

Master's thesis for the degree of Management of Technology

How researchers evaluate opportunities and construct confidence under persistent uncertainty:

Research-direction decision-making in AI-integrated biotech health technology innovation

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Abstract

Researchers in emerging biomedical innovation environments must frequently determine future research directions despite substantial uncertainty regarding feasibility, value, impact, and future applicability. Because these futures cannot yet be directly observed, researchers are often required to evaluate opportunities and commit resources before their eventual outcomes are known.

This study examines how researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions within an artificial intelligence (AI)-integrated biotech health technology innovation context. An exploratory qualitative research design was adopted using semi-structured interviews with eight researchers involved in the development of an early-stage precision medicine platform technology. The interview data were analysed using reflexive thematic analysis.

The findings suggest that uncertainty remains a persistent feature of research-direction evaluation rather than a condition that can be eliminated before decisions are made. Three interconnected processes were identified: collective judgement through distributed expertise, future-oriented opportunity evaluation, and evidence generation and interpretation. Through collective judgement, researchers draw upon expertise distributed across multiple actors and disciplines to assess uncertain opportunities. Through future-oriented opportunity evaluation, researchers assess future value, feasibility, impact, and relevance when comparing alternative directions. Through evidence generation and interpretation, researchers develop an empirical basis for assessing whether opportunities remain sufficiently credible and worthwhile to pursue.

A cross-theme analysis indicates that these processes collectively contribute to the construction of sufficient confidence despite uncertainty remaining unresolved. Confidence construction emerged as an interpretive concept that helps explain how researchers become able to move from evaluation to commitment before certainty has been achieved. The findings therefore suggest that research-direction decisions cannot be explained solely through uncertainty reduction and that confidence construction may help explain how commitment becomes possible under persistent uncertainty.

Although the study was conducted within an AI-integrated research environment, AI did not emerge as an independent basis for selecting research directions. Instead, AI functioned as a contextual condition that shaped expertise requirements, opportunity spaces, uncertainty conditions, and evidential capabilities. The study contributes to understanding how researchers evaluate opportunities, navigate uncertainty, and become able to commit to future research directions despite persistent uncertainty. Through the concept of confidence construction, it provides a process-oriented explanation of how commitment becomes possible when future outcomes remain uncertain.

Executive summary

Background and research objective

Determining future research directions is a critical yet challenging aspect of scientific research. Researchers are frequently required to decide which opportunities warrant continued investment despite incomplete knowledge regarding their future scientific value, feasibility, impact, and applications. This challenge is particularly evident in rapidly evolving research environments, where new opportunities emerge continuously while important uncertainties remain unresolved.

Although artificial intelligence (AI) has become an important component of contemporary biomedical research, the focus of this thesis is not AI itself. Rather, the study examines how researchers evaluate opportunities and navigate uncertainty when determining future research directions within an AI-integrated biotech health technology innovation environment. The study addresses the following research question:

How do researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation?

Methodology

An exploratory qualitative research design was adopted. Semi-structured interviews were conducted with eight researchers involved in the development of an early-stage precision medicine platform technology combining biotechnology and AI-enabled computational approaches. Participants represented different disciplinary backgrounds and career stages, including biotechnology researchers, computational researchers, and technology translation researchers. Interview data were analysed using reflexive thematic analysis.

Key findings

Persistent uncertainty shapes research-direction decisions

Researchers encountered multiple interconnected forms of uncertainty throughout the research process, including scientific, evidential, technological, translational, and practical uncertainty. These uncertainties frequently persisted despite ongoing efforts to generate knowledge and evidence. Rather than waiting for uncertainty to disappear, researchers described uncertainty as a normal and enduring feature of research-direction evaluation.

Importantly, uncertainty did not prevent decision-making. Instead, it created the conditions that made evaluation, evidence generation, and prioritisation necessary.

Collective judgement supports evaluation

Future research opportunities were rarely evaluated by individuals working in isolation. Researchers frequently relied on expertise distributed across supervisors, collaborators, clinicians, computational specialists, and wider research networks. Through consultation, discussion, and interdisciplinary interaction, distributed expertise was integrated into collectively informed judgements.

The findings suggest that collective judgement expanded evaluative capacity by enabling opportunities to be assessed from multiple perspectives and through forms of expertise that no individual researcher possessed independently.

Opportunity evaluation is future-oriented

Researchers evaluated opportunities according to their anticipated future value, feasibility, impact, translational relevance, and resource requirements. Evaluation therefore focused not on established realities, but on possible futures.

Many of the characteristics being evaluated could not yet be directly observed. Researchers were required to assess what opportunities might become if they were pursued. As a result, uncertainty emerged not merely from incomplete information, but also from the future-oriented nature of evaluation itself.

Evidence generation and interpretation provide justification

Researchers relied on experimentation, validation, measurement, analysis, and interpretation when assessing whether opportunities remained worthy of continued investment. Evidence generation enabled researchers to evaluate assumptions, refine assessments, and determine whether research directions remained credible and promising.

Importantly, evidence did not eliminate uncertainty entirely. Instead, it strengthened the basis upon which opportunities could be evaluated and justified.

Confidence construction and commitment under persistent uncertainty

A cross-theme analysis suggested that collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation interacted throughout research-direction decision-making. Together, these processes contributed to the development of sufficient confidence despite uncertainty remaining unresolved.

Confidence construction emerged as an interpretive concept explaining how researchers appeared to move from evaluation to commitment before certainty had been achieved. The findings therefore suggest that research-direction decisions cannot be explained solely through uncertainty reduction and that confidence construction may help explain how commitment became possible under persistent uncertainty.

Main contribution

A central finding of the study is that confidence construction may help explain how commitment becomes possible despite persistent uncertainty. The findings suggest that researchers do not eliminate uncertainty before committing to future directions. Instead, they construct sufficient confidence through the interaction of collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation. Confidence construction therefore offers a process-oriented explanation of how commitment becomes possible despite persistent uncertainty.

Practical implications

Researchers

Researchers may benefit from recognising uncertainty as an enduring feature of research rather than a problem that must be eliminated before action can occur. The findings suggest the value of combining diverse expertise, continuous opportunity evaluation, and ongoing evidence generation when determining future directions.

Principal investigators and research leaders

Research-direction decisions appear to benefit from evaluation processes that incorporate distributed expertise and interdisciplinary perspectives. Structured opportunities for consultation, discussion, and reassessment may support more informed evaluation under uncertainty.

Innovation managers

The findings suggest that resource-allocation decisions frequently need to be made before the future value of opportunities can be established. Future-oriented opportunity evaluation should therefore be viewed as an iterative process supported by expertise integration, evidence generation, and continuous reassessment.

Conclusion

This thesis suggests that research-direction decisions cannot be explained solely through uncertainty reduction. Rather, the findings indicate that confidence construction may help explain how researchers become able to commit to future directions despite persistent uncertainty. Through collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation, researchers develop sufficient confidence to continue investing in particular directions despite persistent uncertainty. In doing so, the study provides a process-oriented explanation of how commitment becomes possible before certainty has been achieved.

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1. Introduction

Healthcare continues to face major challenges in effectively treating many diseases. Patients often respond differently to the same treatment and as a result many diseases remain difficult to treat effectively (Johnson et al., 2021; Lohse, 2023; Naithani et al., 2021). These challenges have increased interest in precision medicine, an approach that seeks to tailor treatment to the biological characteristics of individual patients. Advances in biotechnology have contributed strongly to this development by generating detailed biological information about disease mechanisms and treatment responses (Evangel Chinyere et al., 2024). Biomedical research therefore increasingly depends on the ability to generate and interpret large amounts of complex data.

The growing volume of biomedical and health-related data has created a new challenge. Generating data is no longer the primary bottleneck. Increasingly, the challenge lies in making sense of large and heterogeneous forms of information and translating them into meaningful scientific and clinical insights. Advances in computational methods, including artificial intelligence (AI), have expanded researchers' ability to identify patterns, relationships, and signals that are difficult to detect using conventional approaches (Gong et al., 2025; Holzinger et al., 2023). However, the significance of these developments extends beyond analytical capability alone. Biomedical innovation increasingly occurs within environments characterised by rapid technological change and expanding opportunity spaces. New methods emerge continuously, technologies evolve rapidly, and researchers are confronted with an increasing number of potential trajectories for future investigation (Niazi & Mariam, 2025; Secinaro et al., 2021).

These developments have also strengthened the importance of interdisciplinary and collaborative research. Evaluating emerging opportunities increasingly requires expertise distributed across multiple domains, including biotechnology, computational science, clinical research, and data-intensive approaches (Gong et al., 2025; Zhu et al., 2024). Researchers therefore operate in environments where knowledge is distributed across multiple actors and where future directions must often be evaluated before their scientific, translational, or practical value can be fully established (Holzinger et al., 2023; Niazi & Mariam, 2025; Zhu et al., 2024). While distributed expertise broadens the range of opportunities that can be explored, it does not eliminate the uncertainty associated with their future outcomes (Holzinger et al., 2023; Olaye & Seixas, 2023).

This creates a difficult research environment. Many questions remain unanswered during the development of biomedical innovations. It is often unclear whether a new technological approach is technically feasible, whether findings will remain valid outside controlled research settings, or whether a promising research direction will ultimately create meaningful value (Javanmardi et al., 2024; Lohse, 2023). New discoveries may reduce some uncertainties while simultaneously revealing new ones (Borck & Lohse, 2026). Complete certainty is therefore rarely available during research. Consequently, researchers must frequently make decisions regarding future directions despite lacking certainty about which opportunities are most likely to generate meaningful scientific, translational, or practical value.

These challenges become even more significant as technological developments continue to expand the range of opportunities available to researchers. New methods and scientific possibilities continually emerge, creating situations in which researchers must decide where to focus future effort and resources. Understanding how researchers evaluate alternatives and commit to particular directions therefore becomes increasingly important in rapidly evolving research environments. This importance extends beyond AI-integrated biotech health technology innovation, as many contemporary scientific challenges increasingly depend on collaborative, interdisciplinary, and technology-intensive forms of research in which expertise is distributed across multiple actors and domains.

Research problem

The growing number of potential opportunities creates a practical challenge. Researchers must decide which directions warrant continued investment despite uncertainty regarding their potential value. Research projects compete for limited time, expertise, funding, and infrastructure. Decisions must be made about where resources should be allocated and which directions should receive less attention. Such decisions are difficult because the value of a research direction can only be assessed fully after considerable time and resources have already been committed (Courtney et al., 1997; Gertner, 2006).

Comparing competing research opportunities is therefore challenging. Researchers depend on available evidence when comparing alternatives, yet that evidence is often incomplete or difficult to interpret (Dirnagl et al., 2022). In many cases, decisions must be made before it is possible to know whether a project will produce useful knowledge, practical applications, or meaningful impact. Comparing alternatives therefore involves more than assessing existing results. It also requires making judgements about uncertain anticipated outcomes.

This challenge is particularly evident in contemporary biomedical and health technology innovation, where researchers often face a growing number of potential innovation pathways while possessing limited certainty regarding their future scientific, translational, and practical value. New technological capabilities continually create additional research directions while making it harder to determine which deserve further commitment. Decisions between competing projects often need to be made before enough evidence exists to justify one choice conclusively. Questions about feasibility and future development remain unresolved at the point where decisions must be made. Decisions about future research priorities therefore rely heavily on how researchers evaluate alternatives under conditions of uncertainty.

Research gap

Existing literature provides substantial insight into this context. Research has shown that AI-integrated biomedical innovation takes place in environments characterised by complexity and rapid technological change. Previous studies explain why uncertainty emerges and why evaluating research directions can be challenging when evidence remains incomplete (Borck & Lohse, 2026; Courtney et al., 1997; Lohse, 2023).

The literature also demonstrates that important decisions must often be made before uncertainty can be resolved. Researchers regularly commit resources to projects without knowing whether the chosen direction will ultimately prove valuable. Decisions about research priorities and technological approaches cannot simply be postponed until more information becomes available.

Despite these contributions, current understanding remains incomplete. Existing research has focused primarily on the sources and consequences of uncertainty. Comparatively less attention has been devoted to the process through which researchers assess competing opportunities and set future research priorities. We know why uncertainty exists and why decisions are difficult, but we know considerably less about how researchers compare alternative directions and incorporate uncertainty into those assessments.

As a result, current literature provides limited insight into the evaluative processes through which researchers determine whether uncertain opportunities are sufficiently attractive to justify continued investment. This limitation appears particularly relevant in AI-integrated biotech health technology innovation. The field is developing rapidly, new research directions emerge continuously, and important decisions often need to be made before their potential value can be established. More specifically, understanding how researchers become able to develop sufficient confidence to commit to particular research directions despite ongoing uncertainty may provide important insight into how emerging research trajectories are shaped.

Research objective and research question

The present study addresses this research gap by examining how researchers evaluate alternative research opportunities, navigate uncertainty, and become able to commit to future directions despite incomplete knowledge. Particular attention is given to the processes through which opportunities become worthy of continued investment under conditions of persistent uncertainty. Accordingly, the study is guided by the following research question:

How do researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation?

This question is addressed through three subquestions:

- 1. What types of uncertainty do researchers encounter when determining future research directions?*
- 2. How do researchers evaluate alternative research opportunities under conditions of uncertainty?*
- 3. What strategies do researchers use to navigate uncertainty when making research-direction decisions?*

The central concern of this thesis is how researchers evaluate opportunities and determine future research directions in environments characterised by rapid technological change, expanding opportunity spaces, distributed expertise, and persistent uncertainty. More specifically, it examines how researchers become able to commit to particular directions despite persistent uncertainty and explores the processes through which opportunities become sufficiently assessable, credible, and worthwhile to warrant continued investment despite unresolved uncertainty. While the study was conducted within an AI-integrated biotech health technology innovation context, AI serves primarily as a contextual condition rather than the primary object of investigation. The focus therefore lies not on how AI is adopted or implemented, but on how researchers evaluate opportunities and navigate uncertainty within such environments.

To establish the foundation for addressing this question, the following chapter reviews literature on biomedical innovation, uncertainty, opportunity evaluation, and research-direction decisions before introducing the theoretical framework and research gap that guide the present study.

2. Literature review

This chapter reviews literature relevant to understanding how uncertainty shapes research-direction decisions in AI-integrated biomedical innovation. The review is organised into three themes. The first theme examines the characteristics of AI-integrated biomedical innovation as a complex research environment (Section 2.1). The second theme explores the sources and consequences of uncertainty within this environment and their implications for the evaluation of future research opportunities (Section 2.2). The third theme examines how research-direction decisions are made under conditions of uncertainty (Section 2.3). Together, these themes establish the foundation for identifying the research gap and developing the research question addressed in this study. Figure 1 provides an overview of the conceptual progression of the literature review. Before arriving at the research gap, the chapter introduces the NASSS framework and anticipatory uncertainty as theoretical lenses that help interpret the complexity and uncertainty surrounding research-direction decisions (Section 2.4).

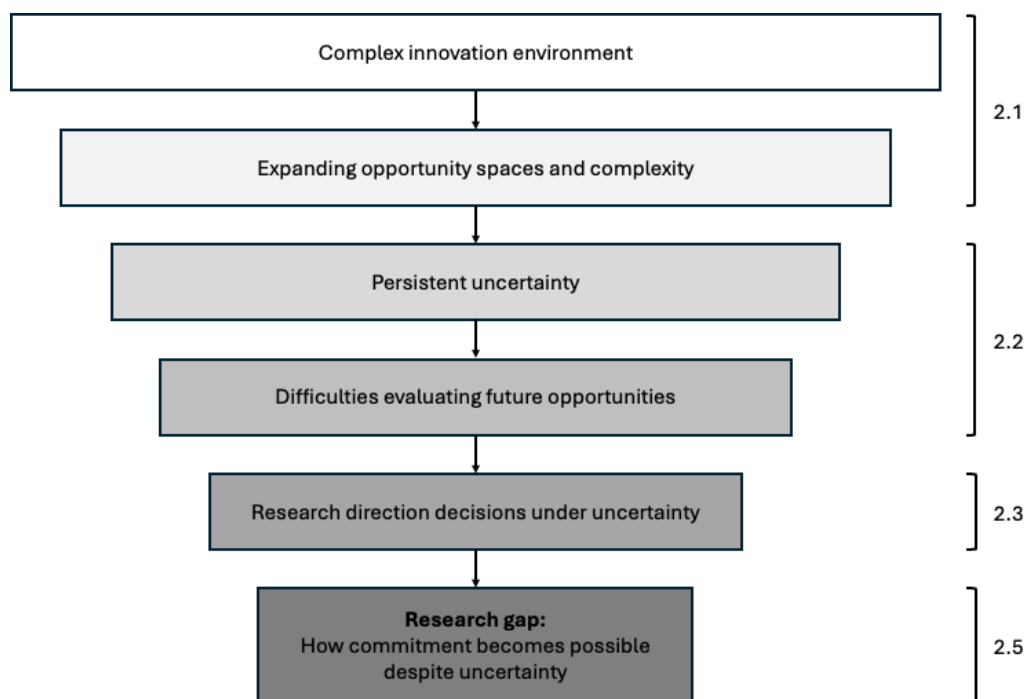


Figure 1. Conceptual structure of the literature review and progression toward the research gap.

2.1 Biomedical innovation as a complex research environment

This theme introduces the broader context in which biomedical innovation occurs. Contemporary healthcare is undergoing a transition towards increasingly personalised and data-driven approaches to prevention, diagnosis, and treatment. Persistent challenges associated with disease heterogeneity, variation in treatment response, and the limitations of generalized healthcare approaches have intensified interest in precision medicine (Johnson et al., 2021; Papadimitriou et al., 2026; Zhu et al., 2024). Precision medicine seeks to account for the biological differences between individuals by drawing upon increasingly detailed forms of genetic, molecular, and clinical information. As a result, healthcare innovation is becoming more reliant on the generation and interpretation of complex forms of biomedical knowledge. Advances in biotechnology have played a central role in this transformation. New methods enable researchers to investigate disease mechanisms and treatment responses at increasingly detailed levels, generating large quantities of biological and health-related data (Doke-Bagade & Bagade, 2024). Consequently, the challenge facing researchers is no longer limited to generating new knowledge. It increasingly involves understanding how diverse forms of

information can be combined to produce meaningful scientific and clinical value. Biomedical innovation therefore takes place within environments characterised by growing informational complexity and expanding technological possibilities.

Within this context, AI has emerged as an increasingly important analytical capability. AI enables researchers to identify patterns, relationships, and signals within large and heterogeneous datasets that are difficult to assess using conventional approaches (Gong et al., 2025; Holzinger et al., 2023; Secinaro et al., 2021). Through the integration of genomic information, clinical records, behavioural data, and other patient-specific information, AI contributes to the development of increasingly personalised forms of medicine (Gong et al., 2025; Johnson et al., 2021). At the same time, AI expands the range of scientific and technological opportunities available to researchers by enabling new forms of data analysis, prediction, and biological discovery.

However, the significance of AI extends beyond its technical capabilities. The integration of AI into biomedical research contributes to broader changes in the research environment itself. Biomedical innovation increasingly depends on interactions between biological systems, computational methods, clinical practice, and large-scale data infrastructures (Holzinger et al., 2023; Niazi & Mariam, 2025; Zhu et al., 2024). Researchers must therefore not only generate knowledge, but also evaluate competing approaches, integrate diverse forms of expertise, and assess the implications of rapidly evolving technologies. As a result, complexity emerges not from AI or biology independently, but from the interaction of multiple technological, organisational, and scientific domains.

These developments have strengthened the importance of interdisciplinary and collaborative research. Progress increasingly depends on expertise distributed across fields such as biotechnology, bioinformatics, machine learning, systems biology, and clinical research (Gong et al., 2025; Zhu et al., 2024). Knowledge is therefore rarely contained within a single discipline or individual researcher. Instead, expertise is distributed across multiple actors who must work together to assess opportunities, interpret evidence, and pursue future directions. The increasing complexity of healthcare innovation has consequently contributed to broader shifts towards collaborative and multidisciplinary forms of scientific research.

At the same time, technological developments in biomedical innovation continue to expand the range of opportunities available to researchers. New methods and scientific possibilities continually emerge, creating multiple potential trajectories for future investigation. Yet these same developments also make future directions increasingly difficult to evaluate with confidence. Available evidence is often incomplete, technologies continue to evolve, future applications remain uncertain, and the implications of emerging innovations may not become visible until much later stages of development. Researchers therefore operate within environments characterised not only by expanding opportunities, but also by increasing complexity and uncertainty.

Taken together, the literature portrays biomedical innovation as a complex and evolving research environment in which opportunities emerge more quickly than they can be fully evaluated. Researchers are therefore required to assess possible future directions despite uncertainty regarding their eventual scientific, translational, and practical value. As a result, research-direction decisions frequently need to be made before sufficient evidence exists to establish certainty regarding future outcomes. Understanding how such decisions become possible under conditions of persistent uncertainty provides the foundation for the remainder of this chapter.

2.2 Sources and consequences of uncertainty in biomedical research

This theme explains why uncertainty is a persistent feature of AI-integrated biomedical innovation and how it constrains the evaluation of future research opportunities. Rather than arising from a single source, uncertainty emerges through incomplete knowledge, limitations in available evidence, challenges in translating discoveries into practice, and the evolving nature of emerging technologies. Collectively, these conditions make it difficult to assess the future scientific, clinical, and practical value of potential research directions. As a result, researchers must compare opportunities using information whose reliability and predictive significance remain uncertain. The discussion begins by examining how incomplete knowledge is embedded within biomedical research itself.

2.2.1 Incomplete knowledge in biomedical research

Biomedical research operates under conditions of incomplete knowledge because the biological systems under investigation are characterised by levels of complexity that cannot be fully understood or predicted with confidence. Diseases emerge through interactions between genetic, molecular, physiological, and environmental factors. Advances in precision medicine continue to uncover additional layers of complexity rather than providing a complete understanding of these relationships. As a result, uncertainty extends beyond isolated gaps in information. Existing knowledge remains provisional because researchers continue to face uncertainty regarding causal mechanisms, the significance of biomarkers, and the clinical relevance of findings. Researchers also remain uncertain about how observed biological phenomena relate to future outcomes (Lohse, 2023).

Furthermore, the evidence base is not static. New discoveries frequently lead researchers to revise existing interpretations and classifications. They may also reveal previously unrecognised factors that influence understanding of disease processes. In this sense, scientific progress does not necessarily reduce uncertainty in a linear manner (Borck & Lohse, 2026). While Lohse (2023) conceptualises uncertainty as a multidimensional and persistent feature arising from the complexity of precision medicine, Borck and Lohse (2026) extend this argument by suggesting that knowledge production itself can generate new uncertainty. As understanding expands, researchers may encounter additional complexity, previously unrecognised interactions, and limitations in existing evidence structures.

Viewed together, these perspectives challenge the assumption that accumulating more data will inevitably lead to greater certainty. Instead, increasing knowledge can simultaneously improve understanding while exposing new unknowns (Borck & Lohse, 2026; Lohse, 2023). Researchers therefore operate in environments where scientific understanding remains subject to revision. Rather than moving steadily toward certainty, scientific progress often reveals additional layers of complexity and raises new questions. Uncertainty is therefore embedded within the process of biomedical knowledge production itself.

2.2.2 Evidence limitations and interpretation challenges

Biomedical evidence is often difficult to interpret because no single form of evidence provides a complete indication of future success. Instead, researchers must draw upon findings generated across multiple stages of innovation. Evidence may originate from laboratory studies, preclinical models, clinical research, computational approaches, or digital health technologies. However, these sources differ in their methods and standards of validation. Consequently, researchers rarely encounter a single, coherent evidence base that clearly establishes the reliability and significance of observed findings. Instead, they must integrate fragmented findings while simultaneously assessing whether the available evidence is sufficiently reliable to support scientific conclusions. A further challenge is that apparently strong evidence may later prove misleading. Findings may be affected by reproducibility problems, publication bias,

weaknesses in underlying models, or limited translational relevance. As a result, findings that initially appear scientifically valuable may fail to reproduce or generate meaningful clinical outcomes when development progresses beyond the research setting (Dirnagl et al., 2022).

At the same time, the growing integration of digital technologies introduces additional challenges for interpreting evidence. Large volumes of data can now be generated from digital systems and AI-enabled tools, but differences in data quality, technological maturity, and the standards used to evaluate findings make meaningful comparison difficult (Mumtaz et al., 2023). Uncertainty therefore persists not because evidence is absent, but because available evidence may be inconsistent, difficult to interpret, or insufficiently predictive of future outcomes.

While Dirnagl et al. (2022) emphasize the reliability and predictive validity of biomedical evidence, Mumtaz et al. (2023) focus on the challenges of evaluating and comparing evidence generated through digital health systems. These findings imply that the central problem is not simply a lack of evidence, but uncertainty regarding which evidence is trustworthy, relevant, and predictive of future value. Consequently, uncertainty persists because the reliability and significance of available evidence cannot always be established with confidence. Researchers must therefore integrate evidence whose meaning and reliability remain contested.

2.2.3 Translation uncertainty

Translation introduces an additional layer of uncertainty because promising scientific findings do not necessarily lead to meaningful clinical impact. In biomedical innovation, evidence generated during discovery provides only a partial indication of future value. Many apparently promising biomarkers, therapeutic targets, AI models, and preclinical findings fail to remain useful when confronted with the realities of clinical practice. This uncertainty emerges because biological mechanisms are often incompletely understood, biomarkers may not accurately represent disease processes, and findings that perform well in controlled experimental settings do not always generalize across heterogeneous patient populations. As a result, strong scientific evidence does not guarantee that a research trajectory will ultimately improve patient outcomes (Seyhan & Carini, 2019).

However, uncertainty does not end once clinical relevance has been established. The pathway from discovery to impact involves a series of transitions, including validation, implementation, and adoption, each introducing new opportunities for failure. In AI-integrated health technologies, innovations must not only demonstrate clinical value. They must also satisfy demanding validation requirements, achieve regulatory acceptance, and fit within existing healthcare practices. Consequently, technologies that appear scientifically promising may still fail to influence patient care because they cannot successfully navigate implementation processes or gain acceptance within healthcare systems (Olaye & Seixas, 2023).

A useful distinction therefore emerges between the two perspectives in the literature. Seyhan and Carini (2019) primarily highlight uncertainty surrounding whether discoveries are genuinely clinically meaningful, whereas Olaye and Seixas (2023) emphasize uncertainty surrounding whether clinically valuable innovations can be successfully translated into practice. The evidence therefore points to translation uncertainty originating from both scientific and implementation challenges. Clinical impact depends not only on whether a discovery works, but also on whether it can survive successive stages of validation, integration, and adoption. Translation uncertainty therefore stems from the fact that scientific promise and real-world impact are separated by multiple stages of innovation implementation. Whether a discovery ultimately generates meaningful clinical value often remains unknowable at the point where early research decisions are made.

2.2.4 Technological uncertainty

Emerging technologies introduce additional uncertainty because both technological capabilities and the systems used to evaluate them are still evolving. In biotechnology, this challenge is no longer limited to missing knowledge about biological mechanisms or treatment outcomes. As technologies become more complex, they increasingly involve interactions between biological, computational, and clinical systems. This makes it difficult for researchers to anticipate downstream effects, long-term consequences, and how technologies may behave outside controlled research environments. Complexity therefore makes it difficult to predict what a technology will ultimately do and how its future scientific or clinical value should be understood (Bouchaut et al., 2022). At the same time, the rapid emergence of AI-integrated technologies has exposed limitations in existing assessment approaches, which often struggle to keep pace with novel technological developments (Bouchaut et al., 2022; Olaye & Seixas, 2023). AI integration therefore introduces additional challenges alongside existing scientific and translational uncertainties because ambiguity arises not only from the technology itself, but also from the frameworks used to evaluate it.

This challenge becomes particularly pronounced in AI-enabled health technologies. Beyond questions of technical performance, researchers must contend with uncertainty regarding explainability requirements, validation strategies, and acceptable forms of evidence. They must also balance predictive accuracy against interpretability (Olaye & Seixas, 2023). As a result, it is often unclear what characteristics define a successful innovation or which forms of evidence will satisfy future evaluators, regulators, clinicians, and healthcare organizations. While Bouchaut et al. (2022) primarily locate uncertainty in the complexity of emerging technologies and the difficulty of predicting their future consequences, Olaye and Seixas (2023) locate uncertainty in the evolving standards used to assess and judge AI systems. These perspectives are complementary rather than contradictory. Together, they indicate that emerging technologies create uncertainty at two levels: uncertainty about future outcomes and uncertainty about the criteria used to evaluate those outcomes. In this sense, uncertainty arises not only because future consequences remain difficult to anticipate, but also because the standards through which future technologies will be judged continue to evolve.

2.2.5 Opportunity evaluation under uncertainty

Evaluating and selecting future research directions is a fundamental challenge in biomedical innovation because researchers must make judgements about scientific, translational, and practical value in the longer term before relevant outcomes can be observed. Research opportunities are typically assessed using indicators of future potential, including preclinical findings, disease models, omics datasets, and existing evidence frameworks. However, the predictive significance of these indicators frequently remains uncertain. Consequently, researchers must evaluate alternative opportunities using information that provides only a partial indication of future success.

Several forms of uncertainty discussed in the preceding sections contribute to this challenge. Available evidence may be incomplete, difficult to interpret, or insufficiently predictive of future outcomes (Dirnagl et al., 2022). Opportunities are often evaluated long before their scientific, clinical, or practical value can be established (Seyhan & Carini, 2019). As a result, researchers must assess anticipated value under conditions where important aspects of future success remain only partially knowable.

Technological developments further complicate evaluation. Advances in genomics, biomarker discovery, AI, and computational modelling have produced unprecedented quantities of information, shifting the challenge from data generation to data interpretation. Researchers increasingly face uncertainty regarding which biomarkers are meaningful, which AI outputs are trustworthy, and which observed patterns are likely to translate into clinically relevant

outcomes. Consequently, distinguishing between stronger and weaker opportunities becomes difficult when the significance of the indicators used for evaluation remains unclear.

Scientific progress may further complicate evaluation rather than resolve it. While improved methods can strengthen assessment, expanding knowledge may also reveal additional complexity and limitations in existing evidence frameworks (Borck & Lohse, 2026). Uncertainty therefore affects both the evidence available for evaluation and the criteria through which opportunities are judged.

Despite these difficulties, research-direction decisions cannot be postponed until uncertainty has been resolved. Researchers must still compare alternatives, prioritise opportunities, and commit resources despite lacking certainty regarding future outcomes. As Fochler and Sigl (2018) suggest, future productivity and success remain uncertain when research choices are required, meaning that evaluation necessarily precedes outcomes rather than follows them. Consequently, uncertainty constrains not only the assessment of individual opportunities but also the selection of future research directions.

Collectively, the literature suggests that uncertainty does not prevent research-direction decisions, but fundamentally shapes the conditions under which they are made (Borck & Lohse, 2026; Dirnagl et al., 2022; Fochler & Sigl, 2018; Seyhan & Carini, 2019). Researchers must evaluate opportunities and commit resources before future outcomes can be known with certainty. While existing literature provides important explanations for why uncertainty complicates such decisions, less is known about how researchers determine that a particular direction warrants continued investment despite unresolved uncertainty.

2.3 Research-direction decisions under conditions of uncertainty

The literature suggests that selecting a research direction is not simply a matter of choosing among available options, but a process of evaluating and committing to alternative trajectories under conditions of uncertainty. Researchers must determine which opportunities warrant continued investment despite incomplete knowledge regarding their eventual outcomes. Although existing research explains why uncertainty complicates these decisions, less is known about how researchers become able to commit to particular directions before future outcomes can be known. This challenge is particularly pronounced during early-stage innovation, where future success depends on conditions that are not yet observable but decisions nevertheless must be made. As a result, researchers must balance competing constraints, expectations, and feasibility considerations while acting without certainty regarding future outcomes. Understanding this relationship between evaluation, uncertainty, and commitment is essential for examining how research-direction decisions occur in AI-integrated biomedical innovation.

2.3.1 Evaluating alternative research directions

Research-direction decisions arise when multiple courses of action are available, but limited resources such as time, funding, expertise, and laboratory capacity prevent all options from being pursued simultaneously. Consequently, selecting a research direction requires evaluating alternative trajectories before resources are committed to one path over another. Decision-making is therefore not simply an act of choosing. It is a process of comparing alternatives and assessing their expected value. This evaluation is inherently future-oriented because the value of a particular option depends not on its present state, but on the outcomes it may produce in the future. Alternative strategies, projects, and research trajectories are therefore assessed according to their anticipated consequences rather than their realised outcomes (Courtney et al., 1997).

Consequently, alternatives must be assessed before it is known whether they will ultimately prove productive or successful. Evaluation therefore cannot rely on certainty, but instead depends on expectations and judgements about possible futures (Courtney et al., 1997). The

literature suggests that the quality of a decision depends not on knowledge of future outcomes, but on how alternative possibilities are assessed before those outcomes materialise.

In research settings, the alternatives under consideration are often competing research trajectories. Because future outcomes cannot yet be observed, researchers rely on indicators such as expected productivity, publication opportunities, and funding prospects when assessing which direction appears most promising (Fochler & Sigl, 2018). Evaluation therefore functions as the mechanism through which researchers distinguish among competing trajectories before resources are committed. However, existing literature provides less insight into how such assessments become sufficiently convincing to support commitment to a particular direction when important uncertainties remain unresolved. Consequently, research-direction selection depends on how researchers evaluate uncertain future possibilities before outcomes become known (Courtney et al., 1997; Fochler & Sigl, 2018).

2.3.2 Evaluating in early-stage innovation

Evaluating future research directions is particularly difficult during early-stage health technology innovation because the outcomes that determine whether a research trajectory will ultimately be successful cannot yet be observed. During this stage, knowledge develops incrementally and understandings of clinical needs, potential solutions, and development pathways continue to evolve. Rather than following a fixed sequence of steps, innovation progresses through ongoing reassessment of assumptions and emerging findings. As a result, researchers are often required to evaluate potential trajectories before the underlying problem, proposed solution, or feasibility of an approach has been fully established (Gertner, 2006).

This challenge is further intensified because several potential directions may appear promising at the same time, while limited evidence is available to distinguish between them. However, uncertainty extends beyond the innovation itself. Gertner (2006) focuses on uncertainty surrounding needs, solutions, and feasibility, whereas Dutta and Dhar (2024) show that eventual success also depends on conditions that emerge later in the innovation process. These include validation, regulatory approval, resource availability, stakeholder adoption, and implementation within healthcare systems. Consequently, evaluating a research direction involves more than assessing its scientific promise. Researchers must also consider whether an innovation is likely to prove viable despite having limited information about the conditions under which implementation may eventually occur (Dutta & Dhar, 2024).

The importance of considering future development and implementation conditions is also reflected in research on front-end innovation and front-loading. Front-loading perspectives suggest that early decisions can strongly influence the future trajectory of an innovation by shaping which opportunities receive continued attention, resources, and development effort (Thomke & Fujimoto, 2000; Trotter, 2011). From this perspective, research-direction decisions are important not only because they guide ongoing research activities, but also because they influence which opportunities remain viable for future development, implementation, and value creation. Early evaluation therefore serves not only to select among current alternatives, but also to shape which opportunities receive continued investment and development attention. As a result, choices made during early stages of innovation can have significant implications for future innovation trajectories.

Despite the importance of these early decisions, existing literature also suggests that evaluating research directions remains inherently difficult because uncertainty exists at multiple levels simultaneously. Researchers are uncertain not only about which pathway is most appropriate, but also whether that pathway can ultimately achieve scientific, clinical, regulatory, or implementation success. Many of the factors that determine eventual outcomes remain unknown during early-stage innovation.

Yet the need to evaluate alternatives does not disappear because of these limitations. Researchers must compare opportunities while balancing scientific promise, feasibility, and future implementation considerations despite possessing only partial knowledge of each. Even when opportunities have been evaluated across these dimensions, important uncertainties remain. Existing literature nevertheless suggests that researchers frequently need to commit resources and effort despite unresolved uncertainty. The literature therefore leaves open the question of how researchers ultimately become able to commit to one direction over competing alternatives when the future value, feasibility, and impact of those alternatives remain uncertain. Put differently, it remains unclear how researchers become sufficiently convinced that a particular direction warrants continued investment despite unresolved uncertainty. While research on uncertainty explains why action remains necessary and why evaluation is future-oriented, less attention has been devoted to understanding how researchers develop sufficient confidence to continue investing in particular directions despite important uncertainties remaining unresolved. While existing literature explains why commitment remains necessary, it offers less insight into how commitment becomes possible under such conditions.

2.3.3 Acting under uncertainty

Researchers rarely have the luxury of selecting a research direction after uncertainty has been resolved. The central challenge is therefore not the existence of uncertainty itself, but the need to continue acting despite it (Fochler & Sigl, 2018; Javanmardi et al., 2024). Fochler and Sigl (2018) observe that researchers often commit effort and resources despite uncertainty regarding future productivity. Similarly, Courtney et al. (1997) argue that innovative environments contain multiple plausible futures, meaning that important uncertainties persist even when substantial analysis has been undertaken. In health technology innovation, this situation is further intensified by the coexistence of technological, regulatory, financial, market, and ecosystem uncertainties that continuously reshape the environment in which research decisions are made (Javanmardi et al., 2024).

Nevertheless, uncertainty does not eliminate the need for action. Researchers operate within funding cycles, publication expectations, project timelines, and organisational requirements that require continued commitment to research activities (Fochler & Sigl, 2018). Waiting for certainty may result in missed opportunities, particularly when scientific and technological possibilities continue to evolve (Courtney et al., 1997; Javanmardi et al., 2024). Consequently, progress depends less on eliminating uncertainty and more on adapting to it. Previous research highlights practices such as balancing projects with different risk profiles, maintaining flexibility, and revising commitments as circumstances evolve (Fochler & Sigl, 2018). More broadly, uncertainty literature highlights the importance of flexibility, incremental commitments, continual learning, and ongoing adjustment as conditions evolve.

As a result, research-direction selection becomes iterative and provisional rather than a search for a single optimal choice. Researchers often operate across multiple possible futures simultaneously and continuously reassess which directions deserve further investment (Courtney et al., 1997; Javanmardi et al., 2024). Existing literature suggests that researchers frequently need to make commitments before uncertainty has been resolved. Strategic decision-making, innovation-management, and anticipatory uncertainty research therefore explain why evaluation remains necessary and why future-oriented judgement is unavoidable. However, they provide less insight into how researchers develop sufficient confidence to continue investing in particular directions despite important unknowns remaining unresolved. While existing work explains why commitment remains necessary, it offers less understanding of how uncertain opportunities become sufficiently convincing, credible, and worthwhile to justify continued investment.

2.3.4 Constraints, stakeholders and feasibility

Research-direction selection depends on more than scientific merit or technical opportunity. Researchers must also consider whether a direction appears feasible within existing organisational, resource, and stakeholder constraints. Rather than selecting the most scientifically interesting option, researchers often need to determine which direction appears feasible enough to justify continued investment. This is particularly evident in academic research environments, where decisions are shaped not only by the possibility of generating new knowledge, but also by publication expectations, funding cycles, career progression, and project timelines. Under such conditions, the evaluation of a potential direction becomes intertwined with judgements about productivity, risk, and feasibility rather than scientific merit alone (Fochler & Sigl, 2018).

At the same time, research priorities are not determined exclusively within research groups. In digital health and medical technology contexts, research directions emerge through interactions among multiple stakeholders whose interests extend beyond knowledge creation. Multiple stakeholders influence which directions are perceived as meaningful and worthy of support, including clinicians, funders, regulators, and implementation partners. Consequently, a direction that appears scientifically promising may receive lower priority if it does not align with stakeholder needs, implementation requirements, governance structures, or organisational objectives. This broadens evaluation from a purely scientific assessment to a negotiation between scientific opportunity and practical relevance (Bamgboje-Ayodele et al., 2023; Dutta & Dhar, 2024).

Across these perspectives, feasibility emerges as a key mechanism through which potential directions are evaluated and filtered. Available expertise, funding, data access, organisational capabilities, and stakeholder support shape which directions appear achievable. Feasibility therefore functions not simply as a constraint on action, but as a criterion through which alternatives are judged before resources are committed.

This can create tensions between directions that maximise academic productivity and those that maximise implementation value. While Fochler and Sigl (2018) emphasize how researchers choose among competing possibilities under institutional pressures, Dutta and Dhar (2024) highlight how organisational and regulatory constraints can remove alternatives before meaningful choice occurs.

These perspectives suggest that research-direction selection is a multidimensional judgement in which scientific value, stakeholder relevance, resource constraints, and anticipated impact must be balanced against considerations of feasibility. Researchers therefore face the challenge of evaluating uncertain future directions while simultaneously managing competing demands and constraints.

Taken together, the literature reviewed in Sections 2.1 to 2.3 suggests that research-direction decisions occur within complex and rapidly evolving innovation environments characterised by persistent uncertainty. Researchers must evaluate alternative opportunities, compare competing trajectories, and commit resources despite incomplete knowledge regarding future outcomes. These decisions are shaped not only by scientific considerations, but also by feasibility constraints, stakeholder interests, and expectations regarding future value. Although existing literature explains why uncertainty complicates research-direction decisions and highlights many of the factors influencing them, the processes through which researchers evaluate alternatives and navigate uncertainty remain less clearly understood.

2.4 Research framework

The preceding literature review highlighted that biomedical innovation occurs within environments characterised by complexity, uncertainty, and rapid technological change. Researchers must evaluate opportunities and determine future directions despite limited certainty regarding their eventual scientific, societal, or clinical value. To examine these conditions, this study draws on two theoretical lenses: the NASSS framework ((Greenhalgh & Abimbola, 2019) and the concept of anticipatory uncertainty (Fochler & Sigl, 2018). These lenses provide concepts for understanding the sources of uncertainty and the conditions under which research opportunities are evaluated. They are not applied as explanatory models of research-direction decisions, but as sensitising concepts that support interpretation of the empirical material.

2.4.1 NASSS as a complexity lens

The NASSS (Non-adoption, Abandonment, Scale-up, Spread, and Sustainability) framework was developed to understand the challenges surrounding technology-enabled innovation in healthcare settings. Central to the framework is the notion that technological innovation occurs within complex systems rather than in isolation. Complexity arises through interactions between technologies, stakeholders, organizations, institutions, and broader contextual conditions that continuously evolve over time (Greenhalgh & Abimbola, 2019).

Although NASSS was originally developed to examine adoption, implementation, and sustainability challenges in healthcare innovation, many of the factors that later shape implementation outcomes are already present during earlier research and development stages. Research on front-end innovation and front-loading similarly suggests that decisions made during early phases can strongly influence subsequent development and implementation outcomes because technological trajectories, resource allocations, and value-creation possibilities are shaped long before eventual outcomes become observable (Thomke & Fujimoto, 2000; Trotter, 2011). Researchers therefore evaluate future directions not only in terms of current scientific merit, but also in anticipation of future issues relating to value creation, stakeholder acceptance, organisational fit, evidence requirements, and adoption. From this perspective, NASSS provides a useful lens for understanding the broader innovation environment within which research-direction decisions are made.

This connection makes NASSS relevant to the present study. The framework highlights how technological characteristics, stakeholder interests, organisational conditions, value considerations, and wider institutional environments shape innovation processes. Several NASSS domains therefore provide useful concepts for understanding the context within which research-direction decisions occur. The technology domain draws attention to the characteristics and capabilities of emerging technologies. The value proposition domain highlights questions regarding feasibility and future value creation. The adopter system, organisational, and wider system domains emphasise the roles of stakeholders, institutional priorities, expertise, funding arrangements, and broader regulatory environments. Rather than representing separate influences, NASSS conceptualises these domains as interacting elements of a larger system whose relationships may change over time.

For the purposes of this study, NASSS is used primarily as a contextual complexity lens. The framework provides concepts for identifying and interpreting the technological, organisational, stakeholder-related, and institutional conditions surrounding AI-integrated biomedical research. Through this lens, uncertainty is understood as a feature of a broader innovation environment shaped by multiple interacting influences. NASSS therefore helps contextualise research-direction decisions within broader innovation environments characterised by interacting sources of complexity and uncertainty.

2.4.2 Anticipatory uncertainty in research practice

While NASSS draws attention to the context in which uncertainty emerges, it offers less insight into how uncertainty may be experienced and managed by researchers themselves. To address this dimension, the study draws on the concept of anticipatory uncertainty (Fochler & Sigl, 2018).

Fochler and Sigl (2018) define anticipatory uncertainty as uncertainty regarding whether ongoing research activities will prove productive within a particular timeframe and according to expectations of successful performance. The concept emphasizes that researchers are not only uncertain about scientific knowledge itself, but also about whether present research efforts will ultimately generate outcomes considered valuable in the future. As a result, they must make judgements about future possibilities before their eventual value can be established. This makes anticipatory uncertainty particularly relevant for understanding how researchers evaluate alternative opportunities when deciding where future effort and resources should be directed. Research activities are therefore inherently future-oriented, requiring researchers to engage with possibilities whose eventual consequences remain only partially knowable.

A key contribution of this perspective is the distinction between epistemic and social uncertainty. Epistemic uncertainty refers to uncertainty arising from the research process itself, including questions regarding scientific feasibility, evidence quality, technological capabilities, or future outcomes. Social uncertainty refers to uncertainty associated with the broader research environment, such as funding opportunities, stakeholder expectations, organisational support, and institutional priorities (Fochler & Sigl, 2018).

Importantly, these forms of uncertainty are often intertwined in practice. Questions regarding scientific feasibility may simultaneously raise concerns about funding, stakeholder relevance, strategic priorities, or future opportunities. Researchers therefore do not necessarily experience epistemic and social uncertainty as separate categories, but as interconnected aspects of future-oriented research work.

Within the present study, this distinction is treated as a sensitising concept rather than a fixed classification of uncertainty. It provides a useful lens for examining how different forms of uncertainty may become entangled when researchers evaluate opportunities and consider future directions.

2.4.3 Integrating the theoretical lenses

The two theoretical perspectives contribute different but related insights to the study. NASSS provides concepts for understanding where uncertainty originates within complex innovation environments, whereas anticipatory uncertainty provides concepts for understanding how researchers experience and respond to those uncertainties in practice. The theories are not used as an integrated explanatory framework, nor are they employed as a predetermined coding structure. Instead, they serve as sensitizing lenses that help focus attention on complexity, uncertainty, and research practice while remaining open to themes that emerge from the empirical material. Consistent with the exploratory nature of the study, the analytical emphasis remains on understanding participants' perspectives rather than testing theoretical propositions. The framework therefore provides concepts for interpreting interview data without presupposing how researchers evaluate opportunities, navigate uncertainty, or determine future directions. Together, the two lenses allow the study to examine both the complexity of the innovation environment and the uncertainty researchers navigate when evaluating future opportunities. This combination is particularly useful because research-direction decisions occur long before implementation, yet are often shaped by uncertainties that may later influence implementation and adoption outcomes. However, neither lens provides a detailed explanation of how researchers become able to commit to particular research directions despite uncertainty, creating space for the present study.

2.5 Research gap

Existing literature demonstrates that biomedical innovation is characterised by complexity, uncertainty, and rapid technological change. Advances in biotechnology, data-intensive research approaches, and AI-enabled analytical capabilities have expanded the range of potential research opportunities while simultaneously increasing the challenges associated with evaluating and pursuing those opportunities. While substantial attention has been devoted to explaining the sources of uncertainty and the difficulties involved in assessing future opportunities, less is known about how researchers actually determine which opportunities warrant continued pursuit in practice.

Despite these insights, comparatively less attention has been focused on understanding how researchers navigate uncertainty when making research-direction decisions. In particular, limited attention has been paid to how researchers evaluate competing opportunities, interpret different forms of uncertainty, and determine which directions warrant continued commitment when future scientific, clinical, and practical outcomes remain uncertain. This limitation is particularly relevant in biomedical innovation environments where rapidly evolving technologies create multiple potential development pathways while the implications of those pathways remain difficult to assess.

Although NASSS and anticipatory uncertainty provide useful concepts for understanding complexity and uncertainty, neither perspective offers a detailed explanation of how researchers determine that a particular research direction warrants continued pursuit. Existing research explains why uncertainty complicates research-direction decisions, identifies factors that may influence opportunity evaluation, and suggests that commitments often need to be made before uncertainty can be fully resolved. However, it provides limited insight into how researchers become able to justify and sustain such commitments when important uncertainties remain unresolved.

While AI-integrated biotech health technology innovation provides the empirical context for this study, the central phenomenon of interest concerns how researchers evaluate opportunities, interpret uncertainty, and determine which future research directions warrant continued pursuit. To address this gap, the present study examines how researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation. Accordingly, the study is guided by the following research question:

How do researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation?

This question is addressed through the following subquestions:

- 1. What types of uncertainty do researchers encounter when determining future research directions?*
- 2. How do researchers evaluate alternative research opportunities under conditions of uncertainty?*
- 3. What strategies do researchers use to navigate uncertainty when making research-direction decisions?*

Collectively, the study seeks to explain how researchers become able to commit to particular research directions despite persistent uncertainty. In doing so, it aims to provide insight into the processes through which researchers navigate uncertainty and become able to commit to future research directions in complex innovation environments.

3. Methodology

3.1 Research design

This study adopted an exploratory qualitative research design to examine how researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation. Because the study sought to understand participants' experiences, interpretations, and decision-making practices, a qualitative approach was considered appropriate. Data were analysed using reflexive thematic analysis (RTA), an approach that supports the development of interpretive themes from participants' accounts and is well suited to exploring underexamined phenomena (Braun & Clarke, 2008; Braun et al., 2022).

An exploratory design was selected because limited insight exists into how researchers evaluate opportunities and navigate uncertainty in practice when determining future research directions. Consistent with the interpretive objective of the study, RTA was used to identify and interpret patterns of shared meaning across participants' accounts while remaining open to concepts that emerged through engagement with the dataset.

Data were collected through semi-structured interviews with researchers involved in AI-integrated biotech health technology innovation. Semi-structured interviews were selected because they allowed participants to discuss their experiences and decision-making practices in their own words, while ensuring that topics relevant to the research question were addressed consistently across interviews.

3.2 Research context

The study was conducted within a biomedical innovation initiative focused on developing a precision medicine platform technology. The research aimed to create a high-throughput screening method based on stem-cell research, with potential applications in areas such as osteoarthritis and cancer treatment. Development took place within the Dutch academic and healthcare research environment and combined biotechnology with deep-learning methods for analysing complex biological data.

At the time of the study, the underlying technology had not been implemented in healthcare practice, and only a limited number of research groups worldwide were working on comparable technologies or related components. Researchers therefore operated in an environment characterised by technological novelty, limited established knowledge, evolving methods, and uncertain development trajectories.

The research team included participants from different disciplinary backgrounds and levels of seniority. Scientific development, computational modelling, and biological experimentation were closely interconnected throughout the innovation process, requiring collaboration across multiple domains of expertise. These conditions made the setting particularly relevant for examining how researchers evaluate opportunities, navigate uncertainty, and determine future research directions.

While AI formed an important component of the research environment, the focus of the study was not AI itself. Rather, the setting provided a context for investigating research-direction decisions under conditions of uncertainty.

3.3 Data collection

3.3.1 Semi-structured interviews

Data were collected through semi-structured interviews with researchers involved in the development of the precision medicine platform described in Section 3.2. The interviews focused on situations in which participants considered future research directions, assessed competing opportunities, and encountered uncertainty during the research process. A total of eight interviews were conducted to generate detailed accounts of participants' experiences of research-direction decision making under uncertainty.

3.3.2 Interview protocol

A consistent interview guide was used throughout the study while allowing flexibility to explore topics that emerged during the interviews. The protocol was structured around the research question and subquestions (Table 1).

Table 1. An overview of the interview structure.

Interview section	Purpose	Related research question
Background	Understand the participant's research context and role	Context
Uncertainty	Identify uncertainties encountered during research-direction situations	SQ1
Evaluation of alternatives	Explore how alternative research directions were assessed and compared	SQ2
Decision-making and strategies	Examine how participants responded to uncertainty and made decisions	SQ3
Stakeholders and constraints	Identify contextual influences on research-direction decisions	RQ

The full interview protocol is provided in Appendix A.

3.3.3 Conduct of interviews

All interviews were conducted online using Microsoft Teams during a four-week period in June and July 2026. Prior to participation, interviewees received information about the study and provided informed consent. Interviews were conducted in English and audio-recorded with participant permission. Eight interviews were completed. Each interview lasted approximately one hour and began with a brief introduction to the study and an explanation of participation expectations. Audio recordings were transcribed using the Microsoft Teams transcription functionality. The resulting transcripts were subsequently reviewed and corrected by the researcher to address transcription inaccuracies and ensure an accurate representation of participants' responses prior to analysis.

3.4 Sampling

3.4.1 Participant eligibility

Researchers were eligible for participation if they were actively involved in the development of the precision medicine platform described in Section 3.2 and had experience with situations involving uncertainty, the evaluation of alternative research directions, or research-direction decision-making. All participants were directly involved in the development of the technology and therefore possessed knowledge relevant to the research question.

3.4.2 Participant characteristics

A total of eight researchers participated in the study. Participant characteristics are summarised in Table 2, and an overview of participants and their individual expertise is provided in Appendix A.3.

Table 2. Participant characteristics.

Characteristic	Description
Number of participants	8
Career stages	MSc (n=1), PhD (n=4), Post-doctoral (n=1), Senior researcher (n=2)
Areas of expertise	Biotechnology, stem-cell research, computational modelling, bioinformatics, technology translation
Primary research focus	Biomedical (n=4), computational (n=2), translational (n=2)
Gender	Female (n=5), Male (n=3)
Age range	20 - 45 years
Research experience (years)	1 - 20+ years

The participant group represented a diverse range of disciplinary backgrounds, research focuses, and career stages, providing perspectives from biomedical, computational, and translational domains.

3.4.3 Recruitment process

Participants were recruited using a network-based approach. The first two participants were contacted through the professional network of the thesis supervisor because of their direct involvement in the project. Additional participants were subsequently recruited through referrals from earlier interviewees (Figure 2). This approach enabled access to researchers with relevant experience of the research situations under investigation.

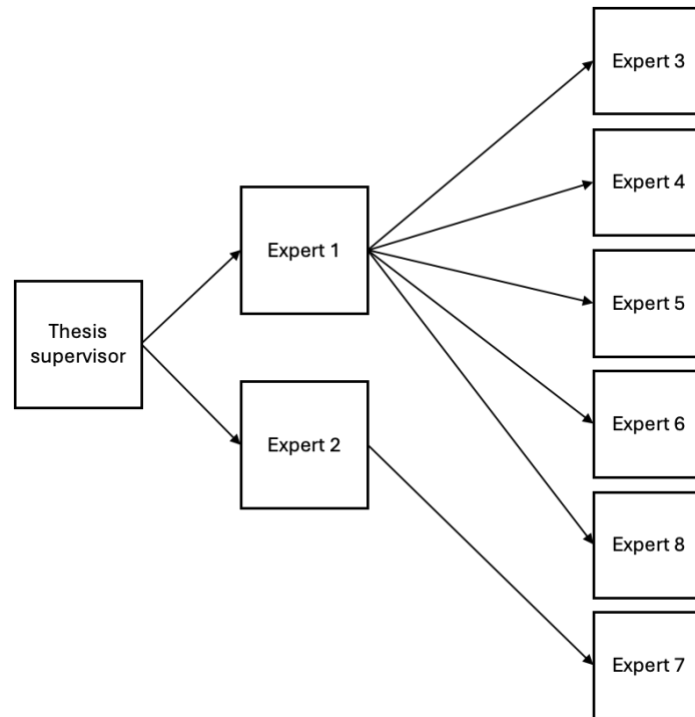


Figure 2. Overview recruitment process through network-based approach.

3.4.4 Sample size

Consistent with RTA, the aim of sampling was not to achieve thematic saturation but to generate a sufficiently rich dataset capable of supporting meaningful interpretive analysis (Braun & Clarke, 2021; Braun et al., 2022). Participants represented different disciplinary backgrounds and career stages. The dataset was considered sufficiently rich because accounts relating to the research questions were distributed across participants and provided adequate depth and variety to support the development of coherent themes capable of addressing the research question.

3.5 Data analysis

As introduced in Section 3.1, the interview data were analysed using RTA. The analysis sought to identify and interpret patterns of shared meaning relating to how researchers evaluate opportunities, navigate uncertainty, and determine future research directions. Consistent with RTA, themes were developed inductively through engagement with the dataset rather than derived from predefined theoretical categories (Braun et al., 2022). Although NASSS and anticipatory uncertainty informed the study as sensitising lenses, coding and theme development were not organised around these concepts. Instead, the findings were interpreted in relation to the literature after themes had been developed. The concepts of collective judgement and confidence construction emerged through this process rather than being specified in advance.

All eight interview transcripts were imported into Microsoft Word and Excel for analysis. Coding was conducted through sustained engagement with the transcripts, with particular

attention given to descriptions of uncertainty, opportunity evaluation, decision-making processes, constraints, and responses to uncertainty. Initial codes were subsequently organised into broader code clusters and iteratively refined into candidate themes. Through repeated movement between coded extracts, the full dataset, and emerging interpretations, themes were reviewed, revised, merged, and redefined until a coherent thematic structure was established. The final three themes were considered sufficiently comprehensive to address the research question.

The researcher's familiarity with biotechnology research facilitated engagement with participants' accounts and understanding of technical terminology. Prior to analysis, it was anticipated that researchers would primarily navigate uncertainty through efforts to reduce it by gathering additional information and evidence. Continued engagement with the dataset suggested instead that participants frequently acted despite uncertainty remaining unresolved. Following theme development, an additional interpretive analysis was conducted to explore relationships between the themes. Particular attention was directed towards understanding how participants became able to continue investing effort and resources in particular directions despite acknowledging substantial uncertainty regarding future outcomes. Rather than considering the themes independently, attention was directed towards how collective judgement, opportunity evaluation, and evidence generation interacted during research-direction decision-making. This cross-theme analysis suggested that these activities collectively contributed to the development of sufficient confidence to pursue particular research directions despite persistent uncertainty. Confidence construction was considered the most coherent explanation of how commitment became possible despite unresolved uncertainty. Consequently, confidence construction was developed as an interpretive concept and subsequently represented within the resulting process model.

Reflective notes were maintained throughout the analytic process to document analytical decisions, emerging interpretations, and the development of codes and themes. These notes supported transparency and reflexive engagement with the research process. Detailed evidence of the analysis is provided in Appendix B, including the thematic structure (Table 4), theme definitions (Table 5), illustrative coding examples (Table 6), and theme development process (Table 7).

3.6 Research quality

Consistent with RTA, quality was supported through methodological coherence, researcher reflexivity, sustained engagement with the dataset, and systematic documentation of analytical decisions. Quality was not assessed through coding reliability, inter-coder agreement, or replication of coding decisions.

Participant quotations are presented throughout Chapter 4 to illustrate the relationship between the empirical material and the interpretations developed through analysis. Quotations were selected not as proof of themes, but as examples demonstrating how the thematic interpretation was grounded in participants' accounts.

The inclusion of researchers from different disciplinary backgrounds and career stages contributed variation in perspectives and experiences, supporting the development of themes that captured different dimensions of opportunity evaluation and uncertainty.

Particular attention was paid to ensuring coherence between the research question, sensitising concepts, data collection methods, analytic approach, and final thematic interpretation. Themes were reviewed in relation to both coded extracts and the dataset as a whole to ensure coherent and distinctive interpretations of the phenomenon under investigation.

Reflexive documentation was maintained throughout the study to support transparency regarding analytical decisions and researcher interpretations.

Several methodological limitations should be acknowledged. First, the study focused on researchers involved in a single innovation project and therefore provides context-specific insights. The aim was not statistical generalisation, but the development of an in-depth understanding of opportunity evaluation and uncertainty within a specific innovation setting.

Second, participants reflected on situations that had already taken place. Their accounts may therefore have been influenced by hindsight bias, whereby past decisions are interpreted in light of information that became available subsequently. To reduce this risk, interviews focused on specific situations and encouraged participants to reconstruct events and decision-making processes step by step.

Third, social desirability bias may have influenced participants' responses. Researchers may have been inclined to present their actions and decisions in a favourable manner or justify previous choices. To mitigate this risk, interview questions focused on challenges, uncertainties, and decision-making processes rather than evaluating whether particular decisions were correct or incorrect.

Finally, confidence construction represents an interpretive concept developed through cross-theme analysis rather than a participant-derived category. Alternative interpretations may therefore be possible. However, confidence construction was considered the most coherent explanation of the relationships observed across the dataset and the way participants continued to commit resources and effort despite persistent uncertainty.

3.7 Ethical considerations

This study involved human participants and was conducted in accordance with the ethical requirements of the Human Research Ethics Committee (HREC) of TU Delft.

Prior to participation, interviewees received information about the purpose of the study, the nature of participation, the data collection procedures, and the intended use of the data. Participation was voluntary, and participants were informed of their right to withdraw from the study at any time. Written informed consent was obtained from all participants before the interviews were conducted.

Interview recordings, transcripts, and related research materials were stored securely in accordance with TU Delft data management procedures. Access to the data was restricted to the researcher and authorised supervisors. Participant information was treated confidentially, and identifying information was removed or anonymised where appropriate in research outputs.

Following transcription, descriptive summaries were shared with participants to provide an opportunity to clarify information, correct factual inaccuracies, and offer additional context where necessary. This process was intended to improve the accuracy of participants' accounts rather than to validate the thematic analysis.

Ethical safeguards relating to informed consent, confidentiality, participant welfare, and data security were maintained throughout the study.

4. Findings

This chapter presents the findings concerning how researchers evaluate opportunities and determine future research directions under conditions of persistent uncertainty. Across interviews, participants consistently described working with unresolved scientific questions, incomplete evidence, evolving technologies, uncertain applications, and practical constraints. Important research-direction decisions were therefore rarely made under conditions of complete knowledge or certainty. Rather than waiting for uncertainty to be resolved, researchers described a range of practices that helped them assess opportunities and determine which directions warranted continued investment despite what remained unknown.

Three interconnected themes explain how this process unfolds. The first theme examines how researchers draw upon distributed expertise to evaluate uncertain opportunities. The second theme explores how opportunities are assessed and compared in the absence of certainty regarding future outcomes. The third theme focuses on the generation and interpretation of evidence as researchers assess whether particular directions remain sufficiently promising to pursue.

While presented separately for analytical purposes, the themes are closely connected and should not be understood as independent processes. Across the dataset, persistent uncertainty formed the overarching condition within which researchers drew upon expertise, evaluated opportunities, and generated evidence. Together, these activities helped researchers determine which opportunities warranted continued investment despite unresolved uncertainty and ultimately contributed to the development of sufficient confidence to pursue particular research directions. This process is later interpreted as confidence construction.

Although this study is situated within an AI-integrated biotech health technology innovation context, participants rarely evaluated AI as a standalone phenomenon. Instead, AI appeared as part of a broader research environment that shaped uncertainty conditions, expertise requirements, opportunity spaces, and evidential practices. The findings therefore focus on the processes through which researchers evaluated and pursued research directions within this context, rather than on AI itself.

Table 3 provides an overview of the three findings themes and their analytical contribution to confidence construction.

Table 3. Overview of the findings themes and their contribution to confidence construction

Theme	Core finding	Contribution to confidence construction
1. Collective judgement through distributed expertise	Researchers draw upon distributed expertise when evaluating opportunities	Broadens evaluative capacity
2. Evaluating future research opportunities under persistent uncertainty	Researchers assess future value, impact and feasibility	Provides reasons for pursuing directions
3. Evidence generation and interpretation under uncertainty	Researchers test, validate and interpret evidence	Provides empirical justification

The chapter first presents the three themes before examining their relationships through a cross-theme analysis. Rather than emerging as a standalone theme, confidence construction was developed as an interpretive concept through analysis of how collective judgement, opportunity evaluation, and evidence generation and interpretation interacted during research-direction decision-making. This confidence-construction process is represented in the process model presented at the end of the chapter.

4.1 Theme 1: collective judgement through distributed expertise

The first theme demonstrates that research-direction decisions were rarely made by isolated individuals. Instead, participants described evaluation processes that relied on distributed sources of knowledge, experience, and expertise. Across interviews, researchers frequently encountered situations in which no single individual possessed sufficient knowledge to independently assess a potential opportunity. This was particularly evident in relation to computational methods, bioinformatics, specialised biological techniques, clinical applications, and emerging technologies. Under these conditions, evaluating future research directions required more than individual expertise. It required access to and coordination of knowledge distributed across supervisors, collaborators, clinicians, consortium partners, and wider research networks.

Rather than treating expertise limitations as barriers to progress, participants typically viewed them as signals that additional expertise was required before meaningful evaluation could occur. Opportunity evaluation therefore appeared closely intertwined with consultation, knowledge exchange, and collaboration. Researchers routinely drew upon expertise distributed across teams and networks when assessing uncertain opportunities. These patterns suggest that research-direction evaluation frequently relied on collectively informed judgements rather than the expertise of individual researchers alone.

Researchers rarely described evaluating opportunities solely on the basis of their own expertise. Instead, they actively sought, mobilised, and coordinated expertise whenever existing knowledge was insufficient for evaluating a potential research direction. Across interviews, expertise limitations were presented as a normal feature of research rather than a deficiency. Participants frequently encountered areas of uncertainty in which they lacked the necessary knowledge to independently assess the implications of a particular opportunity. In these situations, evaluation became dependent on accessing knowledge and experience located elsewhere within research networks.

One common response was to actively seek expertise from multiple sources. Participants described consulting supervisors, colleagues, external collaborators, and specialists to broaden the knowledge available for evaluation. As one participant explained:

“I can be asking my supervisor or my colleagues, or even sometimes colleagues that don't work on it because it's good to also talk with people outside the field.” (P5_065, computational researcher).

This quotation illustrates that expertise seeking was not limited to obtaining technical information. Researchers deliberately exposed ideas to individuals possessing different perspectives and forms of knowledge. Expertise therefore functioned as an evaluative resource. By broadening the range of perspectives involved in assessing an opportunity, researchers increased their ability to judge whether a direction was worth pursuing despite uncertainty. However, expertise mobilisation did not always involve acquiring entirely new knowledge. Researchers also relied heavily on expertise already embedded within existing teams, departments, and research networks. Existing capabilities often shaped which opportunities appeared credible. One participant explained:

“It's an area of application that I also feel more comfortable applying... I can immediately contribute more.” (P8_048, computational researcher).

This illustrates how existing expertise influenced opportunity evaluation. Rather than beginning from a blank slate, researchers frequently assessed opportunities through the lens of prior experience and established knowledge. As a result, opportunities aligned with available

capabilities often appeared more feasible and easier to justify than those requiring entirely new forms of expertise.

Expertise seeking and reliance on existing expertise should therefore not be understood as competing strategies. Instead, they represent complementary approaches through which researchers navigate uncertainty and evaluate potential research directions. Researchers either expanded their networks when knowledge was missing or drew upon expertise already available within existing relationships. In both cases, the objective was to obtain sufficient knowledge to support evaluation.

Importantly, expertise was not simply accessed; it also had to be coordinated. Participants repeatedly described the importance of bringing together different forms of expertise around shared problems. Expertise in biology, computational science, clinical practice, platform development, and data analysis frequently had to be combined before opportunities could be meaningfully assessed. This coordination process transformed expertise from an individual resource into a collective evaluative capability.

The complexity of this process is reflected in examples where expertise mobilisation occurred through much narrower channels. A participant noted:

“It was really just my supervisor... I didn't have conversations with anybody else.” (P7_046, technology translation researcher).

This account introduces an important nuance. Although distributed expertise was a dominant pattern across the dataset, expertise mobilisation did not always involve large collaborative networks. In some contexts, researchers relied heavily on a single trusted expert. Rather than contradicting the broader pattern, this variation suggests that collective judgement can take multiple forms. What matters is not the number of people involved, but whether evaluation draws upon knowledge beyond that of the individual researcher. Even highly localised forms of consultation enabled researchers to access knowledge that they did not personally possess. Taken together, these findings suggest that research-direction evaluation depended less on the knowledge of individual researchers than on the ability to access, combine, and coordinate knowledge from multiple sources. Judgements emerged through processes that transformed fragmented expertise into collectively informed assessments of uncertain opportunities.

However, access to expertise alone was rarely considered sufficient. Participants repeatedly described discussion, feedback, learning, and collaboration as the mechanisms through which distributed expertise was translated into actionable judgement. Researchers therefore not only relied on expertise from others, but also engaged in ongoing interaction to collectively interpret opportunities, challenge assumptions, and evaluate their implications for future research directions.

Knowledge exchange emerged as one of the primary mechanisms through which opportunities were refined and evaluated. Discussions frequently altered researchers' perceptions of potential directions by revealing limitations, highlighting alternative possibilities, and strengthening evaluative reasoning. One participant described the outcome of a collaborative discussion:

“I got there with a list of like 30 things to do differently or to add or remove.” (P5_110, computational researcher).

Rather than functioning as simple communication, discussion actively shaped opportunity evaluation. Through interaction, assumptions became visible, weaknesses were identified, and ideas were refined. Knowledge exchange therefore transformed distributed expertise into collective judgement, suggesting that evaluation emerged through interaction rather than preceding it.

Participants also described learning and capability development as important aspects of opportunity evaluation. Evaluation was not always constrained by the expertise available at a particular moment. Researchers frequently considered whether necessary capabilities could be acquired through collaboration, training, or exposure to specialist environments. One participant described sending a researcher to another laboratory to learn a new technology:

“We sent her to Australia... that lab was the first lab publishing about this technology.” (P1_069, biomedical researcher).

This example indicates that learning and skill acquisition expanded the range of opportunities that could be considered viable. Researchers did not simply ask whether expertise currently existed. They also evaluated whether expertise could reasonably be acquired. Learning therefore functioned as an evaluative resource that enabled opportunities to remain open despite existing capability limitations.

Capability development often emerged precisely because expertise limitations had been recognised. The importance of learning became particularly visible when researchers encountered gaps in their own knowledge. As one participant explained:

“I didn't have any knowledge about like bioinformatics.” (P3_034, biomedical researcher).

This quotation highlights the role of expertise gaps within the evaluative process. Missing knowledge did not necessarily eliminate opportunities from consideration. Instead, it frequently triggered learning, consultation, or collaboration. Knowledge gaps therefore functioned as starting points for further evaluation rather than definitive barriers to pursuing a research direction.

The importance of interaction and learning was further intensified by the interdisciplinary nature of the research environment. Participants repeatedly described situations in which biological, computational, clinical, and methodological expertise had to be brought together when assessing complex opportunities. Evaluating such opportunities required communication across disciplinary boundaries and the integration of multiple perspectives. One participant captured this clearly:

“You need naturally a combination of people that can do these different things and also then talk to each other.” (P8_106, computational researcher).

This quotation emphasises that expertise diversity alone was insufficient. Effective evaluation depended on interaction between specialisms and the integration of different forms of knowledge. Researchers relied on others not only for technical expertise, but also for evaluating implications that extended beyond their own areas of competence.

Collectively, these findings suggest that collective judgement emerged through processes of discussion, learning, consultation, and interdisciplinary interaction. While collaboration facilitated these interactions, its primary significance lay in its evaluative function. Interaction enabled researchers to challenge assumptions, interpret opportunities from multiple perspectives, and develop assessments that extended beyond the knowledge of any individual researcher. Research-direction evaluation therefore emerged as a process through which distributed expertise was transformed into collectively informed judgements capable of guiding future research directions.

Importantly, these collectively informed judgements provided a broader and more credible basis for assessing uncertain opportunities. By drawing upon expertise beyond their own knowledge, researchers were able to evaluate feasibility, interpret implications, and assess the potential of future research directions from multiple perspectives. This did not eliminate

uncertainty. Rather, collective judgement enabled researchers to make assessments that appeared sufficiently robust to support continued evaluation and investment in particular directions. In this way, distributed expertise strengthened the basis upon which confidence in a potential research direction could be developed.

4.2 Theme 2: evaluating future research opportunities under persistent uncertainty

The second theme suggests that research-direction decisions were rarely made under conditions of complete certainty. Instead, participants described operating in environments characterised by scientific, evidential, technological, translational, and practical uncertainty. Important questions frequently remained unanswered, evidence was often incomplete, technologies continued to evolve, and future applications could not be predicted with confidence.

Despite these conditions, researchers continued to evaluate and compare potential research opportunities. Across interviews, participants described exploring possibilities, assessing feasibility, considering future impact, evaluating constraints, and revisiting decisions as new information became available. Evaluation therefore occurred alongside uncertainty rather than after uncertainty had been resolved.

Participants also described uncertainty as closely connected to the evaluation process itself. Unanswered scientific questions, missing evidence, emerging technologies, and practical constraints frequently prompted further assessment, prioritisation, and refinement of opportunities. Rather than preventing action, uncertainty created the need to evaluate, compare, and justify alternative research directions. Through these activities, broad spaces of possibility were gradually narrowed into directions considered worthy of continued investment.

Researchers rarely described beginning with a single, clearly defined research direction. Instead, they frequently encountered broad opportunity spaces containing multiple possibilities for future investigation. These opportunities emerged from unanswered questions, technological developments, clinical needs, emerging findings, and observations made during ongoing projects. Because the future value of alternative directions could not be known in advance, researchers were required to evaluate which opportunities appeared sufficiently worthwhile to justify continued attention and investment.

This process often began with exploration. Participants described considering multiple possibilities simultaneously before gradually narrowing their focus. As one participant explained:

“When you are doing research, you have so many options.” (P2_015, technology translation researcher).

This quotation illustrates the abundance of potential directions confronting researchers. Rather than selecting from a small number of predefined alternatives, researchers often first needed to narrow a broad set of potentially valuable opportunities into a more manageable range for further evaluation.

Exploration alone, however, was insufficient. Participants repeatedly described moving from broad possibilities towards increasingly focused directions through evaluative reasoning. Researchers assessed which opportunities appeared capable of generating meaningful outcomes while remaining achievable within available circumstances. As one participant explained:

“Once I knew that there are no roadblocks... then I started looking at what are the different applications” (P2_014, technology translation researcher).

This quotation indicates that opportunity selection was typically preceded by evaluation. Rather than immediately pursuing attractive ideas, researchers first assessed whether

opportunities appeared sufficiently viable to justify further investment. Evaluation therefore functioned as a filtering process through which broad possibilities were gradually narrowed into a smaller set of promising alternatives.

Importantly, narrowing rarely occurred through a single decision event. Participants frequently described refining opportunities over time as new information became available and circumstances evolved. Potential directions were repeatedly reassessed against project objectives, available capabilities, and emerging findings. One participant explained:

“We try to make the connections that seem to make the most sense for each idea.” (P8_081, computational researcher).

This quotation suggests that opportunity evaluation was iterative rather than episodic. Researchers continually revisited opportunities, reassessed their relevance, and refined their understanding of how particular directions aligned with broader research aims. Future research directions therefore emerged through ongoing evaluation rather than through a single act of selection.

Although evaluation was often exploratory and iterative, participants also described situations in which narrowing occurred under practical pressure. Resource limitations, project expectations, institutional requirements, and delivery demands sometimes constrained the range of feasible alternatives. Under these conditions, researchers were not always able to keep opportunities open indefinitely. One participant explained:

“they really wanted us to narrow down our focuses and our number of applications to try to make our case stronger also for the future.” (P1_020, biomedical researcher).

This account introduces an important complexity. Opportunity evaluation was not always characterised by unrestricted exploration. In some situations, researchers felt compelled to make choices despite uncertainty, incomplete evidence, or limited flexibility. Rather than contradicting the broader pattern, this highlights how research-direction decisions emerged within practical environments that required progress even when important unknowns remained unresolved.

Taken together, these findings suggest that researchers moved from broad opportunity spaces towards increasingly focused research directions through cycles of exploration, evaluation, prioritisation, and refinement. Rather than identifying a single optimal path from the outset, researchers gradually constructed a basis for pursuing particular opportunities by repeatedly assessing their potential value, relevance, and feasibility under conditions of persistent uncertainty.

Following this process of narrowing and refinement, researchers still needed to determine which opportunities warranted continued investment. Across interviews, opportunities were rarely evaluated using a single criterion. Instead, participants repeatedly balanced anticipated value against practical achievability. Opportunity evaluation therefore involved an ongoing tension between ambition and constraint, with opportunities becoming attractive when they appeared both meaningful and realistically achievable.

Participants frequently described evaluating opportunities through multiple criteria simultaneously. One participant explained:

“I looked at, okay, what can be achieved with the technology so reliably, which things you can properly study with the technology, what is the impact of that application and I also use the time horizon that when the benefits can be realised because people want solutions now. ” (P2_018, technology translation researcher).

Another participant explained:

"I think also associated with the factors that I already mentioned, ... you have to consider what is reasonable to do. We might have a great idea, but if that idea, would need ten years to take shape, can we maybe then come up with something that is feasible within still the timeline of the PhD students?" (P8_091, computational researcher).

These quotations illustrate that opportunity evaluation involved balancing multiple considerations simultaneously. Rather than relying on a single criterion, participants weighed anticipated impact, feasibility, resource demands, expertise requirements, timing considerations, and strategic priorities when assessing future research directions.

Future impact emerged as one of the strongest justifications for pursuing particular opportunities. Researchers repeatedly referred to improving healthcare, supporting clinical decision-making, generating societal benefit, and enabling future applications. One participant explained:

"I think it's maybe something more closer to relevant when it stands closer to being applicable in the clinical setting." (P4_043, biomedical researcher).

This quotation may help explain how opportunities gained value through anticipated translational outcomes. Researchers often justified directions not only because they generated knowledge, but because they could contribute to future healthcare improvements. Translational potential therefore functioned as an important evaluative resource that increased the attractiveness of particular opportunities.

However, anticipated impact alone was rarely sufficient. Participants consistently evaluated whether promising opportunities could realistically be pursued within existing technological, organisational, and practical constraints. Feasibility assessments considered technological capabilities, available expertise, resource requirements, project timelines, and implementation challenges. As one participant described:

"You have to consider a lot of factors. So the factors I considered are... what is the impact of the direction... Second is like feasibility, how well the application can be used with the current technology. ... Your technology has certain strengths and within those strengths it can achieve desired outcomes." (P2_017, technology translation researcher).

This quotation captures one of the strongest tensions within the dataset. Researchers did not simply ask whether an opportunity was important. They asked whether it was important enough relative to what could realistically be achieved. Impact and feasibility therefore appeared closely intertwined. Opportunities became attractive when anticipated value and practical achievability aligned.

The complexity of this balancing process is illustrated by situations in which seemingly straightforward evaluation criteria appeared inadequate. One participant reflected:

"Applying only cost and benefits was not sufficient." (P2_074, technology translation researcher).

This quotation highlights the limitations of simplified evaluative approaches. Opportunities were rarely reducible to straightforward calculations because multiple considerations needed to be balanced simultaneously. Scientific significance, feasibility, expertise availability, translational value, timelines, and resource constraints frequently interacted in ways that required judgement rather than formulaic comparison.

Viewed as a whole, these findings suggest that researchers evaluated future research opportunities through a continual balancing of ambition, impact, and practical constraints. Researchers therefore appeared less concerned with identifying either the most ambitious or the most feasible opportunity in isolation. Instead, they sought opportunities that combined anticipated value with practical achievability and that appeared sufficiently promising to justify further investment.

A key finding is that making these evaluations did not require uncertainty to be resolved. Researchers frequently assessed opportunities despite unresolved questions regarding scientific validity, future impact, technological development, and practical implementation. As a result, uncertainty functioned not as a barrier to evaluation, but as an enduring condition within which opportunity evaluation and research-direction decisions took place.

Across interviews, uncertainty emerged not as a temporary obstacle preceding evaluation but as the environment within which evaluation occurred. Participants repeatedly described working with unresolved questions, incomplete evidence, emerging technologies, uncertain applications, and evolving research landscapes. Rather than expecting uncertainty to disappear before decisions were made, researchers appeared to accept uncertainty as a normal feature of innovative research. One participant described this environment directly:

“There is a lot of uncertainty in [the project] and it is a very new technology.” (P2_002, technology translation researcher).

This quotation reflects a broader pattern throughout the dataset. Uncertainty appeared across multiple dimensions. Researchers encountered scientific uncertainty surrounding biological mechanisms and disease processes, evidential uncertainty resulting from limited data and incomplete validation, technological uncertainty associated with emerging methods and computational approaches, translational uncertainty concerning future clinical applications, and practical uncertainty relating to resources, expertise, funding, and project timelines. Participants also repeatedly highlighted missing evidence and unanswered questions. One researcher explained:

“There are so many things that are missing.” (P3_025, biomedical researcher).

Importantly, missing knowledge did not automatically eliminate opportunities from consideration. Instead, knowledge gaps frequently became focal points for evaluation, with researchers assessing whether identified uncertainties represented opportunities that could realistically be addressed. The presence of a gap alone was therefore insufficient. What mattered was whether it appeared actionable and worthy of further investigation. Technological novelty often intensified these uncertainties. Emerging methods frequently lacked established evidence bases, making it difficult to assess future value with confidence. One participant explained:

“There were not enough papers available about characterization.” (P3_003, biomedical researcher).

This quotation illustrates how novelty and uncertainty frequently appeared together. Emerging technologies created opportunities for innovation while simultaneously generating uncertainty regarding capabilities, limitations, and future trajectories. This pattern was particularly visible in relation to AI-related approaches. Participants rarely discussed AI as a standalone decision criterion. Instead, AI appeared embedded within broader developments involving computational innovation, methodological novelty, and rapidly evolving analytical

possibilities. AI therefore contributed to the uncertain conditions within which opportunities were evaluated rather than serving as a justification for pursuing particular opportunities. Despite these uncertainties, researchers continued to evaluate and pursue research directions. Rather than delaying decisions until uncertainty had been removed, participants repeatedly described adapting plans and refining directions as new information emerged. One participant explained:

“No one knew if there would be any influence [on the donor cells] or not.” (P5_028, computational researcher).

This quotation indicates that opportunities were frequently pursued even when future outcomes could not be predicted with certainty. Evaluation therefore enabled progress despite important uncertainties remaining unresolved.

At the same time, uncertainty was not experienced as an insurmountable obstacle. Researchers occasionally concluded that important challenges appeared manageable despite remaining unknowns. A participant explained:

“I couldn't see any limitations that would make the technology unfeasible.” (P2_011, technology translation researcher).

This account introduces an important nuance. Uncertainty did not necessarily imply pessimism or an inability to act. Rather, researchers differentiated between uncertainties that could be accommodated and limitations that genuinely prevented progress. Uncertainty therefore became something to navigate and assess rather than something that had to be eliminated before moving forward.

Together, these findings suggest that opportunity evaluation was less concerned with identifying an optimal research direction and more concerned with developing sufficient justification for pursuing particular directions under conditions of persistent uncertainty. Across interviews, a recurring process emerged in which opportunities were explored and narrowed, potential value was assessed through balancing impact and feasibility, and decisions were continually revisited as new information emerged. Evaluation therefore appeared iterative rather than episodic, with researchers repeatedly moving between exploration, assessment, prioritisation, and adaptation while uncertainty remained present.

At the same time, uncertainty did not disappear during this process. Instead, unresolved scientific, evidential, technological, translational, and practical uncertainties created the conditions that made evaluation necessary. Researchers therefore did not wait for certainty before acting. Rather, they continually assessed whether opportunities appeared sufficiently promising, feasible, and valuable to justify further investment despite the persistence of important unknowns. In this way, opportunity evaluation provided reasons for continued investment and contributed to the development of confidence that a direction remained worth pursuing despite ongoing uncertainty.

4.3 Theme 3: evidence generation and interpretation under uncertainty

The third theme examines how researchers generated and interpreted evidence when evaluating future research directions. Across interviews, experimentation, validation, measurement, analysis, and interpretation were described as important activities for assessing uncertain opportunities and determining whether they remained worthy of continued investment.

Persistent uncertainty surrounding biological mechanisms, cell donor variation, treatment responses, technological capabilities, and future applications meant that important research-direction decisions could not be made on the basis of existing knowledge alone. Researchers

therefore engaged in systematic efforts to evaluate assumptions, investigate emerging findings, and develop a stronger evidential basis for assessing future opportunities.

Rather than eliminating uncertainty altogether, evidence generation and interpretation enabled researchers to assess whether opportunities remained sufficiently credible, feasible, and promising to justify continued evaluation. Through these activities, researchers progressively strengthened the basis upon which future research directions could be assessed and refined.

Researchers frequently encountered situations in which available evidence was insufficient for evaluating future research directions. Across interviews, participants described uncertainties relating to the reliability of experimental systems, the feasibility of emerging approaches, and the interpretation of biological outcomes. To address these uncertainties, researchers relied on activities such as validation, testing, measurement, and analysis.

Evidence generation was therefore not merely concerned with producing data. Instead, it functioned as a way of assessing whether assumptions remained plausible, whether concerns were justified, and whether particular opportunities warranted continued attention despite incomplete knowledge.

A recurring pattern involved validation activities aimed at supporting whether experimental systems could be trusted as foundations for future work. Researchers repeatedly emphasised the importance of determining whether models were sufficiently robust before they could support investigation of broader scientific questions. One participant described how the initial focus of their work centred on evaluating the research model itself:

“So the first decision was, okay, we want to first understand that the model is [reliable]. ... Once we answered this question that it’s a [reliable] and it’s a good model.” (P3_005, biomedical researcher).

Importantly, validation was not discussed as a purely methodological requirement. Rather, validating the model served an evaluative purpose. Before committing resources towards disease applications, researchers first sought evidence that the underlying system could generate trustworthy findings. Validation therefore transformed an uncertain experimental platform into a more credible basis for future investigation.

Alongside validation activities, researchers actively generated evidence through experimental testing. Participants frequently described designing small-scale studies to examine assumptions, investigate concerns, and assess whether proposed approaches appeared viable before larger commitments were made. Rather than proceeding directly towards full-scale implementation, researchers often used preliminary experiments to evaluate feasibility and explore uncertainty. As one participant explained:

“So basically what we did based on this idea or this doubt or this question, we set up a small experiment in which we culture this, for example, four or five [cell] lines together” (P1_053, biomedical researcher).

Testing functioned as an empirical mechanism through which researchers assessed whether concerns were justified, explored potential limitations, and evaluated whether further investment was warranted. Experimentation was therefore closely connected to research-direction evaluation rather than solely to immediate scientific objectives.

Validation and testing frequently operated together within an iterative process through which observations became increasingly trustworthy. Researchers were often unwilling to rely on initial findings alone. Instead, observations were subjected to additional checks intended to determine whether results remained consistent under different conditions. One participant explained how unexpected cell donor responses would trigger further investigation:

“Basically a sort of final check of validation that what you observe was not triggered by the fact that they were surrounded by a lot of other cells” (P1_063, biomedical researcher).

This illustrates a broader pattern visible across interviews. Observations first generated tentative explanations, which subsequently required additional validation before influencing future decisions. Evidence therefore progressed from observation to validation and then to evaluation. Confidence did not stem from isolated findings, but from evidence that had been repeatedly assessed and judged sufficiently trustworthy to inform future directions.

Biological measurement and profiling played a complementary role within this process. Researchers repeatedly described generating detailed measurements capable of linking genetic variation to biological outcomes. Single-cell approaches, molecular profiling, and genotype-phenotype analyses enabled researchers to assess whether observed differences reflected meaningful biological phenomena rather than technical artefacts. Such measurements functioned as evidence-generating mechanisms through which uncertainty surrounding cell donor responses, treatment effects, and biological variation could be investigated systematically.

At the same time, participants consistently recognised the limitations of available evidence. Validation and testing increased confidence in particular findings, but uncertainty never disappeared completely. Researchers frequently reflected on the incompleteness of their evidence, the limitations of available data, and the possibility that future findings might challenge current conclusions. One participant acknowledged this tension directly when discussing the research model:

“There are always limitations. So for instance, we just use four [cell] donors and then like maybe things change if there are like a hundred [cell] donors. So, but we cannot control everything” (P3_011, biomedical researcher).

This reflects a central pattern across the dataset. Evidence generation strengthened researchers' ability to evaluate future directions, yet participants rarely described achieving complete certainty. Findings were instead treated as provisional and contingent upon the available evidence. Limitations associated with sample size, platform maturity, data availability, and methodological constraints remained visible even after validation activities had been completed.

Data limitations further reinforced this tension. Several participants described working with incomplete datasets, waiting for data-generation processes to be completed, or relying on assumptions where evidence remained unavailable. These limitations rarely halted research entirely. Instead, they influenced the degree of confidence researchers could reasonably place in particular conclusions. Researchers therefore appeared to operate within a continuous cycle of evidence generation and evidential assessment, balancing increasing confidence against the recognition that important uncertainties remained unresolved.

Overall, researchers sought evidence that was sufficiently robust to support informed judgements regarding future research directions rather than complete certainty regarding future outcomes. Through validation, testing, measurement, and analysis, uncertain opportunities became progressively more assessable while important unknowns remained. Evidence

generation therefore functioned as a mechanism through which researchers could evaluate opportunities and strengthen the basis for future decisions despite ongoing uncertainty.

However, generating evidence alone was rarely sufficient for informing research-direction decisions. Across interviews, participants emphasised the importance of understanding why observed patterns occurred and what they might imply for future work. Evidence generation therefore appeared closely intertwined with interpretation and knowledge production. Before evidence could inform future commitments, researchers needed to determine what the evidence meant, whether observed patterns were meaningful, and how emerging findings should influence the evaluation of future research opportunities.

A prominent feature of this process involved the search for mechanistic explanations capable of accounting for biological variation and differential responses. Researchers repeatedly described attempts to move beyond descriptive observations towards understanding underlying causal processes. As one participant explained:

“We are interested in what are the genetic differences between them and how do these genetic differences influence how these [cell] donors respond” (P5_003, computational researcher).

Mechanistic understanding appeared particularly valuable because it provided a stronger basis for evaluating future research directions. Explanations linking genetic variation to treatment responses, disease processes, or biological outcomes enabled researchers to assess whether observed findings were meaningful and potentially transferable across contexts. Understanding mechanisms therefore helped researchers move beyond isolated observations towards more robust assessments of future opportunities.

Computational analysis played a crucial role in transforming biological complexity into interpretable evidence. Participants frequently discussed the need to process large volumes of biological information before meaningful conclusions could be drawn. Computational approaches enabled researchers to connect cell donor identities, genotype information, and biological outcomes in ways that would otherwise be difficult to achieve. One participant described a core analytical task as follows:

"So all of those cell behaviours can be considered as cell features. But some other cell feature are really computational features which are out of the biology, so ... our computational people, they look at the maybe very like details in the cells" (P6_028, biomedical researcher);

"Then we can use different features ... in terms of [cell senescence] and activation, and ... we can use those features to predict that ... this cell is going to be a senescent cell ... within five days." (P6_029, biomedical researcher).

Through bioinformatics, machine learning, and analytical workflows, researchers transformed complex datasets into evidence that could inform the evaluation of future research directions. Evidence only acquired practical significance once it had been interpreted. Across interviews, participants frequently described revising their understanding after analysing results, discussing findings with others, or recognising previously overlooked factors. One participant explained:

“Sometimes I'm doing things and only after talking with others I realize, oh, I'm actually missing this” (P5_104, computational researcher).

Findings were situated within broader explanatory frameworks, challenged through discussion, and reconsidered in light of alternative perspectives. Through this process, researchers connected emerging findings to broader explanations and future research questions.

Interpretation was often difficult because researchers needed to distinguish meaningful biological signals from misleading outputs or analytical artefacts. Several participants reflected on this challenge directly, particularly within computationally intensive research environments. One participant explained:

“You need to be able to distinguish what is garbage, what is nonsense, from what is relevant biologically” (P5_124, computational researcher).

This observation highlights the importance of interpretation within the broader evaluative process. Analysis alone did not guarantee useful knowledge. Researchers still needed to determine whether patterns reflected genuine biological phenomena or artefacts generated by analytical procedures. Interpretation therefore functioned as a critical filtering process through which evidence was assessed before influencing future research-direction decisions.

Knowledge generation rarely represented an endpoint within this process. Instead, new findings often created additional questions, opportunities, and uncertainties. Researchers frequently described knowledge production as opening further avenues of investigation rather than resolving evaluation processes entirely. As one participant reflected:

“You always try to go in the direction that you don't know fully what can happen, because it's how you generate knowledge” (P1_085, biomedical researcher).

Consequently, evidence generation and interpretation created iterative cycles of investigation. Findings generated explanations, explanations generated new questions, and those questions motivated further experimentation and analysis. Knowledge generation therefore expanded the space of future opportunities rather than closing it.

AI-related approaches occupied a similar position within this broader evidential process. Participants primarily discussed machine learning, bioinformatics, and computational methods as tools that strengthened analytical capabilities and biological understanding. Rather than functioning as independent decision criteria, these approaches were valued according to their role in enhancing evidence quality and research utility. AI therefore influenced research-direction decisions indirectly by enhancing evidential capabilities rather than directly determining research directions.

Taken together, these findings suggest that evidence generation and interpretation enabled researchers to move beyond observation towards explanation when evaluating future research opportunities. Validation, testing, measurement, computational analysis, and interpretation allowed researchers to assess whether emerging findings were sufficiently credible, meaningful, and relevant to inform future directions. Evidence therefore functioned as more than a source of information. It became a mechanism through which uncertain opportunities could be systematically assessed and refined.

Significantly, these activities did not eliminate uncertainty entirely. Researchers continued to recognise limitations in available evidence, evolving knowledge, and unresolved scientific questions. Nevertheless, evidence generation and interpretation strengthened the empirical basis upon which research directions could be evaluated. By assessing assumptions, validating findings, and developing explanatory understanding, researchers strengthened the basis upon which opportunities could be evaluated and judged worthy of continued investment. In this way, evidence generation and interpretation provided the empirical justification that supported confidence in future research directions despite ongoing uncertainty.

4.4 Cross-theme analysis: towards confidence construction

Considered together, the three themes suggest that research-direction decisions appear not as discrete choices made after uncertainty has been resolved, but as an ongoing process through which researchers construct a sufficient basis for action despite important unknowns remaining. The cross-theme analysis revealed that collective judgement, opportunity evaluation, and evidence generation and interpretation did not operate as independent processes. Rather, they interacted in mutually reinforcing ways that enabled researchers to develop sufficient confidence to pursue particular research directions under conditions of persistent uncertainty.

The process begins with persistent uncertainty. Across the dataset, researchers frequently encountered unanswered scientific questions, unclear biological mechanisms, knowledge gaps, emerging technologies, limited data, and uncertain future applications. Importantly, these uncertainties were not described solely as obstacles. They also generated opportunities for investigation and motivated further evaluation. Uncertainty therefore functioned as both the starting condition for research-direction evaluation and the source of many of the opportunities being considered.

Collective judgement provided the first component to this process. Researchers rarely relied solely on individual expertise when evaluating uncertain opportunities. Instead, they drew upon supervisors, collaborators, clinicians, bioinformaticians, and wider professional networks to access knowledge extending beyond their own expertise. Through consultation, learning, collaboration, and expertise coordination, fragmented knowledge was transformed into collectively informed judgements. Collective judgement therefore broadened evaluative capacity by enabling researchers to assess opportunities from multiple perspectives and challenge assumptions that might otherwise remain unquestioned.

The second component emerged through opportunity evaluation. Researchers continually assessed the future value, impact, feasibility, resource requirements, and strategic relevance of potential directions. Opportunities became attractive not because they performed strongly on a single criterion, but because they appeared sufficiently worthwhile to justify continued investment. Opportunity evaluation therefore provided reasons for pursuing particular directions while simultaneously narrowing a broader space of possibilities into a more focused set of opportunities considered worthy of further attention.

The third component emerged through evidence generation and interpretation. Researchers relied on validation, testing, experimentation, analysis, and interpretation to evaluate assumptions and assess emerging findings. Evidence generation and interpretation provided an empirical basis for evaluating opportunities and determining whether they remained sufficiently credible, meaningful, and promising to pursue. Rather than eliminating uncertainty entirely, these activities enabled researchers to make increasingly informed assessments despite important unknowns remaining unresolved.

Taken together, these three components reveal more than separate aspects of research-direction evaluation. Collective judgement broadened evaluative capacity through distributed expertise. Opportunity evaluation provided reasons for pursuing particular directions. Evidence generation and interpretation supplied empirical justification. These activities operated recursively and reinforced one another throughout the evaluation process. Through their interaction, researchers developed a sufficiently robust basis for action despite persistent uncertainty.

Confidence construction emerged as an interpretive concept that captures how collective judgement, opportunity evaluation, and evidence generation and interpretation interacted throughout research-direction evaluation. Rather than emerging as a standalone theme, confidence construction was developed through analysis of the relationships between the three

themes. The concept therefore provides an interpretive explanation of how researchers become able to move forward despite persistent uncertainty.

The findings further suggest that these interacting processes culminated in sufficient confidence to continue pursuing particular directions. As one participant explained:

"The trick is not to jump too much high in one go, but just do incremental steps that they allow you to have a certain level of confidence" (P1_086, biomedical researcher).

This statement illustrates how confidence was developed progressively through successive evaluations and smaller commitments rather than emerging only after uncertainty had been resolved.

Confidence emerged through the combined effects of collective judgement, opportunity evaluation, and evidence generation and interpretation, each providing a different basis for assessing future directions. Researchers therefore did not appear to wait until uncertainty had been eliminated. As one participant noted:

"You make the best decision you can with the information you have." (P5_032, computational researcher).

This reflects how decisions were made despite incomplete knowledge rather than after certainty had been achieved. They gradually developed enough confidence to move forward while recognising that important unknowns remained. This distinction is important because it suggests that commitment was enabled by confidence construction rather than by the achievement of certainty.

Although AI did not emerge as an independent basis for research-direction decisions, it influenced the broader environment within which these processes occurred. Across the themes, AI shaped uncertainty conditions, expertise requirements, opportunity spaces, and evidential capabilities. Researchers rarely evaluated opportunities because they involved AI. Instead, AI-related approaches were assessed using the same considerations applied to other opportunities, including feasibility, anticipated impact, evidential value, and scientific relevance. AI therefore functioned as a contextual condition that shaped confidence construction rather than as the primary object of evaluation.

The findings suggest that sufficient confidence enabled provisional commitment to particular research directions. Researchers subsequently selected directions, determined priorities, allocated resources, and pursued specific projects. However, these commitments did not imply certainty or permanence. Rather, commitment reflected a willingness to move forward while acknowledging that future developments could necessitate change.

As new evidence emerged, commitments remained open to revision. Adaptation frequently generated additional questions, opportunities, and uncertainties, creating renewed cycles of evaluation and reassessment. Rather than progressing from uncertainty to certainty, researchers appeared to move through recurring cycles of confidence construction and adaptation.

Taken together, the findings suggest an integrated process through which researchers become able to commit to future research directions despite persistent uncertainty. While the process unfolds through identifiable components, the relationships between these components are iterative and mutually reinforcing rather than strictly linear. The resulting synthesis is represented in the process model presented in Figure 3.

4.5 Process model of confidence construction

The process model (Figure 3) visualises the confidence-construction process that emerged through the themes and cross-theme analysis presented in Sections 4.1 to 4.4. The model synthesises the relationships between the themes and illustrates how researchers become able to commit to particular research directions despite persistent uncertainty.

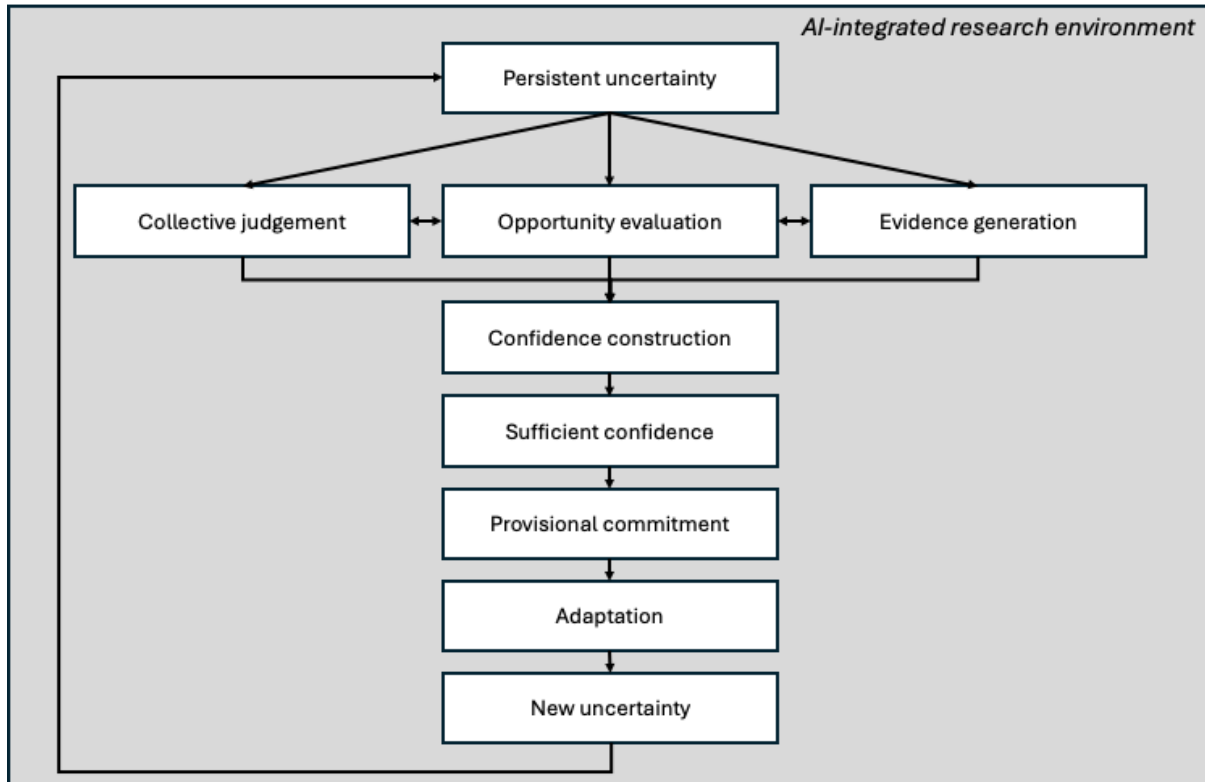


Figure 3. Interpretive process model of confidence construction under persistent uncertainty.

The model integrates the three themes into an iterative process through which researchers develop sufficient confidence to pursue particular research directions despite persistent uncertainty. Rather than depicting a linear decision-making sequence, the model represents a dynamic and iterative process in which confidence is continuously constructed, reassessed, and adapted as new information becomes available. AI appears as a contextual condition influencing uncertainty, expertise requirements, opportunity spaces, and evidential capabilities rather than as an independent decision criterion.

5. Discussion

This chapter interprets the findings in relation to the research question, existing literature, and the broader theoretical framework of the study. The study sought to understand how researchers evaluate opportunities and navigate uncertainty when determining future research directions within an AI-integrated biotech health technology innovation context. While Chapter 4 presented the empirical findings, this chapter examines what these findings reveal about how researchers determine future research directions and become able to commit to particular opportunities despite persistent uncertainty.

The findings suggest that research-direction decisions cannot be explained solely through processes of uncertainty reduction. Across the findings, important uncertainties frequently remained unresolved throughout evaluation and decision-making processes. Nevertheless, researchers continued to assess opportunities, commit resources, and pursue particular directions. The findings therefore suggest that confidence construction may help explain how commitment became possible despite persistent uncertainty. Building on the process identified in Chapter 4, this chapter develops confidence construction as an interpretive explanation of how researchers appeared to move forward before certainty had been achieved.

The discussion develops this argument in five stages. The first three sections progressively address the core elements of the research question. Section 5.1 examines the forms of uncertainty that characterised research-direction evaluation and considers why uncertainty remained a persistent condition rather than a temporary obstacle. Section 5.2 explores how researchers evaluated future opportunities through collective judgement and future-oriented opportunity evaluation. Section 5.3 then develops confidence construction as an interpretive explanation of how researchers became able to move from evaluation to commitment despite unresolved uncertainty. Building on this progression, Section 5.4 integrates these insights to answer the research question directly. Section 5.5 discusses the theoretical implications of the findings.

5.1 Persistent uncertainty and the need for evaluation

Prior literature suggests that important decisions frequently involve evaluating future possibilities rather than established realities. Strategic decision-making research argues that actors often assess alternative futures whose outcomes cannot yet be observed (Courtney et al., 1997), while work on anticipatory uncertainty suggests that researchers must continually anticipate whether ongoing research activities will generate valued future outputs (Fochler & Sigl, 2018). Similarly, research on early health technology assessment demonstrates that technologies are routinely evaluated before evidence regarding their effectiveness, implementation, or societal impact is available (Grutters et al., 2022; IJzerman et al., 2017).

The findings are consistent with these observations while providing a more detailed account of how future-oriented evaluation appeared within research-direction decision-making. Rather than evaluating established outcomes, researchers assessed potential future states associated with particular directions, including anticipated scientific advances, translational applications, implementation pathways, societal impacts, future feasibility, and future value. These characteristics were not directly observable at the time decisions were made. Instead, researchers were required to assess what a research direction might become if it were pursued. This observation suggests that research-direction evaluation was fundamentally future-oriented. Future feasibility, impact, applications, and scientific value could not be directly assessed because they had not yet materialised. Researchers therefore made judgements about possibilities whose eventual consequences remained uncertain. In this respect, the findings align with literature describing the assessment of future opportunity spaces and the evaluation of expected value before outcomes exist (Grutters et al., 2022; Jones et al., 2025).

At the same time, the findings suggest a broader object of evaluation than is typically emphasised in anticipatory uncertainty research. Whereas anticipatory uncertainty is often discussed in relation to the future productivity of research activities (Fochler & Sigl, 2018), participants appeared to evaluate a wider range of possible futures, including future scientific, translational, societal, and practical outcomes. The findings therefore suggest that uncertainty arose not only from questions regarding productivity, but also from the need to assess multiple possible futures whose eventual value remained unclear.

The findings further indicate that uncertainty was not merely a temporary obstacle surrounding evaluation. Existing literature increasingly recognises that uncertainty may persist despite additional information, analysis, and knowledge production (Borck & Lohse, 2026; Courtney et al., 1997; Lohse, 2023). The current findings support this perspective while providing insight into why uncertainty remained so closely intertwined with evaluation. Researchers were required to assess future directions whose consequences could not yet be directly observed, meaning that uncertainty remained embedded within the object of evaluation itself.

In this sense, uncertainty appeared to function less as a problem awaiting resolution and more as a condition within which evaluation occurred. Additional evidence could refine assessments and narrow possibilities, but it could not fully eliminate uncertainty because future consequences had not yet materialised. Researchers therefore evaluated opportunities while uncertainty remained present rather than after it had been resolved.

Viewed in this way, uncertainty appears inseparable from research-direction evaluation. Researchers were required to assess future possibilities while recognising that their eventual feasibility, value, and relevance could not yet be known with certainty. Evaluation therefore occurred alongside uncertainty rather than after uncertainty had been removed.

Understanding uncertainty in this way helps explain why researchers could not rely on certainty when determining future research directions. Instead, they were required to evaluate opportunities despite incomplete knowledge and unresolved unknowns. This raises a further question: how do researchers become able to assess opportunities and move forward under such conditions? The following section addresses this question by examining the roles of collective judgement and future-oriented opportunity evaluation.

5.2 Collective judgement and future-oriented opportunity evaluation

Within the studied context, research-direction evaluation appeared to emerge through a collective evaluative process assembled through distributed expertise. When faced with uncertain future opportunities, researchers rarely relied solely on their own knowledge. Instead, evaluation emerged through the integration of expertise distributed across multiple actors, disciplines, and domains. This observation raises an important question: why did researchers appear to depend so heavily on expertise distributed across multiple actors when evaluating future opportunities?

The findings suggest that future research opportunities often required forms of expertise that could not be accessed through individual judgement alone. Rather than evaluating opportunities independently, researchers drew upon knowledge distributed across multiple actors and domains. Expertise therefore became a prerequisite for evaluation, with consultation, learning, and interaction across expertise domains enabling opportunities to be assessed despite limitations in individual knowledge.

Existing literature helps explain why expertise becomes distributed in biomedical innovation environments. Precision medicine depends upon specialised expertise spanning genomics, bioinformatics, clinical medicine, pharmacology, laboratory science, and data-intensive approaches, making collaboration a practical necessity rather than an organisational preference (Zhu et al., 2024). Similarly, digital health innovation requires expertise distributed across stakeholder groups, organisational settings, and implementation contexts (Bangboje-Ayodele

et al., 2023; Reidy et al., 2023), while healthcare technology adoption depends upon knowledge distributed across clinicians, managers, technical specialists, and end users (Gagnon et al., 2012). More broadly, Polanyi (1962) argued that scientific knowledge is inherently distributed, meaning that no individual researcher possesses a complete understanding of the broader scientific landscape.

The findings are consistent with these observations while providing insight into how distributed expertise appeared in research-direction evaluation. Future opportunities contained scientific, technological, translational, implementation, and feasibility uncertainties that no individual researcher could confidently assess simultaneously. Researchers therefore drew upon specialised expertise distributed across multiple actors, disciplines, and domains when evaluating competing opportunities. In this sense, distributed expertise did not merely support research activity. It enabled opportunities to become assessable in the first place.

This observation suggests that expertise played a role not only in producing knowledge but also in evaluating future possibilities. While existing literature emphasises collaboration in complex innovation environments, the findings suggest that the integration of expertise contributed directly to the formation of evaluative judgements regarding future opportunities. However, recognising that expertise is distributed does not by itself explain how future opportunities become evaluable. The critical question is therefore how expertise distributed across multiple actors became capable of supporting evaluation.

The findings suggest that researchers did not simply distribute work across expertise networks. They distributed judgement. Participants routinely sought feedback, engaged in discussion, consulted specialists, developed new capabilities, and collaborated across disciplinary boundaries when evaluating future opportunities. The significance of these interactions extended beyond information exchange. Consultation, feedback, discussion, and interdisciplinary interaction enabled dispersed knowledge and expertise to be brought into ongoing evaluative conversations. Through these interactions, opportunities were collectively explored, questioned, refined, and assessed. Evaluation therefore emerged through interaction rather than remaining individual.

This interpretation aligns with arguments that scientific evaluation emerges through overlapping networks of expertise rather than individual reasoning (Polanyi, 1962). Similarly, research on innovation and interdisciplinary collaboration suggests that opportunities often emerge through the integration of specialised expertise across multiple actors (Bamgboje-Ayodele et al., 2023; Reidy et al., 2023). The findings support these observations while suggesting that distributed expertise became incorporated into the evaluative process itself rather than merely supporting it.

A key implication is that evaluation should not be understood solely as an individual cognitive activity. The findings suggest that evaluative judgements emerged through the integration of expertise distributed across multiple actors and domains. Interaction across distributed expertise therefore functioned as an important means through which evaluation occurred. Research opportunities were not evaluated by individuals who subsequently consulted others. Instead, evaluative judgements emerged through the integration of expertise during the evaluation process itself. Collective judgement was constructed through repeated interaction, consultation, and expertise integration across multiple actors and domains.

Viewed in this way, collective judgement may be understood as the process through which distributed expertise was integrated into the evaluation of uncertain opportunities. It helped explain how researchers remained capable of assessing future directions despite limitations in individual knowledge and persistent uncertainty regarding future outcomes. More importantly, collective judgement appeared to expand what researchers became capable of evaluating. Its significance therefore lies not simply in bringing experts together, but in enabling uncertain future opportunities to become sufficiently assessable for meaningful evaluation.

The findings therefore suggest that collective judgement contributed to what may be described as evaluative capacity: the ability to meaningfully assess future feasibility, scientific value, translational relevance, methodological suitability, implementation potential, and future impact. Existing literature explains why expertise becomes distributed and why collaboration becomes necessary within complex research environments (Javanmardi et al., 2024; Reidy et al., 2023; Zhu et al., 2024). However, these studies tend to focus primarily on knowledge production and coordination. The present findings suggest an additional implication. Through collective judgement, dimensions of future opportunities that would have been difficult to assess through individual expertise became sufficiently assessable for meaningful evaluation. This observation is particularly important because the object of evaluation was fundamentally prospective rather than directly observable. Researchers were required to assess possible future applications, impacts, implementation challenges, and scientific trajectories despite incomplete knowledge and persistent uncertainty. Collective judgement did not remove these uncertainties. Rather, it broadened researchers' ability to engage with them.

Taken together, these observations suggest that the significance of collective judgement lies not simply in bringing together different forms of expertise, but in expanding what researchers became capable of evaluating. Through collective judgement, uncertain opportunities became sufficiently assessable for comparison, prioritisation, and further consideration despite persistent uncertainty.

Importantly, evaluative capacity alone does not explain how commitment became possible under persistent uncertainty. Collective judgement helped make uncertain opportunities assessable, but assessment does not automatically produce commitment. Researchers still needed to determine whether opportunities appeared sufficiently worthwhile, feasible, valuable, and credible to justify continued investment. This raises a further question: how did evaluation become commitment despite unresolved uncertainty? The following section addresses this question through the concept of confidence construction.

5.3 Confidence construction

Prior research consistently challenges the assumption that uncertainty can be eliminated through the accumulation of knowledge. Across different contexts, uncertainty is increasingly conceptualised not as a temporary absence of information but as a persistent feature of decision making and knowledge production (Borck & Lohse, 2026; Courtney et al., 1997; Fochler & Sigl, 2018; Lohse, 2023). Research on anticipatory uncertainty, strategic decision making, and precision medicine similarly suggests that uncertainty often persists despite the accumulation of evidence and may even expand as knowledge advances. Important decisions therefore frequently need to be made without complete knowledge of future outcomes, feasibility, impact, or value.

The findings are consistent with this perspective. Participants continued to encounter uncertainties surrounding future feasibility, scientific value, applications, societal impact, and translational potential despite extensive experimentation, analysis, and evaluation. In several cases, additional evidence clarified particular questions while simultaneously generating new uncertainties and opportunities for investigation. Consistent with the observations of Lohse (2023) and Borck and Lohse (2026), knowledge production often appeared to transform uncertainties rather than eliminate them.

This observation is important because it challenges explanations of research-direction decision-making that implicitly assume commitment becomes possible only once sufficient uncertainty has been removed. Within the studied context, commitment frequently occurred while important uncertainties remained unresolved. Researchers nevertheless continued to allocate resources, attention, and effort toward particular directions.

The findings therefore suggest that uncertainty reduction alone does not fully explain how commitment becomes possible. Existing literature provides important explanations for why uncertainty persists and why future-oriented evaluation remains necessary. However, it offers less insight into how researchers become able to continue investing in particular directions despite unresolved uncertainty. This raises a further question: if uncertainty remains present throughout evaluation, how do researchers become able to move forward?

Building on the cross-theme analysis presented in Section 4.4, confidence construction provides a useful interpretive lens for understanding how researchers became able to continue investing in particular directions despite persistent uncertainty. Rather than waiting until uncertainty had been eliminated, researchers appeared to develop a sufficiently convincing basis for continued investment while important unknowns remained unresolved.

Confidence refers here to the collectively constructed judgement that a research direction is sufficiently feasible, valuable, and evidentially supported to justify continued investment. Unlike certainty, confidence does not imply that important unknowns have been eliminated. Rather, it reflects a judgement that available reasons are sufficient to continue despite uncertainty remaining present.

Existing literature explains why uncertainty persists and why researchers frequently need to continue acting despite incomplete knowledge (Borck & Lohse, 2026; Courtney et al., 1997; Fochler & Sigl, 2018; Lohse, 2023). The findings build on these observations by providing insight into how researchers appeared to navigate this challenge in practice. Rather than residing within individual researchers, confidence emerged through the interaction of collective judgement, opportunity evaluation, and evidence generation and interpretation.

As discussed in Section 5.2, collective judgement enabled uncertain opportunities to become assessable through the integration of distributed expertise. Opportunity evaluation provided reasons for pursuing particular directions by enabling researchers to assess future value, impact, feasibility, translational relevance, and strategic importance. Evidence generation and interpretation provided empirical justification by allowing assumptions, opportunities, and emerging findings to be examined through experimentation, validation, analysis, and interpretation.

Viewed collectively, these processes generated more than information. They provided a sufficiently robust basis for continued action. Collective judgement broadened evaluative capacity, opportunity evaluation supplied reasons for pursuing particular directions, and evidence generation and interpretation offered empirical support for those assessments. Through their interaction, researchers gradually developed confidence that a direction remained worthy of continued investment despite important uncertainties remaining unresolved.

Importantly, the findings do not suggest that confidence replaced uncertainty. Rather, confidence and uncertainty appeared to coexist. Researchers frequently acknowledged limitations, unknowns, and alternative possibilities while simultaneously continuing to invest in particular directions. Confidence therefore appeared to reflect a practical judgement that available reasons were sufficient for continued action despite remaining uncertainty.

The findings suggest that confidence played an important role in connecting evaluation and commitment. Once a research direction appeared sufficiently justified, researchers became able to allocate resources, attention, time, and effort towards its pursuit. Confidence therefore appeared to function as a bridge between evaluation and action.

At the same time, these commitments remained provisional rather than final. Participants continued to recognise the possibility that future findings could challenge assumptions, reveal limitations, or redirect research trajectories. Commitment did not imply certainty regarding future outcomes. Rather, it reflected a willingness to proceed while remaining open to revision.

This observation differs from accounts that implicitly frame commitment as the outcome of progressively reducing uncertainty. Within the studied context, commitment frequently occurred while important unknowns remained present. The significance of confidence construction therefore lies not in resolving uncertainty, but in helping explain how action remained possible despite it.

Viewed in this way, commitment appeared to become possible despite important uncertainties remaining unresolved. Rather than eliminating uncertainty, researchers developed sufficient confidence to support provisional commitment despite persistent unknowns remaining present. The findings therefore suggest that confidence construction may help explain how researchers become able to continue investing in particular directions despite never possessing complete certainty regarding future outcomes.

Viewed through the theoretical lenses introduced in Chapter 2, confidence construction can be interpreted as a response to both innovation complexity and anticipatory uncertainty. NASSS highlights the interacting sources of complexity and uncertainty surrounding innovation processes, while anticipatory uncertainty emphasises the challenge of evaluating possible futures before their outcomes are known. The findings suggest that collective judgement, opportunity evaluation, and evidence generation and interpretation provided ways through which researchers appeared to navigate these conditions in practice. In this sense, confidence construction may help explain how action became possible within the forms of complexity and uncertainty described by these perspectives.

This interpretation provides the foundation for answering the research question addressed in this study: how researchers evaluate opportunities and navigate uncertainty when determining future research directions. The following section develops this answer explicitly.

5.4 Answering the research question

This thesis sought to answer the following research question:

How do researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation?

The preceding sections examined uncertainty as a defining condition of research-direction evaluation, explored how opportunities became assessable through collective judgement and opportunity evaluation, and developed confidence construction as an explanation of how commitment became possible despite unresolved uncertainty. Together, these insights provide the basis for answering the research question.

Regarding the first subquestion, researchers encountered multiple interacting forms of uncertainty, including scientific, technological, translational, evidential, implementation-related, and practical uncertainty. These uncertainties frequently persisted despite ongoing efforts to generate knowledge and evidence and formed a defining condition of research-direction evaluation.

The second and third subquestions concerned how researchers evaluated opportunities and navigated uncertainty under such conditions. The findings suggest that this occurred through the interaction of collective judgement, opportunity evaluation, and evidence generation and interpretation. Through collective judgement, distributed expertise enabled opportunities to become assessable despite limitations in individual knowledge. Opportunity evaluation enabled researchers to compare alternatives in terms of anticipated value, feasibility, impact, and relevance, while evidence generation and interpretation strengthened the basis upon which opportunities could be evaluated and justified.

Taken together, these findings help explain how researchers became able to move from evaluation to commitment. Through the interaction of collective judgement, opportunity evaluation, and evidence generation and interpretation, researchers developed sufficient confidence that a direction remained worthy of continued investment despite important uncertainties remaining unresolved. Rather than operating as independent activities, these processes reinforced one another and collectively enabled researchers to move forward before certainty had been achieved.

Accordingly, the answer to the research question is that researchers evaluated opportunities and navigated uncertainty through the interaction of collective judgement, opportunity evaluation, and evidence generation and interpretation. These processes enabled uncertain future opportunities to become assessable, justifiable, and empirically supported. Together, they contributed to the construction of sufficient confidence for continued investment despite persistent uncertainty and, in doing so, enabled researchers to commit to future research directions despite unresolved unknowns. In this sense, confidence construction provides an empirically grounded explanation of how researchers appeared to become able to commit to future research directions before certainty had been achieved.

5.5 Theoretical implications

Having answered the research question, this section examines the theoretical implications of the findings by considering how they relate to existing literature on uncertainty, distributed expertise, innovation complexity, and technology assessment.

Existing literature on anticipatory uncertainty argues that researchers must continually assess the future consequences and potential productivity of ongoing research activities despite incomplete knowledge of future outcomes (Fochler & Sigl, 2018). The findings are broadly consistent with this perspective by suggesting that research-direction evaluation is fundamentally future-oriented. Researchers were required to assess future feasibility, scientific value, translational potential, societal impact, implementation possibilities, and anticipated benefits before such outcomes could be directly observed.

The findings also suggest that anticipatory uncertainty may extend beyond concerns regarding future research productivity alone. Participants appeared to evaluate multiple possible futures simultaneously, including scientific, translational, societal, implementation-related, and practical futures. This implies that anticipatory uncertainty may be particularly relevant in innovation environments where multiple forms of future value must be considered concurrently. In this respect, the findings broaden understanding of the types of futures that may become objects of evaluation during research-direction decision-making.

Existing literature explains why expertise becomes distributed across actors, organisations, and disciplinary domains in complex innovation environments (Bamgboje-Ayodele et al., 2023; Reidy et al., 2023; Zhu et al., 2024). The current findings support these observations while suggesting an additional theoretical implication. Distributed expertise did not merely facilitate knowledge production or coordination. Instead, expertise appeared to become embedded within the evaluative process itself.

Through collective judgement, researchers were able to assess dimensions of future opportunities that would have been difficult to evaluate through individual expertise alone. This suggests that distributed expertise may contribute not only to the generation of knowledge, but also to the assessment of uncertain future possibilities. The findings therefore highlight the importance of collective evaluative capacity in environments characterised by interdisciplinary collaboration, technological complexity, and distributed knowledge.

The findings also reinforce arguments that uncertainty is not simply a temporary absence of information but an enduring feature of innovation and knowledge production (Borck & Lohse, 2026; Courtney et al., 1997; Lohse, 2023). Additional evidence frequently clarified particular questions while simultaneously generating new uncertainties and opportunities for investigation. In this respect, the findings support perspectives that view uncertainty as an ongoing condition of innovation rather than a problem that can be fully resolved through further information generation.

Additional implications emerge when the findings are considered through the NASSS framework. NASSS conceptualises innovation as unfolding within interacting domains of complexity and uncertainty that influence adoption, implementation, and sustainability (Greenhalgh & Abimbola, 2019). The findings are broadly consistent with this perspective. Participants encountered uncertainty relating to technologies, evidence, stakeholders, implementation considerations, and organisational constraints while evaluating future possibilities whose eventual value remained uncertain.

Taken together, the findings suggest that research-direction evaluation occurs within environments characterised by interacting forms of complexity and future-oriented uncertainty. In this respect, NASSS and anticipatory uncertainty provide complementary perspectives. NASSS highlights the interacting sources of complexity surrounding innovation processes, whereas anticipatory uncertainty highlights the challenge of evaluating possible futures before their outcomes can be known. The findings provide insight into how researchers appeared to navigate these conditions while continuing to evaluate opportunities and move forward despite persistent uncertainty.

Taken together, these theoretical implications suggest that research-direction decisions occur at the intersection of future-oriented evaluation, distributed expertise, innovation complexity, and persistent uncertainty. The findings provide insight into how these conditions relate to one another and how researchers remain capable of evaluation and action despite unresolved uncertainty.

6. Conclusion

Determining future research directions is an important yet challenging aspect of scientific research, particularly in environments characterised by rapid technological change, evolving opportunities, and persistent uncertainty. These challenges are especially evident within AI-integrated biotech health technology innovation, where researchers must frequently make decisions despite incomplete knowledge regarding future feasibility, impact, applications, and value.

This thesis examined how researchers evaluate alternative opportunities and become able to commit to particular research directions under such conditions. The discussion chapter showed that researchers navigated persistent uncertainty through the interaction of collective judgement, opportunity evaluation, and evidence generation and interpretation. Together, these processes contributed to the development of sufficient confidence for continued investment despite unresolved uncertainty.

Building on these findings, this concluding chapter discusses the study's main contribution, practical implications, limitations, and directions for future research.

6.1 Main contribution

This study contributes to understanding how researchers evaluate opportunities and become able to commit to future research directions under conditions of persistent uncertainty. Rather than proposing a new theory of research-direction decision-making, the study offers an empirically grounded interpretation based on the experiences of researchers working within an AI-integrated biotech health technology innovation context.

The principal interpretive contribution emerging from the study is the concept of confidence construction. Existing literature provides valuable explanations for why uncertainty persists, why future-oriented evaluation is necessary, and why important decisions frequently need to be made before future outcomes can be fully known. Comparatively less attention, however, has been devoted to understanding how researchers become able to continue investing in particular directions when important uncertainties remain unresolved. The findings suggest that confidence construction may help explain how commitment became possible despite persistent uncertainty. In this sense, confidence construction provides an interpretive perspective on how researchers appeared to move forward before certainty had been achieved.

This interpretation is grounded in three interconnected findings. Collective judgement enabled distributed expertise to become part of the evaluative process, future-oriented opportunity evaluation enabled researchers to assess uncertain possibilities whose outcomes could not yet be observed, and evidence generation and interpretation provided empirical support for continued investment. Together, these processes helped explain how researchers appeared to move from evaluation to commitment despite persistent uncertainty.

The study therefore suggests that commitment should not be understood solely as the outcome of uncertainty reduction. Rather, commitment appeared to emerge when opportunities became sufficiently assessable, justifiable, and evidentially supported for continued investment despite important unknowns remaining present. Confidence construction captures this process by explaining how researchers developed a sufficiently robust basis for action while certainty remained unattainable.

While confidence construction should be understood as an interpretive concept developed from a specific empirical context, it provides an empirically grounded perspective on how commitment may become possible under persistent uncertainty. In doing so, the study

contributes to understanding how researchers continue evaluating, prioritising, and investing in future directions despite incomplete knowledge regarding their eventual feasibility, value, and impact.

6.2 Management of Technology perspective

This thesis was conducted within the context of a Master's degree in Management of Technology (MOT). Throughout the programme, particular emphasis was placed on understanding how technological opportunities are identified, evaluated, prioritised, and translated into action within environments characterised by uncertainty and complexity. The findings of this study demonstrate the relevance of these themes within AI-integrated biotech health technology innovation.

A central insight gained through the study is that technological opportunities cannot be evaluated solely on the basis of technical performance or scientific novelty. Researchers were required to make decisions regarding where expertise, time, attention, and resources should be invested long before the eventual value of a technology could be determined. From a MOT perspective, this highlights the importance of future-oriented opportunity evaluation and resource-allocation decisions during the early stages of technological development.

The study also emphasises the importance of knowledge integration, a recurring theme within MOT. Evaluating uncertain opportunities required expertise distributed across multiple individuals, disciplines, and domains. The findings therefore demonstrate that technology management is not only concerned with managing technologies themselves, but also with coordinating the knowledge required to assess and develop those technologies.

In addition, the study illustrates how emerging technologies reshape the conditions under which innovation occurs. AI influenced expertise requirements, expanded opportunity spaces, and altered evidential capabilities. Rather than functioning simply as a technological tool, AI affected the broader environment within which evaluation and decision making took place.

Perhaps most importantly, the study reinforced a broader MOT lesson that uncertainty is not necessarily a problem that can be eliminated before action occurs. Instead, technological development frequently requires commitments to be made before future outcomes are known. From a MOT perspective, confidence construction may be understood as the process through which technological opportunities become sufficiently justified for continued investment despite persistent uncertainty. This highlights that technology management involves not only evaluating technologies, but also developing a sufficiently robust basis for committing resources to particular innovation trajectories. Confidence construction therefore provides insight into how decisions concerning technological opportunities can move from evaluation to commitment before their eventual value has been fully established.

Viewed in this way, the findings suggest that a MOT perspective is particularly valuable for understanding how technological opportunities move from possibility to commitment. The study highlights how opportunity evaluation, knowledge integration, evidence generation and interpretation, and resource allocation interact when decisions must be made before future outcomes are known. More broadly, the findings suggest that effective technology management may depend less on eliminating uncertainty and more on developing a sufficiently informed basis for action within uncertain and evolving innovation environments.

6.3 Practical implications

Researchers

A key implication for researchers is that uncertainty should be recognised as an enduring feature of research rather than a problem that must be eliminated before action can occur. Waiting for complete certainty before committing to a research direction is often unrealistic, particularly in rapidly evolving fields characterised by technological change, interdisciplinary dependencies, and uncertain future outcomes.

Instead, researchers may benefit from approaching uncertainty as something that can be navigated through opportunity evaluation, evidence generation and interpretation, and engagement with expertise distributed across collaborators, supervisors, and research networks. Seeking diverse perspectives and continuously evaluating emerging evidence may support more informed evaluations of potential research directions even when important unknowns remain.

The findings also suggest that researchers should explicitly consider multiple possible future trajectories when evaluating opportunities. Decisions were frequently made before scientific, translational, societal, or practical outcomes could be directly observed. Consequently, evaluating opportunities may require researchers to consider not only current evidence, but also potential future applications, impacts, implementation challenges, and value-creation possibilities.

The findings further suggest that research-direction decisions benefit from ongoing reassessment rather than one-off evaluations. Rather than treating commitment as a final choice, researchers may benefit from viewing commitment as provisional and revisable. Opportunities were continually reassessed as new evidence emerged, making adaptation an important component of research-direction decision making.

More broadly, the findings suggest that researchers may benefit from focusing on developing a sufficiently robust basis for action rather than attempting to eliminate uncertainty entirely. Confidence appeared to develop through collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation, enabling continued investment in promising directions despite unresolved unknowns.

Principal investigators and research leaders

The findings indicate that principal investigators and research leaders play an important role in shaping the conditions under which research-direction decisions are made. Because future opportunities often require expertise distributed across multiple disciplines and domains, effective evaluation depends upon access to diverse perspectives and specialised forms of knowledge.

A key implication is that principal investigators should actively support evaluation processes that draw on diverse forms of expertise. Creating opportunities for interdisciplinary collaboration, specialist input, and critical discussion may help support collective judgement. The findings suggest that uncertain opportunities became more assessable when expertise from multiple domains could be integrated into the evaluation process.

Research leaders may also benefit from recognising that research-direction decisions rarely occur as single events. Instead, opportunities are continually reassessed as new evidence emerges. Supporting recurring evaluation, reflection, and reassessment throughout the research process may therefore help teams adapt priorities and respond to changing scientific and technological conditions.

More broadly, the findings suggest that research leaders should focus on creating conditions that support informed evaluation under uncertainty. Establishing regular review moments, involving relevant specialists in key decisions, and encouraging discussion of alternative

directions may broaden the basis upon which research-direction decisions are made in rapidly changing environments.

Innovation management

A key implication for innovation managers is that resource-allocation decisions frequently need to be made before the future value of an opportunity can be established. This challenge is particularly relevant when evaluating emerging technologies, where scientific, technological, translational, and implementation-related uncertainties remain substantial.

Rather than delaying decisions until uncertainty has been significantly reduced, innovation managers may benefit from recognising that continued investment often depends upon developing sufficient confidence rather than achieving certainty. The findings suggest that resource-allocation decisions frequently relied on the gradual development of confidence that an opportunity remained worthy of further investment despite unresolved uncertainty.

Opportunity selection may therefore be approached as an iterative process involving periodic reassessment, evidence generation, and refinement as new information becomes available. In practice, this may require governance approaches that support staged investment, ongoing review, and flexibility in the allocation of resources across competing opportunities.

The findings also suggest that effective evaluation benefits from access to diverse forms of expertise. Innovation managers should therefore create opportunities for interaction between experts from relevant scientific, technical, clinical, and application domains when assessing future directions. Structured interdisciplinary discussions may broaden the basis upon which opportunities are evaluated before significant resources are committed.

In addition, the findings suggest that experimentation, validation activities, pilot investigations, and other forms of evidential work play a dual role. Beyond generating knowledge, they help decision makers evaluate whether opportunities remain sufficiently credible, feasible, and worthwhile to justify continued investment. Such activities therefore contribute to decision making as well as learning.

Across researchers, research leaders, and innovation managers, the findings suggest that effective decision making under uncertainty depends upon processes that support collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation. Together, these processes appeared to contribute to the development of sufficient confidence for continued investment despite unresolved uncertainty. From a practical perspective, the findings suggest that effective action may depend less on eliminating uncertainty and more on developing a sufficiently informed basis for commitment while uncertainty remains present.

6.4 Limitations

While this study provides insights into how researchers evaluate opportunities and navigate uncertainty when determining future research directions, several limitations determine boundaries regarding the contexts, actors, and processes to which the findings may apply.

Contextual boundary

The findings were developed within AI-integrated biotech health technology innovation during the development of an early-stage precision medicine technology in the Netherlands. Although the confidence-construction process identified in this study may extend beyond this context, the findings should therefore be interpreted as an analytical explanation developed from a specific empirical setting rather than as a universally applicable claim about how research-direction decisions occur across all innovation environments. In addition, the findings may partly reflect characteristics of the particular research project, organisational environment, leadership structures, and collaborative practices within which participants were operating. The

relative importance and interaction of the identified processes may therefore differ across research settings, such as industrial R&D, engineering innovation, or basic scientific research.

Researcher perspective

This study focused exclusively on researchers. Consequently, the findings explain how researchers evaluate opportunities and navigate uncertainty but do not capture the perspectives of other actors who may influence research-direction decisions, including funders, clinicians, regulators, policymakers, and industry partners. Future research may therefore reveal additional mechanisms through which research directions are shaped across broader innovation ecosystems.

In addition, participant recruitment partly relied on professional networks connected to the supervisory team. While this facilitated access to a specialised interdisciplinary research environment and enabled the inclusion of participants with relevant experience, it may also have influenced which perspectives were represented within the sample. Researchers with different experiences, more critical viewpoints, or lower levels of engagement with the project may therefore be underrepresented. The findings should consequently be interpreted as reflecting the perspectives of participating researchers rather than a complete representation of all viewpoints that may exist within similar innovation environments. The collaborative and interdisciplinary nature of the research environment may also have increased the prominence of collective interactions and distributed expertise within participants' accounts. Consequently, the importance of collective judgement identified in this study may partly reflect characteristics of the sampled environment as well as the underlying phenomenon being investigated.

Temporal boundary

The findings are based on researchers' retrospective accounts of research-direction evaluation rather than longitudinal observation of decision-making processes as they unfolded over time. As a result, the study explains how participants described the development of confidence and commitment but cannot fully capture how these processes evolved in real time. Longitudinal research may therefore provide deeper insight into how confidence develops, shifts, and is revised throughout the course of technological development.

Interpretive boundary

The concept of confidence construction represents an interpretive concept developed through cross-theme analysis rather than a participant-derived category. As such, alternative interpretations of the relationships observed across the dataset may be possible. However, confidence construction was considered the most coherent explanation of how collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation combined to enable commitment despite persistent uncertainty. The concept should therefore be understood as an interpretive explanation grounded in the analysed dataset rather than as a definitive account of how commitment emerges across all research and innovation contexts.

6.5 Future research

Several opportunities for future research emerge from the limitations of this study.

First, future studies could examine whether the confidence-construction process identified in this thesis operates similarly across other innovation contexts and scientific domains. Comparative research across settings such as industrial R&D, engineering innovation, and basic scientific research could help determine which aspects of the process are context-specific and which are more broadly transferable.

Second, longitudinal research could investigate how confidence develops over time and how commitments evolve as new evidence is generated and interpreted and as new uncertainties emerge. Such research would provide greater insight into how research directions are maintained, adapted, or abandoned throughout innovation processes.

Third, future research could examine collective judgement at the team level by exploring how interdisciplinary teams assemble, negotiate, and maintain shared evaluations of uncertain opportunities. While the present study identified collective judgement as an important mechanism, additional research could provide deeper insight into how these processes unfold in practice.

Finally, future studies could investigate how emerging AI capabilities continue to reshape expertise requirements, opportunity spaces, uncertainty conditions, and evidence-generation practices. As AI technologies continue to evolve, their influence on research-direction evaluation may also change.

Taken together, these directions suggest that the confidence-construction process identified in this thesis should be viewed as a foundation for further investigation rather than a definitive explanation of research-direction decision making under uncertainty.

6.6 Final conclusion

This thesis examined how researchers evaluate alternative research opportunities and navigate uncertainty when determining future research directions in AI-integrated biotech health technology innovation. The findings suggest that uncertainty remains an enduring feature of research-direction decision-making and that important decisions frequently need to be made despite incomplete knowledge regarding future feasibility, value, and impact.

Although the study was conducted within an AI-integrated biotech health technology innovation context, the findings suggest that the processes identified may provide insight into how researchers navigate uncertainty more broadly. Researchers appeared to evaluate future opportunities through the interaction of collective judgement, future-oriented opportunity evaluation, and evidence generation and interpretation while important uncertainties remained unresolved.

The central conclusion of this thesis is that research-direction decisions cannot be explained solely through uncertainty reduction. Rather, the findings suggest that confidence construction may help explain how researchers became able to commit to future directions despite persistent uncertainty. While this interpretation is grounded in a specific empirical context, it provides insight into how action and commitment may become possible before certainty has been achieved. Rather than waiting for certainty, researchers appeared to move forward by developing sufficient confidence to act despite persistent uncertainty.

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Use of AI

AI tools were used to support several aspects of the thesis process. AI was used to assist with the development and refinement of chapter and section outlines and to review drafts of the thesis for structure, coherence, argumentation, and alignment with qualitative research principles and methodological guidelines. These activities were supported using Microsoft Copilot made available through TU Delft. The version used includes Enterprise Data Protection (EDP), which provides organisational data-protection safeguards during use.

AI was used solely as a support tool and was not used to generate original research findings, conduct data analyses, develop codes or themes, perform the cross-theme analysis, interpret interview data, develop the concept of confidence construction, or draw conclusions. All decisions regarding the inclusion of literature, methodological choices, coding, theme development, analysis, interpretation, argumentation, and final writing remained the responsibility of the author. All AI-generated suggestions were critically evaluated, adapted where necessary, and only incorporated when considered appropriate and consistent with the research objectives and findings.

Appendix

A. Interview protocol

A.1 Study introduction

Before the start of the interview, participants received information regarding:

- Purpose of the study
- Reason for their selection
- Expected interview duration
- Voluntary participation
- Confidentiality and anonymity
- Right to withdraw
- Recording and data storage procedures

Participants are asked for consent before recording commenced.

A.2 Interview structure

Section 1: participant background

To understand the participant's role, research activities, and position within the project.

Example questions

- Could you briefly describe your current role in the project?
- What type of research are you involved in?
- How long have you been involved in this project?
- To what extent are you involved in decisions about future research directions?

Section 2: research-direction situation

To identify a concrete situation in which the participant considered future research directions.

Example questions

- Can you describe a situation in which a decision had to be made about a future research direction?
- What triggered this decision?
- What alternative directions were being considered?
- Why was this situation important for the project?

Follow-up questions

- Who was involved?
- When did this occur?
- What was at stake?

Section 3: uncertainty

To explore uncertainties encountered during the situation.

Related research question: SQ1

Example questions

- What was uncertain at the time?
- What information was unavailable?
- What made the situation difficult to evaluate?
- Were there uncertainties regarding the technology, research process, or future outcomes?

Follow-up questions

- How important was this uncertainty for the decision?
- Did different people view the uncertainty differently?
- Did the uncertainty change over time?

Section 4: evaluation of alternatives

To understand how opportunities and research directions were evaluated.

Related research question: SQ2

Example questions

- What options were available?
- How were these options compared?
- What information did you use to evaluate the alternatives?
- What made one option appear more attractive than another?

Follow-up questions

- Were there specific criteria that influenced the evaluation?
- How did uncertainty affect the comparison of alternatives?
- Were some alternatives rejected early? Why?

Section 5: decision-making and navigation strategies

To explore how participants acted despite uncertainty.

Related research question: SQ3

Example questions

- How was the final decision reached?
- What helped you move forward despite uncertainty?
- Were there strategies used to reduce uncertainty?
- Did you keep alternative options open?

Follow-up questions

- Did you seek additional information?
- Did you postpone parts of the decision?
- Did you change the direction later?

Section 6: stakeholders and constraints

To understand contextual influences on the decision.

Example questions

- Were other people involved in the decision?
- What role did they play?
- Were there resource limitations or practical constraints?
- Did funding, expertise, timelines, or organisational priorities influence the decision?

Follow-up questions

- Did different stakeholders have different preferences?
- Were there disagreements?
- How were competing priorities managed?

Section 7: general probing questions

- Could you tell me more about that?
- Could you give an example?
- Why was that important?
- How did that affect the decision?
- What happened next?
- How did other team members respond?
- How certain were you at that moment?
- What information would have helped you most?

A.3 Participant overview

Expert 1 (P1): biomedical researcher

Expert 2 (P2): technology translation researcher

Expert 3 (P3): biomedical researcher

Expert 4 (P4): biomedical researcher

Expert 5 (P5): computational researcher

Expert 6 (P6): biomedical researcher

Expert 7 (P7): technology translation researcher

Expert 8 (P8): computational researcher

B. RTA evidence tables

B.1 Thematic structure

Table 4. Hierarchical structure of themes, sub-themes, organizing concepts, and interpretive meanings. The organizing concepts represent interpretive patterns identified across code clusters and provide the analytical building blocks underpinning each sub-theme and theme.

Theme	Sub-theme	Organizing concept	Concept interpretation
1. Building collective judgement through distributed expertise	Building collective judgement through distributed expertise	Mobilising expertise	Researchers access, coordinate, and develop expertise to evaluate opportunities that exceed individual knowledge.
		Building collaborative research networks	Collective judgement emerges through collaboration, knowledge exchange, and interaction across research networks.
2. Evaluating research opportunities under persistent uncertainty	Balancing scientific ambition against practical constraints	Navigating research direction	Researchers evaluate, refine, and prioritise opportunities as they move from broad possibility spaces toward provisional commitments.
		Working within practical constraints	Opportunities are assessed in relation to feasibility, available resources, time horizons, and other practical constraints.
	Navigating uncertainty through iterative adaptation	Managing uncertainty	Researchers navigate uncertainty through ongoing adaptation, reflection, and reassessment rather than waiting for certainty.
		Building knowledge foundations	Existing knowledge, literature, and identified gaps provide foundations for evaluating future opportunities.
		Designing methodological approaches	Methodological and technological choices help researchers investigate uncertain opportunities and generate actionable knowledge.
	Orienting discovery toward future clinical impact	Translating research toward impact	Anticipated clinical, societal, and translational impacts shape the attractiveness of future research opportunities.
3. Constructing confidence through evidence	Establishing confidence in emerging	Building experimental systems	Researchers establish and refine experimental systems

generation and interpretation	research systems		that provide a foundation for credible future investigation.
		Designing and executing experiments	Experimental activities generate evidence used to assess assumptions, feasibility, and future research directions.
		Establishing trustworthy evidence	Validation and verification activities establish confidence in the credibility and reliability of emerging evidence.
	Transforming biological complexity into actionable knowledge	Conducting computational analysis	Computational methods transform complex biological data into evidence that can inform future decisions.
		Investigating biological mechanisms	Researchers seek mechanistic explanations that increase understanding of biological processes and strengthen confidence in findings.
		Producing and integrating knowledge	Researchers integrate evidence, interpretations, and explanations into knowledge that can support future commitments.

B.2 Theme definitions

Table 5. Theme definitions and central organising concepts.

Theme	Central organizing concept	Theme definition
1. Building collective judgement through distributed expertise	Research-direction evaluation emerges through collective rather than individual judgement.	Researchers evaluate opportunities through expertise distributed across people, disciplines, institutions, and collaborative networks.
2. Evaluating research opportunities under persistent uncertainty	Research opportunities are evaluated and pursued despite uncertainty remaining unresolved.	Researchers assess, prioritise, and refine opportunities by balancing feasibility, impact, constraints, and future potential under conditions of persistent uncertainty.
3. Constructing confidence through evidence generation and interpretation	Evidence must be actively constructed before researchers can justify future commitments.	Researchers construct confidence through experimentation, validation, analysis, and interpretation that transform uncertainty into actionable knowledge.

B.3 Analytical development process

B.3.1 Worked coding examples

Analytical development process. The analysis proceeded through a series of interpretive stages in which interview excerpts were coded, grouped into code clusters, developed into organizing concepts, and subsequently refined into sub-themes and themes. The sequence can be summarised as:

Excerpt (n=652) → Initial codes (n=1312) → Code cluster (n=59) → Organizing concept (n=14) → Sub-theme (n=6) → Theme (n=3)

This sequence is presented as a simplified representation of the analytical process rather than as a strictly linear procedure. Consistent with RTA, movement between levels of analysis was iterative and involved ongoing interpretation and refinement. Coding, clustering, and thematic development involved repeated movement between data, codes, candidate themes, and emerging interpretations.

Table 6. Illustrative examples of analytical development from interview excerpts to themes.

Interview extract	Initial code(s)	Code cluster	Organizing concept	Theme
“clinical care pathway of this chemotherapeutic drug and its effects on hematological toxicities, it appears to be cost-effective, so i think this is a promising direction.” (p2_053)	Assessing cost effectiveness; evaluating applications; selecting direction	Research direction selection	Navigating research direction	Evaluating research opportunities under persistent uncertainty
“in the end, it's all a model that somehow a little bit mimics the real body. And i think that we can already get a lot of knowledge from that.” (p4_012)	Using model system; comparing model to real body; assessing model usefulness	Platform & technology use	Building experimental systems	Constructing confidence through evidence generation and interpretation
“then even when he didn't have some knowledge for questions, he would then go to his supervisor too.” (p7_015)	Consulting supervisor's supervisor	Expertise seeking & acquisition	Mobilising expertise	Building collective judgement through distributed expertise
“i think the platform allows you to then branch out to also multiple, many different applications” (p8_025)	Expanding applications	Opportunity exploration	Navigating research direction	Evaluating research opportunities under persistent uncertainty

B.3.2 Theme development

Table 7. Summary of theme development and associated example code clusters and codes.

Theme	Number of code clusters	Example code clusters	Number of codes instances	Example codes
1. Building collective judgement through distributed expertise	10	Expertise seeking & acquisition; expertise gaps & limitations; collaboration building & maintenance; knowledge exchange & discussion	327	seeking expertise; collaborating with experts; combining expertise; matching expertise; brainstorming ideas; seeking stakeholder input
2. Evaluating research opportunities under persistent uncertainty	27	Feasibility assessment; constraint assessment; method development; literature engagement	735	assessing feasibility; identifying limitations; evaluating constraints; assessing impact; reviewing literature; applying health technology assessment
3. Constructing confidence through evidence generation and interpretation	22	Experimental design; validation & verification; computational analysis; knowledge generation	438	conducting preliminary studies; testing assumptions; validating results; validating model; assessing robustness; controlling conditions