. Therefore, localized ethics frameworks are needed to connect international principles with the realities of engineering practice in Iran. Such frameworks should consider local legal requirements, cultural expectations, professional norms, data governance conditions, and institutional capacities.

This study has several limitations. First, the sample was limited to 24 engineers working in Tehran, which may restrict the transferability of findings to engineers in other Iranian cities or international contexts. Second, the study relied only on semi-structured interviews; therefore, the findings reflect participants' self-reported experiences rather than direct observation of engineering meetings, design reviews, or ethical decision-making processes. Third, participants worked across different engineering fields, which strengthened multidisciplinary variation but limited the depth of field-specific analysis. Fourth, because ethical challenges can be sensitive, some participants may have avoided discussing organizational failures, conflicts with managers, or specific project risks in detail.

Future studies should examine ethical challenges in specific technology domains such as artificial intelligence in healthcare, smart-city systems, robotics, renewable energy infrastructure, nanotechnology, and industrial automation. Comparative studies across different cities, countries, and regulatory environments could show how ethical concerns vary by institutional context. Future research may also use ethnographic observation, case-study analysis, or document review to examine how ethical decisions are actually made during design meetings and project approval processes. Quantitative studies could further develop and validate scales measuring ethical climate, anticipatory responsibility, and perceived accountability in engineering organizations. Longitudinal research would also be valuable for tracking how ethical concerns change from early design to deployment and post-deployment monitoring.

Engineering organizations should integrate ethics into the full technology lifecycle rather than treating it as a separate or symbolic activity. Practical steps include establishing multidisciplinary ethics review panels, requiring ethical risk documentation, using privacy-by-design and safety-by-design checklists, conducting stakeholder consultations, and creating post-deployment monitoring systems. Managers should provide engineers with safe channels for reporting concerns without fear of retaliation. Universities and professional associations should also strengthen applied engineering ethics education by using real multidisciplinary cases, simulation exercises, and project-based ethical analysis. Finally, organizations should ensure that ethical performance is included in project evaluation criteria alongside cost, speed, innovation, and technical performance.

5. Conclusion

This qualitative study explored engineers' perspectives on ethical challenges in emerging multidisciplinary technologies. The findings indicate that engineers encounter ethical challenges mainly through uncertainty, fragmented accountability, data-related risks, public welfare tensions, and insufficient institutional support. Participants emphasized that emerging technologies generate ethical concerns before their consequences are fully visible and that multidisciplinary collaboration can make responsibility difficult to locate. They also highlighted privacy, fairness, algorithmic opacity, dual-use risks, safety, sustainability, and commercial pressure as key areas of concern.

The study concludes that ethical engineering in emerging technologies requires more than individual awareness or professional codes. It requires anticipatory responsibility, interdisciplinary accountability, value-sensitive design, transparent data practices, stakeholder inclusion, and organizational governance mechanisms that give ethics a real role in technical decision-making. For engineers, ethics must become part of design, testing, implementation, and monitoring. For organizations, responsible innovation requires structures that support ethical reflection, protect professional judgment, and prioritize public welfare alongside technological advancement.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

Acknowledgments

Authors thank all who helped us through this study.

Conflict of Interest

The authors report no conflict of interest.

Funding/Financial Support

According to the authors, this article has no financial support.

References

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. doi:10.1191/1478088706qp063oa

Brey, P. A. E. (2012). Anticipatory ethics for emerging technologies. *NanoEthics, 6*(1), 1–13. doi:10.1007/s11569-012-0141-7

Collingridge, D. (1980). *The social control of technology*. St. Martin's Press.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry and research design: Choosing among five approaches* (4th ed.). SAGE Publications.

European Commission, High-Level Expert Group on Artificial Intelligence. (2019). *Ethics guidelines for trustworthy AI*. European Commission.

Friedman, B., Kahn, P. H., Jr., & Borning, A. (2006). Value sensitive design and information systems. In P. Zhang & D. Galletta (Eds.), *Human-computer interaction in management information systems: Foundations* (pp. 348–372). M. E. Sharpe.

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59–82. doi:10.1177/1525822X05279903

Herkert, J. R. (2005). Ways of thinking about and teaching ethical problem solving: Microethics and macroethics in engineering. *Science and Engineering Ethics, 11*(3), 373–385. doi:10.1007/s11948-005-0006-3

IEEE. (2019). *Ethically aligned design: A vision for prioritizing human well-being with autonomous and intelligent systems* (1st ed.). IEEE Global Initiative on Ethics of Autonomous and Intelligent Systems.

Jobin, A., Ienca, M., & Vayena, E. (2019). The global landscape of AI ethics guidelines. *Nature Machine Intelligence, 1*, 389–399. doi:10.1038/s42256-019-0088-2

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. SAGE Publications.

Mittelstadt, B. D., Allo, P., Taddeo, M., Wachter, S., & Floridi, L. (2016). The ethics of algorithms: Mapping the debate. *Big Data & Society, 3*(2), 1–21. doi:10.1177/2053951716679679

National Institute of Standards and Technology. (2023). *Artificial intelligence risk management framework (AI RMF 1.0).* NIST AI 100-1. doi:10.6028/NIST.AI.100-1

National Society of Professional Engineers. (n.d.). *Code of ethics for engineers.* NSPE.

Nissenbaum, H. (2010). *Privacy in context: Technology, policy, and the integrity of social life*. Stanford University Press.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*(1), 1–13. doi:10.1177/1609406917733847

Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Science and Public Policy, 39*(6), 751–760. doi:10.1093/scipol/scs093

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences, 4*(2), 155–169. doi:10.1007/BF01405730

Saldaña, J. (2021). *The coding manual for qualitative researchers* (4th ed.). SAGE Publications.

Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a framework for responsible innovation. *Research Policy, 42*(9), 1568–1580. doi:10.1016/j.respol.2013.05.008

UNESCO. (2021). *Recommendation on the ethics of artificial intelligence*. United Nations Educational, Scientific and Cultural Organization.

Van de Poel, I. (2016). An ethical framework for evaluating experimental technology. *Science and Engineering Ethics, 22*(3), 667–686. doi:10.1007/s11948-015-9724-3

Van de Poel, I., & Royakkers, L. (2011). *Ethics, technology, and engineering: An introduction*. Wiley-Blackwell.