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Review

The functional resonance analysis method in healthcare: How knowledge is produced within and across scientific communities

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ABSTRACT

The Functional Resonance Analysis Method (FRAM) is a valuable tool for understanding and improving complex socio-technical healthcare systems. This Focused Mapping Review and Synthesis (FMRS) explores how the FRAM is used to produce knowledge and create insight about healthcare systems across three scientific communities: safety/engineering, human factors/cognitive science, and healthcare/health services research. We examined 33 included studies and identified key themes in how FRAM is applied within and across communities. The review highlights the critical role of knowledge brokers and boundary spanners in fostering interdisciplinary collaboration and knowledge transfer. There is limited epistemological clarity in most studies, which complicates cross-study comparisons and practical application. In addition, most studies are descriptive and do not develop actionable and robust interventions. We argue for greater transparency in epistemological positioning, methodological reflexivity, and the development of reporting guidelines to enhance the consistency and utility of FRAM studies. This review is a conceptual synthesis rather than a proof of concept. Future empirical studies should test whether explicit articulation of epistemological assumptions improves FRAM analyses, using the probes identified in this review as a starting point.

1. Introduction

The Functional Resonance Analysis Method (FRAM) has gained significant traction in healthcare, as evidenced by a growing body of literature (McGill et al., 2022, McGill et al., 2023). The FRAM is increasingly seen as a valuable tool for understanding the complex dynamics of healthcare systems and for shedding light on persistent challenges in patient safety (Sujan et al., 2023). Unlike traditional approaches that tend to focus on errors and failures, the FRAM offers a complementary lens for examining how everyday work processes unfold (Hollnagel, 2012). Particularly in healthcare environments, in which there is a continuous need for safe services despite relentless fluctuating demand, dynamic contexts, and resource constraints, an understanding of the nature of variability becomes even more important. Health systems often operate under conditions of chronic resource constraint, conflicting goals, and political pressures, which introduce tensions and trade-offs that cascade down to affect everyday clinical work (Page et al., 2023). For example, winter pressures may cause a surge in demand for emergency services, which may respond flexibly by temporarily changing how they triage patients, where patients are treated (e.g., non-critical patients being moved to corridors), and how they move patients (e.g., admitting patients into hospital before a diagnosis is made). Understanding variability at the system level is therefore crucial, as it not only sets the context for local adaptations but also influences the resilience, or brittleness, of healthcare delivery as a whole (Jatobá et al., 2025).

The FRAM is characterised by a focus on understanding normal work, or "work-as-done" and offers a non-normative perspective on system misalignments, pressures, and trade-offs that drive adaptations (Furniss et al., 2020). The FRAM offers a structured way to represent the key activities that make up a process using visual models. In these models, each activity is illustrated as a 'function', typically shown as a

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hexagon with six labeled 'aspects' that capture different dimensions of the function's role and influence. FRAM models can be constructed using diverse sources of data, such as clinical guidelines, direct observations, or interviews with frontline staff. Examples of a graphical FRAM instantiation can be found in previous studies that have applied FRAM in healthcare settings (Damen et al., 2021; Patriarca et al., 2020). Rather than viewing safety, and hence safety management, as an effort to reduce the number of things going wrong (i.e., decremental safety approaches), more recent safety theories shift the focus to what goes right and how adjustments enable successful outcomes, i.e., incremental safety practices (Hollnagel, 2014). This systems perspective makes the FRAM particularly well-suited for analysing contexts such as healthcare, which has been described as a complex adaptive system where variability and complexity are the norms rather than the exceptions (Braithwaite et al., 2013).

Given the growing interest in the FRAM as a tool to improve safety in healthcare, it is important to understand how this method is being applied and with what kinds of theoretical underpinnings across different safety-related scientific communities. Different communities have different scientific traditions and priorities, and different perspectives on how knowledge is created and communicated. This can influence the way in which methods such as the FRAM are understood and applied. We can expect variability with respect to the types of issues the FRAM is applied to, how data are collected, what kinds of findings are constructed, and how these findings are interpreted and communicated. In order to advance the theory and practice of applying the FRAM in healthcare, similarities and differences across scientific communities should be explored and made explicit. This will help to describe both variability as well as best practices, and it can help improve the reporting quality of studies that apply the FRAM.

To explore the use of the FRAM in healthcare across different scientific communities, we undertook a Focused Mapping Review and Synthesis (FMRS), a recent type of literature review that distinguishes itself from other forms of reviews by focusing on how knowledge within a field is constructed and how knowledge production varies by scientific community (Bradbury-Jones et al., 2019). Therefore, a FMRS does not seek to exhaustively collate all "evidence" on a given topic or problem but rather looks selectively at the nature of scientific discourse on a specific topic within and across communities. As this is a mapping review, the product is a conceptual synthesis rather than an empirical demonstration.

Specifically, the aims for this study were:

- Describe the key features and topography of how the FRAM is applied in healthcare contexts and how this varies across scientific communities.
- Examine how knowledge is constructed through use of the FRAM in healthcare.
- Discuss recommendations for planning and reporting studies that aim to apply the FRAM in healthcare settings.

The next section describes the review approach. Then, we report the results of the review and discuss the implications and limitations of the findings. In the concluding section, we provide an outlook and recommendations for undertaking and reporting FRAM studies in healthcare.

2. Method

2.1. Focused mapping review and synthesis

FMRS is a recent type of literature review, first applied in 2017, and then described more formally in 2019 (Bradbury-Jones et al., 2019; Jones et al., 2017). Bradbury-Jones and colleagues state that the aim of FMRS is "to address epistemological questions that relate to a particular research field" (Bradbury-Jones et al., 2019). This focus on exploring knowledge production within a field distinguishes the FMRS approach from other types of literature reviews, such as Systematic Reviews and Scoping Reviews (Arksey and O'Malley, 2005; Liberati et al., 2009), which appraise and map the existing body of evidence relating to a particular question.

FMRS entails three steps (Bradbury-Jones et al., 2019): focus, mapping and synthesis. In the first phase (focus), the review aims are developed, inclusion and exclusion criteria are specified, and target journals and a relevant time frame are selected for the searches. FMRS emphasises focused searches over exhaustive search, i.e., there is deliberately no attempt to track down every single article written on the topic of the review. Instead, within FMRS, the analysts select key journals in advance, which act as proxies for the respective scientific communities. Selection of the publication time frame is done pragmatically to strike a balance between having sufficient data and the corresponding effort required for undertaking the review. Mapping is done using a data extraction template specific to the review aims, and this can combine both quantitative and qualitative data. Within the mapping stage calibration is possible, whereby the extraction template can be adjusted as the review progresses better to accommodate data to facilitate analysis and interpretation. Synthesis can be done using aggregates (quantitative data) and by theming the (qualitative) data. Mapping and synthesis are done both within communities (i.e., journals) as well as across communities. See Fig. 1.

2.2. Review aims

As described above, this study aimed to examine how knowledge is constructed in studies that apply the FRAM in healthcare, both within and across different scientific communities. Building on this, suggestions for advancing the theory and practice of the FRAM in healthcare can be developed.

The focus on knowledge production suggests that the FMRS approach would be the best suited review approach. In addition, the authors were also interested in exploring and demonstrating the application of this recent review approach in the field of safety science.

2.3. Focus

Based on a broad understanding of the FRAM publication landscape through prior reviews (Patriarca et al., 2020; Salehi et al., 2021) and the authors' own familiarity with the topic, we selected three relevant scientific communities for further in-depth study. The application of the FRAM in healthcare has been reported frequently in the safety and engineering community, in the human factors and cognitive science community, and in the healthcare and health services research community. These three broad communities were selected for the review, and then representative journals were identified for each community based on the standing of the journal in the community and the availability of FRAM articles published in these journals. For the healthcare community, we selected a larger number of journals because of the small number of FRAM studies published in each journal. This led to the following grouping of journals by community:

- Safety/Engineering Community: Safety Science journal; Reliability Engineering and System Safety journal
- Human Factors/Cognitive Science Community: Applied Ergonomics journal; Cognition, Technology and Work journal
- Healthcare Community: BMC Health Services Research journal; BMJ Open Qual journal; Implementation Science journal; BMC Medicine journal; Annals of Emergency Medicine journal; Advances in Simulation journal

The list above includes only journals that have at least one relevant published FRAM study as of July 2023 and, therefore, excludes other journals that might also have a high standing within their respective community. The above journals were searched in July 2023 using

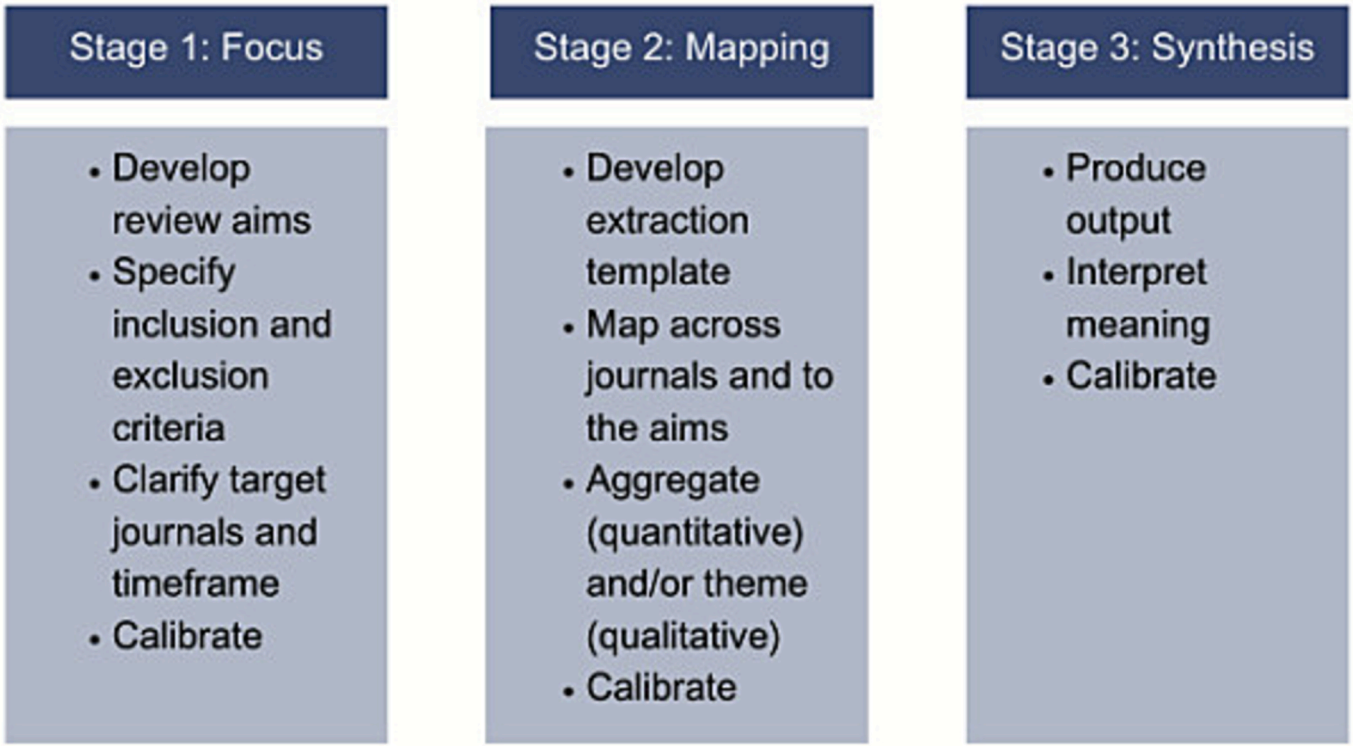

Fig. 1. Adapted from Bradbury-Jones and colleagues' "Advancing the science of literature reviewing in social research: The focused mapping review and synthesis" (2019) (Bradbury-Jones et al., 2019).

"FRAM healthcare" and "Functional resonance healthcare" search terms. All resulting articles were exported into Microsoft Excel and screened for eligibility as per the criteria below.

2.4. Inclusion and exclusion criteria

Two authors (OL, MS) initially reviewed a set of six articles from initial searches to develop and refine the inclusion and exclusion criteria. Based on this preliminary screening, the following criteria shown in Table 1 were adopted.

Table 1
Inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Type	Empirical work that describes the application of the FRAM	Reflection articles, literature reviews, hypothetical applications of the FRAM
Geography	Any country	–
Setting	All healthcare settings, including primary care, secondary care, and social care	–
Date Range	Published January 2015 – July 2023	–
Journals	Published in any of the following: ● Safety/Engineering Community: Safety Science; Reliability Engineering and System Safety ● Human Factors/Cognitive Science Community: Applied Ergonomics; Cognition, Technology and Work ● Healthcare Community: BMC Health Services Research; BMJ Open Qual; Implementation Science; BMC Medicine; Annals of Emerg Med; Advances in Simulation	Articles published in other journals

2.5. Article screening

Articles were exported and stored in Microsoft Excel for review and deduplication. Titles and abstracts were screened independently by two authors. Disagreements were reconciled in discussions between authors.

All included full texts were reviewed by one author (OL). Thirty percent of the full texts were also reviewed by a second author (MS). Extracted data were reviewed, discussed, and reconciled between two authors on a fortnightly basis. Core details were extracted from all included articles, per the extraction template (Table 2). The template was calibrated throughout data extraction to accommodate the characteristics of the data.

2.6. Data extraction and mapping

The initial data extraction template was developed by two authors with expertise in the FRAM (MS, OL) and was used to extract data from all included studies. After the first round of extraction, the findings were discussed with the larger group of authors with expertise in the FRAM (MS, OL, RP, LP, MdV), and the extraction template was modified based on the discussion of the results from the first round. All articles were

Table 2
Data extraction template.

Authors	Full author list
Aims	What were the aims? (Multiple choices possible) ● Used to illuminate problems/opportunities for improvement ● Used to inform interventions/facilitate implementation ● Used to advance the method/theory ● Used to advance the method/theory alongside other approaches
Epistemology	Did the authors explicitly state their epistemology? (Y/N) Realist, constructivist, or unclear?
Use of Theory	Free text
Data Collection	Free text

reviewed a second time by one author (OL) with the calibrated extraction template.

We extracted data about the journal in which each study was published and the list of authors. The journal information was used to categorise the paper into the corresponding scientific community. The list of authors was analysed to assess cross-community collaboration by identifying whether individual authors had published in multiple scientific communities. This analysis also involved examining the authors of each paper to determine the extent of interdisciplinary publishing and collaboration across different communities.

We developed four article/study aims categories based on reflections from a previous review (Patriarca et al., 2020) and discussion with the wider team. Aim categories were discussed, iteratively developed and refined based on the articles reviewed. The aims classification applies to only the application of the FRAM. Therefore, if the application of the FRAM was but one section within other sections of an article, only the application of the FRAM was considered in this analysis. More than one aim category could be selected per article.

Knowledge construction is related to the mindset of the analyst using the FRAM and their underlying beliefs and assumptions about how we can come to know things about the world (or a system or a specific issue). In philosophical and scientific debate this is commonly referred to as epistemology. We included epistemological clarity in the extraction template. Having clarity about the analyst's epistemological perspective is important because it will influence what kinds of data are collected, how they are analysed and interpreted (Braun, 2021). For example, the underlying epistemology in FRAM studies will affect how the analyst studies and interprets concepts such as work-as-done and performance variability. It also ensures that the knowledge constructed aligns with the purpose of the analysis, and it provides clarity and transparency to other stakeholders, including those that are a part of the specific studies as well as those within the wider research community. While there is a lot of deep and philosophical debate about epistemology, for the purpose of this review we adopted a simple and broad distinction as to whether the underlying epistemology was largely realist, constructivist or remained unclear, see Box 1.

The intention is not to assign an unambiguous label to the respective epistemological stance per se, but rather to gauge the extent to which authors are aware and self-reflective of their epistemology, and where they broadly sit on this simple spectrum between realist and constructivist paradigms.

The next data item to be extracted is the link to theory. As described by Hollnagel, the FRAM uses four theoretical principles (Hollnagel, 2012): (1) equivalence of success and failure; (2) approximate adjustments; (3) emergence; and (4) functional resonance. These theoretical principles could be regarded as the theory that is "built into" the FRAM, because the analyst is guided by the steps of the method to focus on work-as-done in different contexts, to consider variability, to study how functions interact to produce outcomes, and to apply in some shape and form the principle of resonance as the detectable signal that emerges from everyday performance variability of many interacting functions. Any study applying the FRAM should include these theoretical principles by default. However, the FRAM was developed within a broader theoretical debate and scientific discourse about safety. The fields of Resilience Engineering as well as Safety-II provide important theoretical underpinnings to situate the application of the FRAM within the wider safety science context (Hollnagel, 2014). We included the use of theory with specific interest in whether researchers expanded on the FRAM's built-in theory by referencing wider resilience theory or used the FRAM's built-in theory alone. If they used broader theoretical concepts, we were also interested in understanding whether this was done to motivate the study, e.g., in the introduction, whether theory was used retrospectively, e.g., in the discussion, or whether the broader theoretical context was applied consistently to inform the research question, data collection and analysis, and, where applicable, intervention development.

Lastly, approaches to data collection were captured to understand the different methods used within FRAM communities. The final data extraction template is shown in Table 2.

2.7. Synthesis

Data from each community were first thematically analysed (qualitative data) and aggregated (quantitative data) in isolation to identify key themes specific to each context. Then, we compared the findings across communities to highlight similarities and differences in themes in an attempt to uncover community-specific patterns. Authorship was mapped to shed light on the extent to which authors published across communities.

3. Results

3.1. Bibliographic study characteristics

A total of 33 articles were included in the full text review, which included 13 from the Safety/Engineering community, 12 from the Human Factors/Cognitive Science community and eight from the Healthcare/Health Services Research community. The search was run in July 2023, therefore any papers published after July 2023 were not captured. Results for identification and screening are shown in the flowchart in Fig. 2. A summary of study characteristics in terms of scientific community, journal, first author and title is shown in Table 3.

3.2. Author characteristics

Of the 33 included papers, 23 (69.7 %) had at least one co-author who had collaborated on papers published across scientific communities. The mapping of authors who have published papers across communities is shown in Fig. 3. Authors who have published in just one community are not shown in the figure. To note, only publications included in the review are considered.

Box 1
Characteristics of realist and constructivist epistemologies used for this review.

A realist epistemology was characterised by indications that authors were attempting to reveal an objective reality. Indicators for such a stance might be attempts to objectively describe and quantify variability in order to compute bottlenecks and functional resonance.
A constructivist epistemology was characterised by indications that authors did not assume an objective reality but rather sought to explore how meaning was made by those involved in the work. Indicators for this stance, in turn, might be attempts to elicit and reconcile different accounts of variability in the system to understand system tensions people experience and the trade-offs they make.

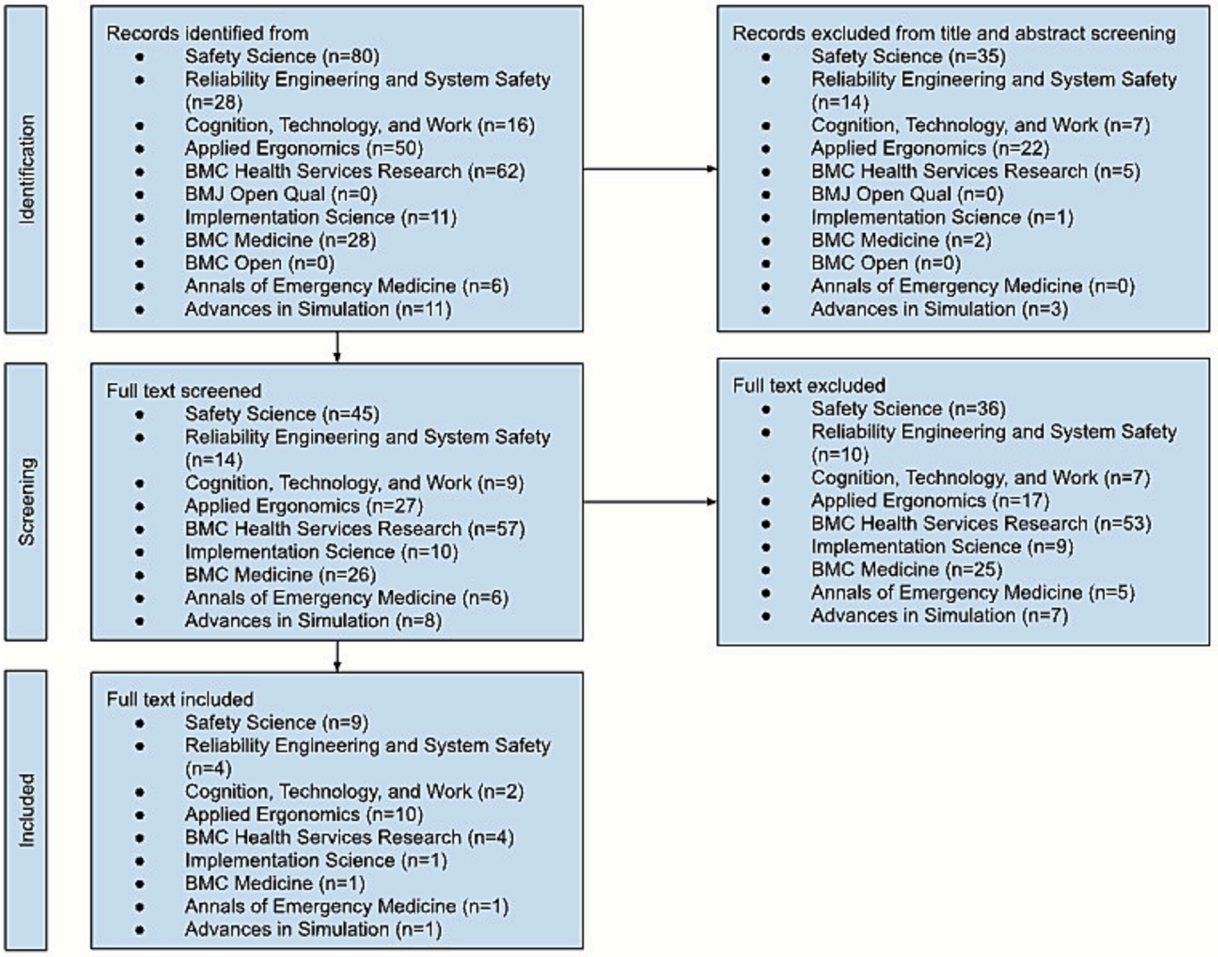

Fig. 2. Article identification and screening.

3.3. Aims by scientific community

Of the total 33 articles included in the study, most (n = 26) applied the FRAM to illuminate problems and opportunities for improvement, eight applied the FRAM to inform interventions and facilitate implementation, six applied the FRAM to advance the theory or method, and eight applied the FRAM to advance the theory or method alongside other theories or methods. The mapping of aims within each scientific community is shown in Fig. 4 and described in more detail in Table 4. Note that one paper could have applied more than one aim and therefore the percentages may add up to more than 100 %.

3.4. Epistemology by scientific community

Only two articles gave explicit clues about their epistemological perspective (Raben et al., 2018; Wachs and Saurin, 2018). Wachs and colleagues (Wachs and Saurin, 2018), in the Human Factors/Cognitive Science community, stated that their approach was rooted in "knowing through making" (see Table 5). Therefore, we classified this article as being based on a constructivist epistemology. Raben and colleagues (Raben et al., 2018), in the Safety/Engineering community, clarified their constructivist epistemology by explicitly stating that different researchers might obtain different results and whether other researchers would have arrived at the same leading indicators remains uncertain. Aside from these two examples of relative epistemological clarity, the epistemological approach to all other articles had to be inferred from less explicit indicators in the text. In addition to the lack of epistemological clarity, it was found that the healthcare/health services research community appears to favour realist applications of the FRAM, with no article in this community adopting a constructivist approach.

3.5. Theoretical visibility examples

By default, most studies refer to the theory that is built into the FRAM, either by describing explicitly the four theoretical principles or by implicitly operationalising them in their study design. However, we saw two prototypical scenarios across the included articles: studies that only relied on the four FRAM principles and studies that were informed by the broader theoretical constructs. In the latter case authors leveraged the wider theoretical context to design and interpret their FRAM study. Illustrative examples for each scenario are shown in Box 2 and Box 3.

3.6. Data collection methods by scientific community

Across all communities, interviews, document review, and observation were the most common data collection methods, see Table 6.

4. Discussion

We conducted this Focused Mapping Review and Synthesis to understand how the FRAM has been applied in healthcare and how knowledge is constructed in healthcare FRAM studies across three scientific communities – safety/engineering, human factors/cognitive science, and healthcare/health services research. The findings suggest that, encouragingly, there was significant collaboration across these

Table 3
Bibliographic study characteristics.

Community	Journal	First author (date)	Title
Safety/ Engineering	Safety Science	Arcuri et al (2020)	Gatekeeper family doctors operating a decentralized referral prioritization system: Uncovering improvements in system resilience through a grounded-based approach
		Buikstra et al (2020)	Understanding variability in discharge planning processes for the older person
		Damoiseaux-Volman et al (2021)	Falls and delirium in older inpatients: Work-as-imagined, work-as-done and preferences for clinical decision support system
		Kaya et al (2019)	Using the functional resonance analysis method on the drug administration process to assess performance variability
		Safi et al (2023)	FRAM and LEAN as tools for describing and improving the referral process between outpatient clinics in a Danish Hospital: Complementary or conflicting?
		Schutijser et al (2019)	Double checking injectable medication administration: Does the protocol fit clinical practice?
		Slater et al (2022)	A systems analysis of the COVID-19 pandemic response in the United Kingdom – Part 1 – The overall context
		Slater et al (2022)	A systems analysis of the UK COVID 19 pandemic response: Part 2-Work as imagined vs work as done
		van Dijk et al (2022)	Daily practice performance (Work-as-Done) compared to guidelines (Work-as-Imagined) of medication reconciliation at discharge: Outcomes of a FRAM study
	Reliability Engineering and System Safety	Patriarca et al (2018)	Resilience engineering for socio-technical risk analysis: Application in neuro-surgery
		Raben et al (2018)	Application of a non-linear model to understand healthcare processes: Using the functional resonance analysis method on a case study of the early detection of sepsis
		Raben et al (2018)	Learn from what goes right: A demonstration of a new systematic method for identification of leading indicators in healthcare
		Saurin & Werle (2017)	A framework analysis of slack in socio-technical systems
Human Factors/ Cognitive Science	Applied Ergonomics	Arcuri et al (2022)	On the brink of disruption: Applying resilience engineering to anticipate system performance under crisis
		Furniss et al (2020)	Using FRAM to explore sources of performance variability in IV infusion administration in the ICU: A non-normative approach to systems contradictions
		O'Hara et al (2020)	Handing over to the patient: A FRAM analysis of transitional care combining multiple stakeholder perspectives
		Pickup et al (2017)	Blood sampling-Two sides to the story
		Ransolin et al (2020)	Integrated modelling of built environment and functional requirements: Implications for resilience
		Ross et al (2018)	A systems approach using the functional resonance analysis method to support fluoride varnish application for children attending general dental practice
		Rosso & Saurin (2018)	The joint use of resilience engineering and lean production for work system design: A study in healthcare
		Salehi et al (2021)	Modelling and analyzing hospital to home transition processes of frail older adults using FRAM
		Sujan et al (2022)	Failure to rescue following emergency surgery: A FRAM analysis of the management of the deteriorating patient
		Wachs & Saurin (2018)	Modelling interactions between procedures and resilience skills
	Cognition, Technology and Work	Jatobá et al (2018)	Patient visits in poorly developed territories: A case study with community health workers
		Raben et al (2017)	Proposing leading indicators for blood sampling: application of a method based on the principles of resilient healthcare
Healthcare/ Health Services Research	BMC Health Services Research	Bos et al (2022)	Implementing structured follow-up of neonatal and pediatric patients: An evaluation of three university hospital case studies using FRAM
		de Carvalho et al (2023)	Transformative dimensions of resilience

(*continued on next page*)

Table 3 (*continued*)

Community	Journal	First author (date)	Title
			and brittleness during health systems' collapse: A case study using FRAM
		de Quadros et al (2023)	Daily work variability in falls prevention of hospitalized patients: Nursing team's perception
		Hedqvist et al (2023)	Exploring interdependencies, vulnerabilities, gaps and bridges in care transitions of patients with complex care needs using the Functional Resonance Analysis Method
	Implementation Science	Clay-Williams et al (2015)	Where rubber meets road: Using FRAM to align WAI and WAD when implementing clinical guidelines
	BMC Medicine	McNab et al (2018)	Participatory design of an improvement intervention for the primary care management of possible sepsis using the FRAM
	Annals of Emergency Medicine	Anderson et al (2023)	Mapping processes in the emergency department using the FRAM
	Advances in Simulation	MacKinnon et al (2021)	A novel approach to explore safety-I and safety-II perspectives in in situ simulations- The structured what if functional resonance analysis methodology

communities supported by the presence of knowledge brokers and cultural boundary spanners, or those who facilitate the translation of knowledge and practices between communities. However, explicit reflection on the process of knowledge production, i.e., the underpinning epistemology, was notably limited across the studies. We also observed that the FRAM was being used predominantly for describing systems, with fewer examples of intervention development.

4.1. *Knowledge brokers and cultural boundary spanners within the interdisciplinary FRAM community*

Over two-thirds of the reviewed articles included at least one co-author who had published across multiple scientific communities. The authors appear to serve a dual role as both knowledge brokers who can facilitate the transfer of technical knowledge, and as cultural boundary spanners who connect otherwise distinct scientific communities. Their contributions likely played a significant role in reducing differences in how the FRAM was applied across the different scientific communities. The concepts of knowledge brokering and cultural boundary spanning have been widely studied, with significant literature supporting their application both in healthcare as well as other domains (Long et al., 2013). Such roles are critical for ensuring that healthcare, a community with its own long-standing traditions, cultures and epistemologies, is connected to other scientific communities. They also help ensure that methods originating from other communities are transferred to healthcare with an appropriate understanding and appreciation of their respective theoretical and cultural foundations. Recognising these foundations is important, as demonstrated by the limited success of transferring other safety science paradigms, frameworks and methods to healthcare, such as the theory of High Reliability Organisations, incident reporting systems or safety checklists (Clay-Williams and Colligan, 2015; Pasquini et al., 2011; Sutcliffe et al., 2017).

The mechanisms that enable knowledge brokers and boundary spanners to emerge and to successfully foster collaboration across scientific communities cannot be deduced from this review alone. However, it is plausible that long-standing interdisciplinary networks, such as FRAMily, have played a significant role. Similarly, the Resilient Health Care Society, which evolved from the annual interdisciplinary Resilient Health Care Network meeting, continues to foster dialogue between disciplines. Upcoming events through the Resilience Engineering Association are leading with an emphasis on collaboration across boundaries for adaptation in the era of complexity (Resilience Engineering Association, 2025). Furthermore, the growing integration of the discipline of human factors into healthcare is another promising development (Sujan et al., 2021). A small but steadily increasing number of healthcare organisations now employ embedded human factors professionals (Catchpole et al., 2021), who can act as knowledge brokers within their respective organisations and serve as boundary spanners linking healthcare to other scientific communities.

4.2. *Epistemological clarity in FRAM studies*

A notable finding from this review is the limited number of studies that explicitly stated their epistemological stance. Epistemology refers to one's beliefs and assumptions about what can be known and how knowledge is created. This is a broad philosophical field, which can be daunting and complex to access as reflected in sometimes controversial and confused debates on epistemology in qualitative research (Braun, 2021; Corbin, 2014; Vaus, 2001). However, implicitly, researchers will approach their studies with a set of beliefs and assumptions about knowledge production, and when they fail to clarify and reflect on these, it can create ambiguity that complicates comparisons between studies, because different assumptions about reality and knowledge may lead to fundamentally different interpretations of the same method or findings.

Clarity and reflection on epistemology are particularly important for FRAM studies because of the flexibility that the FRAM affords. While the FRAM is based on four theoretical principles, the use of the FRAM in practice can be approached from very different perspectives. FRAM analysts need to ensure that their underlying beliefs and assumptions fit with the purpose of the analysis, including the nature of data used for designing the analysis, the resolution chosen for the analysis and the FRAM model, how the boundaries of the analysis are chosen, and how findings are interpreted and communicated (Sujan et al., 2023). For instance, studies employing the FRAM within a constructivist perspective may focus on uncovering subjective, context-dependent insights, whereas those adopting a realist lens might seek to identify objective and generalisable patterns. Without explicit epistemological framing, practitioners may struggle to understand the methodological differences, or the nature of insights derived, potentially leading to misapplications or conflicting interpretations of the findings and recommendations from FRAM studies.

It is important to acknowledge that FRAM analyses are often conducted pragmatically, drawing on diverse data sources and stakeholder perspectives to build a rich understanding of variability and functional couplings in complex systems. In practice, this means that analysts may blend different epistemological positions, for example combining realist assumptions when interpreting performance data with constructivist approaches during participatory workshops. This is not a limitation, but rather a reflection of the practical realities of conducting a FRAM analysis. However, even when such a pluralist stance is adopted, making this explicit can help others to better understand the focus of the analysis, the types of knowledge being synthesised, and the limits of interpretation. Without this reflexivity, analysts may inadvertently shift between different assumptions about what counts as valid knowledge. For example, they may treat interview data as subjective accounts in one

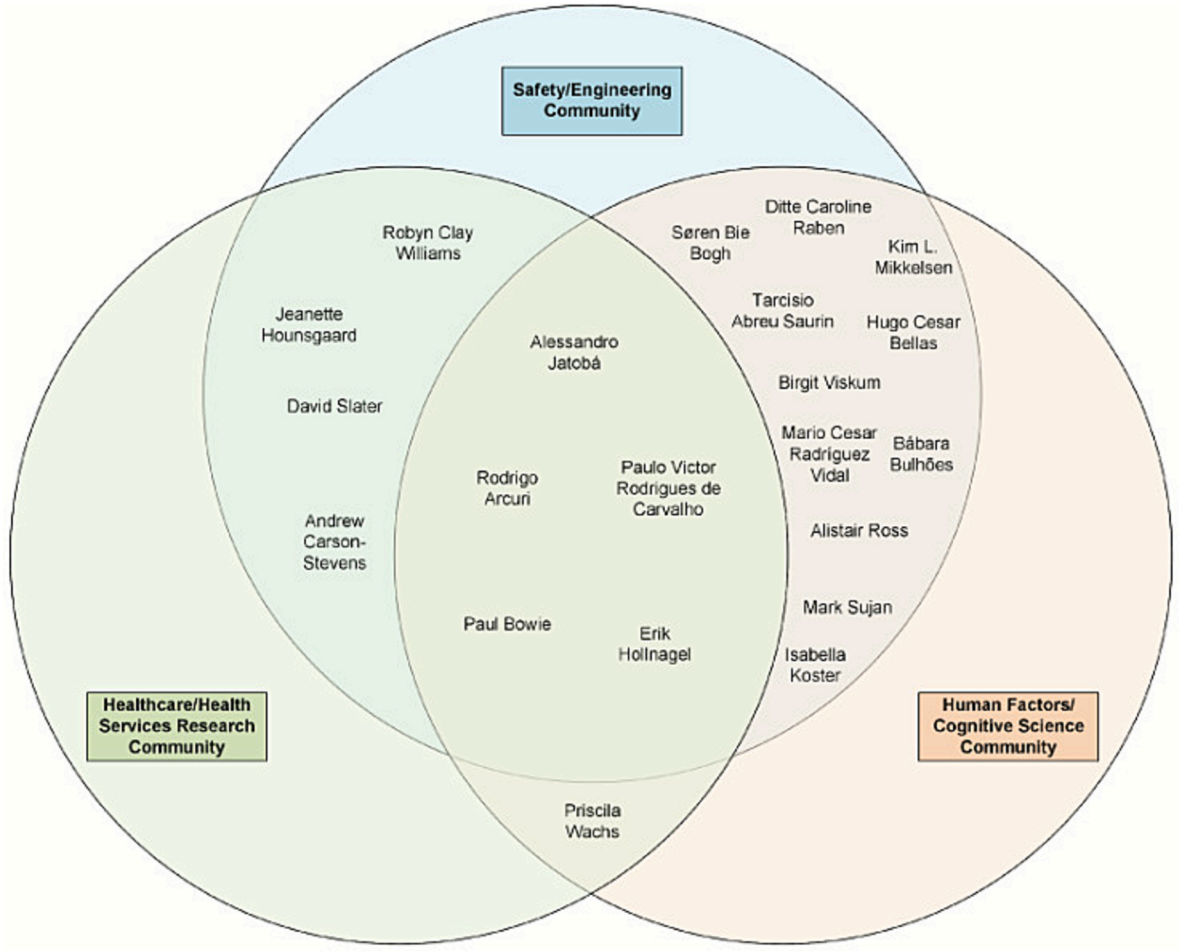

Fig. 3. Mapping of authors who have published in different scientific communities.

moment, and as objective representations of work in another, which can lead to confusion in how findings are interpreted, communicated, and used. Such slippage can compromise the coherence of the analysis, obscure the purpose of the FRAM model, and undermine confidence in its conclusions. The recommendation for epistemological clarity is therefore not intended to enforce rigid categorisation, but to support transparency and thoughtful alignment between purpose, data, and interpretation. This is particularly valuable as FRAM is increasingly used in interdisciplinary and applied settings.

A potentially useful framework for supporting epistemological clarity and self-reflexivity in FRAM studies is the WAx (work-as-x) concept (Patriarca et al., 2021). This concept extends the binary classification of work-as-imagined and work-as-done and introduces further perspectives on work, such as work-as-disclosed and work-as-observed. These additional varieties highlight the inaccessibility of work-as-done and, therefore, promote active reflection on the relationship between analytical focus and epistemological position. For a concept as ambiguous as WAD, triangulating knowledge from multiple perspectives (i.e., using the work-as-x concept) is particularly valuable to 'see' the concept from multiple angles.

The lack of epistemological clarity can also hinder cross-fertilisation and collaboration across scientific communities. Each community operates with its own implicit epistemological assumptions, which shape its understanding of methods, practices and findings. This is illustrated in this review in particular in the healthcare/health services research community, where, implicitly, a realist approach was adopted across the reviewed studies. When assumptions about knowledge production are left unarticulated, misunderstandings may arise, even within interdisciplinary teams, as individuals interpret findings and approaches through differing lenses. Moreover, the badge of "FRAM" applied uniformly across studies risks obscuring the diversity of its applications and insights. Such ambiguity may inadvertently create barriers to collaboration or lead to fragmented applications. To address these challenges, FRAM practitioners and researchers should strive for greater transparency regarding their epistemological stance, as it fosters clearer communication, aids cross-disciplinary understanding, and enhances the reproducibility and utility of findings.

To further assist in this reflective process, we have developed two prototypical examples that illustrate how different epistemological perspectives can inform the application of the FRAM to the study of central line associated bloodstream infections (CLABSI), see Box 4 and Box 5. The examples serve as generalised prototypes of realist and constructivist epistemology. Both examples were informed by articles reviewed and illustrate how and why both epistemological standpoints might be applied. One epistemological standpoint is not "better" than the other. Rather, the transparency in how knowledge was constructed is key to clarify assumptions and inform future work.

In order to support epistemological clarity in FRAM studies, it is helpful to look to adjacent fields, such as reflexive thematic analysis, where structured reflection on epistemology and researcher positioning has become common practice (Braun, 2021). In that context, researchers are encouraged to articulate their epistemological stance, clarify the role of the analyst in constructing meaning, and reflect on the relationship between data, interpretation, and claims made. Drawing on this tradition, we propose a preliminary self-assessment prompt list for FRAM studies. This prompt list is intended to encourage analysts to reflect on

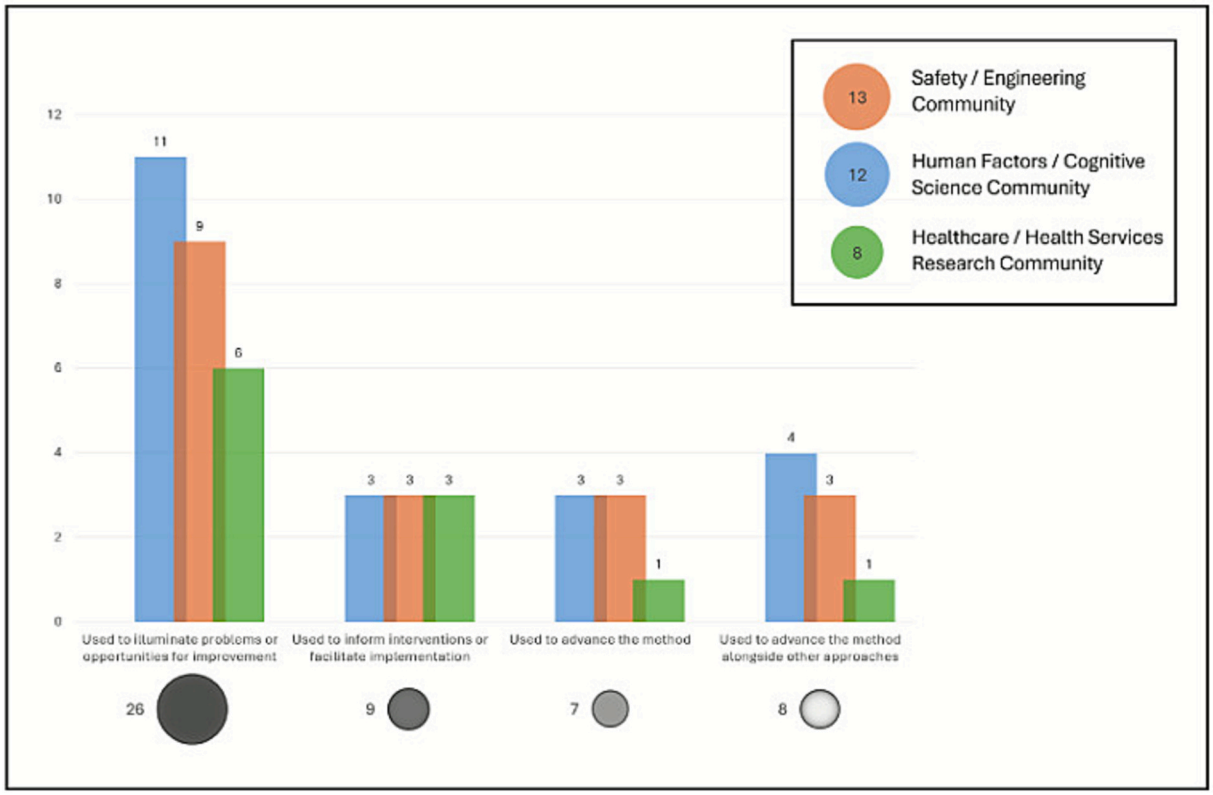

Fig. 4. Overview of aims by community.

Table 4
Detailed mapping of aims by community.

Aim	Total articles n = 33 %, n	Total Number of Articles in the Safety/ Engineering Community n = 13 %, n	Total Number of Articles in the Human Factors/Cognitive Science Community n = 12 %, n	Total Number of Articles in the Healthcare/Health Services Research Community n = 8 %, n
Used to illuminate problems or opportunities for improvement	81 %, 26	85 %, 11 Patriarca et al., 2018 (Patriarca et al., 2018 Dec); Arcuri et al., 2020 (Arcuri et al., 2020); Buikstra et al., 2020 (Buikstra et al., 2020 Jan); Kaya et al., 2019 (Kaya et al., 2019 Oct); Schutijser et al., 2019 (Schutijser et al., 2019 Oct); van Dijk et al., 2022 (van Dijk et al., 2022); Slater et al., 2022 (Slater et al., 2022 Feb); Slater, 2022 (Slater, 2022 Feb); Safi et al., 2023 (Safi et al., 2023 Oct); Raben et al., 2018 (Raben et al., 2018 Jan); Raben et al., 2018 (Raben et al., 2018 Sep)	75 %, 9 Salehi et al., 2021 (Salehi et al., 2021 May); Sujan et al., 2022 (Sujan et al., 2022 Jan); Furniss et al., 2020 (Furniss et al., 2020 Jul); Rosso et al., 2018 (Rosso and Saurin, 2018 Sep); Arcuri et al., 2022 (Arcuri et al., 2022 Feb); Ross et al., 2018 (Ross et al., 2018 Apr); Pickup et al., 2017 (Pickup et al., 2017 Mar); Wachs et al., 2018 (Wachs and Saurin, 2018 Apr); Jatobá et al., 2018 (Jatobá et al., 2018 Feb 1)	75 %, 6 de Carvalho et al., 2023 (de Carvalho et al., 2023 Apr 10); Hedqvist et al., 2023 (Hedqvist et al., 2023 Aug 11); de Quadros et al., 2023 (de Quadros et al., 2023 Aug 31); Clay-Williams et al., 2015 (Clay-Williams et al., 2015 Aug 29); McNab et al., 2018 (McNab et al., 2018 Oct 11); Anderson et al., 2023 (Anderson et al., 2023 Sep 1)
Used to inform interventions or facilitate implementation	25 %, 8	15 %, 2 Damoiseaux-Volman et al., 2021 (Damoiseaux-Volman et al., 2021 Oct); Raben et al., 2018 (Raben et al., 2018 Jan)	25 %, 3 O'Hara et al., 2020 (O'Hara et al., 2020 May); Ransolin et al., 2020 (Ransolin et al., 2020 Oct); Ross et al., 2018	38 %, 3 Bos et al., 2022 (Bos et al., 2022 Feb 14); Clay-Williams et al., 2015; McNab et al., 2018
Used to advance the method	19 %, 6	15 %, 2 Slater et al., 2022; Slater, 2022	25 %, 3 Furniss et al., 2020; O'Hara et al., 2020; Ransolin et al., 2020	13 %, 1 Anderson et al., 2023
Used to advance the method alongside other approaches	22 %, 7	31 %, 4 Arcuri et al., 2020; Safi et al., 2023; Saurin et al., 2017 (Saurin and Werle, 2017 Nov); Patriarca et al., 2018	25 %, 3 Rosso et al., 2018; Wachs et al., 2018; Raben et al., 2017 (Raben et al., 2017 Nov 1)	13 %, 1 MacKinnon et al., 2021 (MacKinnon et al., 2021 Jun 5)

Table 5
Mapping of epistemology.

		Safety/Engineering Community n = 13 %, n	Human Factors/Cognitive Science Community n = 12 %, n	Healthcare/Health Services Research Community n = 8 %, n
Epistemology overtly stated in the application of the FRAM?	Yes	8 %, 1	8 %, 1	0 %, 0
	No	92 %, 12	92 %, 11	100 %, 8
Interpretation of epistemology?	Realist	62 %, 8	33 %, 4	88 %, 7
	Constructivist	31 %, 4	42 %, 5	0 %, 0
	Unclear	8 %, 1	33 %, 3	12 %, 1

Box 2
Example illustrating reliance on the four theoretical principles of the FRAM.

Van Dijk and colleagues (2022) (van Dijk et al., 2022) aimed to understand the reasons for low compliance with medication reconciliation standards by using the FRAM to compare national and hospital work-as-imagined (WAI) with work-as-done (WAD). There were references to the four basic FRAM theoretical underpinnings throughout the article.

Equivalence of successes and failures refers to the same conditions influencing vastly different outcomes. Van Dijk and colleagues demonstrated this principle by stating that there is a need to better understand "normal work" in order to improve medication reconciliation. Authors explicitly recognised that valuable insights are missed by exclusively studying negative clinical outcomes, such as adverse drug events, and therefore focused their data collection on everyday work.

The principle of **approximate adjustments** recognises that those within complex systems regularly make adaptations to achieve goals under varying conditions, and therefore, perfect alignment with work-as-imagined is rare. In their introduction, Van Dijk and colleagues referenced previous literature explaining that professionals' adaptations in complex environments are essential to preserve safety and highlighted similar findings from their interviews. Authors also compared their WAI and WAD data through the lens of adaptations in response to variations, rather than using punitive language.

The principle of **emergence** refers to system behaviour and outcomes "emerging" from system interdependencies, rather than from individual actions. Authors explicitly referred to the concept of emergence by stating that the system outcomes are dependent on interactions between its components. Specifically, authors stated that professionals' adaptations impacted medication reconciliation due to the interdependency of all components of the healthcare system.

Finally, the principle of **functional resonance** refers to the concept that small variations in functions can compound and produce significant effects on the process. Authors leveraged the efficiency-thoroughness trade-off (ETTO) principle to reflect back to practitioners the ways in which performance variability in one part of the process can impact other, downstream activities.

Box 3
Example illustrating the use of broader theoretical concepts.

Furniss and colleagues (2019) (Furniss et al., 2020) applied the FRAM to study performance variability in intravenous medication administration in an intensive care unit. While the authors explicitly and thoroughly explain the four FRAM principles on which the FRAM is based, they also expanded beyond the FRAM's in-built theory, as described below:

- **Non-normativity**: Authors made their non-normative standpoint clear throughout the article, which positioned the FRAM as an approach to understand normal work, not necessarily to critique or improve compliance with WAI, as is common in other improvement tools. Instead, authors positioned variability as "inevitable and potentially useful", following Hollnagel.
- **Use of cultural-historical activity theory**: Authors drew on cultural-historical activity theory, specifically the understanding that human activities are complex, socially situated phenomena, to introduce the concept of "system contradictions". System contradictions were understood to represent historical tensions in a system that often cannot be designed out (e.g., mismatch between demand and capacity, competing organisational priorities etc) and which act as the driver for system evolution. This is a concept that can be used alongside the FRAM to better understand the drivers to the observed gap between WAI and WAD
- **Use of broader resilience engineering theory**: Authors introduced concepts from resilience engineering in suggesting that understanding of performance variability can contribute to better design of technology by enhancing, rather than diminishing, the ability for individuals and teams to adapt drawing on the notion of resilience abilities or resilience potentials.

how work is conceptualised (e.g., as work-as-done or work-as-disclosed), who is interpreting it, what assumptions underpin the FRAM model, and what its intended scope and limitations are. The aim is not to prescribe a particular stance, but to foster greater transparency and reflexivity in FRAM studies, particularly in interdisciplinary healthcare settings.

The self-assessment prompt list in Table 7 may be used as a starting point to guide epistemological clarity in future FRAM studies. We

Table 6
Mapping of data collection methods.

Data Collection Method	Total Number of Articles in Which Data Collection Method Was Employed Across All Communities	Total Number of Articles in the Safety/Engineering Community n = 13 %, n	Total Number of Articles in the Human Factors/Cognitive Science Community n = 12 %, n	Total Number of Articles in the Healthcare/Health Services Research Community n = 8 %, n
Interviews	24	69 %, 9	92 %, 11	62 %, 5
Focus Groups (including roundtables, meetings, group interviews)	13	46 %, 6	50 %, 6	25 %, 2
Observations	18	46 %, 6	75 %, 9	50 %, 4
Surveys (including questionnaires)	4	15 %, 2	17 %, 2	0 %, 0
Document Review (including documentation review, policy review)	20	69 %, 9	50 %, 6	62 %, 5
Other	4	15 %, 2	25 %, 3	0 %, 0

Box 4
Example of the FRAM applied within a realist epistemology.

Using a CLABSI bundle is a key mechanism to prevent central line infections in critical care areas. Critical care leaders in a hospital noticed a decrease in CLABSI bundle compliance and sought to address this problem. The leaders used the FRAM as a tool to study the problem in hopes of identifying system-based solutions. Critical care leaders developed a standardised observation form to be used when CLABSI nursing representatives observed CLABSI bundle processes. This form was piloted and iterated to minimise variability in interpretation of the questions during the observations. The findings from these observations were discussed with a group of critical care nurses to validate the findings. A focus group was facilitated to build the FRAM model, in hopes of producing an objective depiction of WAD on the unit related to CLABSI bundle compliance. The draft FRAM model was circulated throughout the ward to verify the model with the staff. This FRAM model was used to identify functions with high levels of aggregate variability and to inform interventions in the critical care area. This was also used to develop similar interventions on the acute medical wards.

This example illustrates a realist epistemological position, where an objective reality is believed to exist and can be captured and validated. The use of a standardised form reflects the belief that an objective reality can be systematically documented. The steps taken to validate the FRAM model (engaging the critical care nurses in verifying the findings) reinforced a shared understanding within a uni-disciplinary framework. Furthermore, the extension to other wards illustrates the assumption that the insights derived are universal and applicable across contexts, rooted in the realist perspective of stable, system-level mechanisms.

Box 5
Example of the FRAM used within a constructivist epistemology.

In another hospital, leaders sought to understand why compliance with a CLABSI bundle varied across different shifts and units. The leaders adopted a constructivist approach to explore the human experiences and perceptions underpinning this variability. Semi-structured interviews and reflective focus groups were conducted with multidisciplinary team members, including nurses, doctors, families, and support staff. Participants were asked to reflect on their everyday work in terms of the functions they undertake, and how factors such as workload pressures, communication patterns, and interpretations of the CLABSI bundle impacted their practices, the trade-offs they needed to make, and how they draw on their professional expertise and experience. The narratives collected were used to construct a FRAM model that depicted the functions performed across shifts and units. Participants contributed directly to identifying functions, variability and couplings. The FRAM model served as a tool for visualising and exploring everyday performance variability in terms of systemic tensions and contradictions that were not immediately apparent when reviewing previously collected CLABSI bundle compliance data. The FRAM model was treated not as an objective representation of system performance but rather as a co-constructed artifact for the purpose of the analysis.

This example illustrates the constructivist position that reality is subjective and constructed through human experiences and interactions. The leaders in this organisation designed their data collection and analysis methods accordingly, based on this epistemological belief. The findings were discussed within the socio-cultural context of the unit and organisation, which illuminated the situated nature of knowledge related to CLABSI prevention practices. Unlike realist approaches, which seek to identify objective mechanisms, the application of the FRAM within the constructivist epistemology serves as a reflective and participatory tool to explore performance variability in terms of individual experiences of system tensions, contradictions and the socio-cultural context.

Table 7
Prompt list to support epistemological clarity in FRAM studies.

Domain	Prompt
Focus of the analysis	What form of work-as-x is primarily being represented (e.g., is the analysis focused on WAI, WAD, or something else)? What data supports this categorisation?
Role of the analyst and other stakeholders	Who is interpreting the work and how? What is the role of the analyst versus the participants or practitioners?
Epistemological assumptions	What assumptions underpin the analyst's construction and interpretation of the FRAM model (e.g., are there assumptions of causality? How is system variability conceptualised? Is the model intended to represent an objective version of reality?)
Analysis scope and boundaries	What are the FRAM model's limits (e.g., is it clear what aspects of the system are excluded? Was this exclusion intentional and if so, why?)

hypothesise that articulating epistemological assumptions may improve the FRAM analyses. Though this current literature review was not equipped to empirically test this statement, future studies may consider applying the prompts in Table 7 to see if/how they might influence the FRAM.

4.3. The challenge of developing interventions from the FRAM

Regardless of the scientific community, the FRAM was primarily used for analysing system performance and identifying broad areas for improvement, rather than to directly inform the development and evaluation of interventions. This aligns with the method's core strength of capturing the complexity and variability inherent in everyday work. Additionally, these results highlight a strength of the FRAM for the analysis of WAD but also evidence a gap in translating FRAM insights into actionable solutions.

Recommendations emerging from a FRAM study often reflect this whole-systems perspective. The FRAM does not seek to identify causal chains or so-called root causes, as is often the case in more traditional decremental approaches (i.e., Safety-I thinking), which tend to draw a more immediate and linear link between a risk and a specific control. Rather than proposing narrowly targeted risk controls, FRAM analyses may prompt reflection with relevant stakeholders on everyday trade-offs, how professionals weigh these tradeoffs, and what they need in order to be able to make this evaluation in the optimal way possible based on the content. As a result, the need to strengthen broader systemic resilience abilities, such as enhancing organisational learning, improving processes for data collection and analysis, or supporting longer-term anticipation of demand, is likely to emerge via FRAM analyses. These recommendations tend to be more open-ended, less prescriptive, and more difficult to implement than conventional interventions based on Safety-I thinking. Furthermore, because these recommendations may call for changes across multiple organisational layers, they may encounter resistance, particularly where they challenge existing practices, resource allocations, or institutional priorities. Importantly, this is not a limitation of the FRAM, but rather a reflection of its alignment with complex systems thinking, where intervention design and evaluation are acknowledged to be inherently uncertain and emergent. In this context, FRAM can also serve as a valuable tool for upward communication within organisations, making visible those tolerated risks that have previously been difficult to articulate or visualise. By increasing transparency around these risks, FRAM may enhance the confidence of those in leadership roles to reframe problems and consider alternative priorities for resource allocation and safety improvement.

Recognising this, one challenge is developing ways of supporting the design and testing of interventions that appreciate the systems and functional insights the FRAM provides. Thus, while FRAM provides a powerful means to design for resilience across the health system, realising the benefits of such systemic recommendations requires organisational commitment, cross-level collaboration, and leadership support over an extended period.

FRAM is well-suited to addressing resilience not only at the sharp end (clinical practice) but also at the blunt end of healthcare systems, where policy, management, and strategic decisions are made. By modelling the functional interdependencies across different levels of the system, from frontline care to governance structures, FRAM can illuminate how variability at the policy or organisational level shapes, constrains, or enables local adaptations (Slater et al., 2022; Ross et al., 2018). In doing so, it offers a means to understand how decisions regarding resource allocation, regulatory requirements, or system priorities resonate through the system to impact everyday clinical work. Applied at the health systems level, FRAM can help stakeholders anticipate how intended interventions may interact with existing functions, where mismatches or unintended consequences may arise, and where reinforcing structures can be designed to support resilient performance across the entire system. Thus, FRAM has the potential to contribute to system-level resilience by supporting better alignment between blunt-end decisions and sharp-end realities.

4.4. Limitations

While this Focused Mapping Review and Synthesis provides valuable insights into how the FRAM is used in healthcare and how knowledge is constructed in healthcare FRAM studies, several limitations must be acknowledged.

First, the FMRS approach prioritises a focused search over breadth and exhaustiveness. As a result, this review did not aim to capture every FRAM study in healthcare but instead focused on identifying key themes across a focused sample of literature.

Second, the relatively small sample size limits the robustness of any quantitative mapping. For instance, while trends in authorship and application could be identified, statistical comparisons across the scientific communities were not feasible.

Third, this review primarily synthesises findings from academic studies, which often reflect the perspectives of researchers rather than practitioners. The voices of practitioners — those who implement the FRAM in real-world settings — are less visible, potentially limiting the understanding of practical challenges and contextual nuances associated with the application of the FRAM. Future work should incorporate practitioner perspectives to address this gap.

Fourth, assessing differences by scientific community proved challenging due to the degree of cross-fertilisation observed in the authorship of included studies. With over two-thirds of the papers featuring co-authors publishing across multiple communities, distinguishing clear epistemological or methodological divides between communities was not straightforward. While this interconnectedness highlights the valuable role of knowledge brokers and boundary spanners, it also blurs the distinctions necessary for making more precise community-level comparisons. This limitation underscores the complexity of analysing knowledge production in interdisciplinary contexts and suggests that further work is needed to disentangle these relationships.

Fifth, this review focused on the FRAM's use in healthcare specifically. It should be recognised that FRAM has been extensively applied in other industries, including but not limited to maritime, construction, and oil and gas (Patriarca et al., 2017; del Pardo-Ferreira et al., 2020; França et al., 2022). Future researchers may consider comparing the epistemological challenges to enrich the understanding of cross-industry FRAM use, opportunities, and challenges.

Finally, the synthesis and interpretation of findings is influenced by the authors' own perspectives and prior experiences, which shape the analysis.

5. Conclusion

The increasing use of the FRAM in healthcare benefits from knowledge brokers and cultural boundary spanners who contribute to an interdisciplinary and integrated FRAM community. Across all communities, there is a need for greater epistemological clarity and self-reflexivity in studies that use the FRAM. The healthcare and health services research community specifically may benefit from diversity in realist versus constructivist epistemological perspectives. Further, the FRAM is still being used predominantly to describe systems, and there is a need to consider actionable interventions and evaluations that can provide evidence of improvement in practice.

Collaboration across scientific communities is essential for meaningful application of the FRAM and its further development. Building on the existing networks of knowledge brokers and boundary spanners identified in this review, future efforts should focus on fostering interdisciplinary dialogue and shared learning. Expanding existing networks and integrating practitioner perspectives can ensure that the FRAM continues to evolve as a relevant and impactful tool for understanding and improving complex healthcare systems.

Greater self-reflexivity is needed to ensure transparency in how researchers approach FRAM studies. This includes explicit articulation of epistemological stances, theoretical frameworks, and methodological assumptions. Reflecting on these issues not only aids the reproducibility and comparability of FRAM studies but also fosters a more integrative and self-aware FRAM community. Encouraging researchers to engage in this reflective process should be a priority for advancing both the theory and practice of the FRAM in healthcare. As a conceptual synthesis, our review does not test these propositions. Future work should empirically evaluate whether making epistemological assumptions explicit (e.g., using the prompts in Table 7 as a starting point) influences FRAM processes and outcomes.

The next phase of FRAM studies in healthcare should focus on moving from description to intervention and evaluation. In particular, future studies should develop suitable incremental safety evaluation frameworks that can be used for assessing the impact of interventions.

The diversity in how the FRAM can be applied with respect to aims, epistemological position and breadth of theoretical background, highlights the need for a standardised reporting framework. A dedicated reporting guideline for FRAM studies could serve multiple purposes: assisting practitioners in understanding and applying the FRAM effectively, promoting transparency, and enabling critical comparisons across studies. Such a guideline should include recommendations for detailing epistemological positions, justifying the decisions around use of theory, describing data collection and analysis methods, and explicitly linking findings to interventions and outcomes. Developing this guideline collaboratively, with input from researchers, practitioners, and interdisciplinary stakeholders, could significantly enhance the consistency and impact of FRAM studies.

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O. Lounsbury: Writing – review & editing, Writing – original draft, Project administration, Methodology, Formal analysis, Data curation. **L. Pickup:** Writing – review & editing, Validation, Methodology. **Riccardo Patriarca:** Writing – review & editing, Validation, Methodology. **Marit S. de Vos:** Writing – review & editing. **Kate Preston:** Writing – review & editing, Visualization. **Mark Sujan:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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