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Optimising the design and prospective implementation of a test result review app to support antimicrobial stewardship in emergency departments – A qualitative study

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Abstract

Background

Antimicrobial stewardship is increasingly important to ensure appropriate antibiotics use and reduce antimicrobial resistance. In Emergency Department (ED), test results are often pending at discharge, particularly microbiology findings that may require follow-up action. Delays in reviewing these results can lead to ineffective treatment and inappropriate antibiotic use and contribute to antimicrobial resistance. While decision support tools can support test result management, few solutions are tailored to the ED workflows, and challenges remain in seamless integration and clinician acceptance. This study involved co-designing a test result review app with clinicians in an ED of a paediatric hospital, building on an existing research prototype which cross-references microbiology results with prescribed antibiotics to prioritize identification of drug-bug mismatches and support timely follow-up.

Methods

We conducted semi-structured interviews with clinicians responsible for test result review. The aims were to map the current review workflow, identify design requirements, and understand factors influencing the app implementation to enable strategy identification. Five interview sessions were held with five nurse practitioners and three paediatric senior medical officers in the ED. Scenario-based evaluation of the prototype were also conducted during the sessions. Data were analysed using thematic analysis to identify workflow characteristics and design considerations. Factors influencing implementation were coded using the CFIR (Consolidated Framework for Implementation Research) and subsequently mapped to the ERIC (Expert Recommendation for Implementation Change) framework to generate implementation strategies.

Results

The study revealed key activities in the test result review workflow, including checking and assessing results, escalation and consultation, antibiotic review and adjustments, documentation in result review pools and Integrated Electronic Medical Record (ieMR), sign-off and patient follow-up. Current challenges included high result volumes, lack of function tools such as prioritization, incomplete documentation, navigation burdens across medical systems, and the workload of follow-up. Participants viewed the proof-of-concept positively and provided design feedback across functions, features, usability and integration. Ten CFIR-based influencing factors were identified, covering innovation suitability, adaptability, design, relative advantage, complexity, information technology infrastructure, work infrastructure, local conditions, communications and tension for change. Resulting ERIC recommended key strategies included: adapt and tailor to context, develop stakeholder interrelations and use evaluative and iterative strategies.

Conclusion

The study generated detailed design considerations for further development of the test result review app and identified key implementation influencing factors and strategies using established implementation science frameworks. These findings will inform the next steps, including technology refinements, stakeholder workshops to map optimal workflows, and development of actionable implementation strategies for a pilot trial.

1 Introduction

The importance of antimicrobial stewardship, where antibiotics are only prescribed when needed, and for the correct microorganism is increasing. Failure to prescribe the right “drug” for the right “bug” contributes to microbial resistance. Timely review of test results in the Emergency Department (ED) is crucial [1–3]. Test results are often pending at the time of patient discharge from ED and clinicians are taking a best guess at the most appropriate antibiotic to prescribe. In addition, reviewing results is a timely endeavour and finding time in a busy shift can be difficult for both treating clinicians and other clinicians involved in patient care. Tests pending at discharge pose a significant patient safety risk, particularly when microbiology results that return after discharge require clinical action [1–4]. Delayed follow-up can lead to ineffective antibiotic treatment, penitential resulting in poorer patient outcomes and compromised patient care, while also contributing to antimicrobial resistance due to inappropriate antibiotic use [1–3].

Health information technology, including decision support systems, plays an increasing role in the management of diagnostic test results and supporting antimicrobial stewardship (AMS) [2, 4–8]. While the use of digital tools to support clinician management of test results has been reported, relatively few studies focused on the ED context [2, 4–7]. Moreover, while decision support systems have shown the potential in improving healthcare practices and efficiency, challenges remain in developing solutions that seamlessly integrate into existing workflow, and in measuring their outcomes and acceptance [5, 7, 9, 10].

The design and implementation of digital health technologies have been widely explored in the fields of technology design, human-computer interaction and implementation science. Workflow analysis is increasingly recognized as a critical step in the design and integration of digital technologies into routine clinical practices [11]. Prior research on the development and deployment of decision support and Artificial Intelligent (AI) tools in ED has shown the importance of early problem assessment and clinical workflow design in parallel with technology and infrastructure development [8, 12]. User-centred design approaches, including contextual enquiry that combines observation with in-situ prototype discussion, support the design of digital tools and the assessment of how the tools align with actual clinical practices [13, 14]. Recent research has identified a lack of systematic pre-implementation assessment in the development of decision support tools for AMS [8]. While implementation science frameworks have been increasingly used support digital health deployments [15–20], strategies for implementing AMS-

focused decision support tools are inconsistently reported, with limited detail on strategy selection, operationalization, and outcome evaluation [8]. These challenges continue to motivate research at the intersection of decision support and AI technology, human-computer interaction and implementation science, with increasing emphasis on understanding context, aligning technology with clinical work and identifying effective implementation strategies to support sustained adoption [6, 8, 9, 21, 22].

Researchers at CSIRO (Commonwealth Scientific and Industrial Research Organization) have collaborated with the ED at Queensland Children's Hospital (QCH) in Australia to co-design a decision support application (app) which aims to improve the efficiency of test result review process and enhance quality prescribing. The test result review app has been developed by the CSIRO team based on an existing research prototype which cross-references antibiotic sensitivities with documented antibiotics prescriptions to identify drug-bug mismatches to support timely follow-ups and clinical actions [6].

As the first step of the design process, a qualitative interview study was conducted with clinicians involved in test result review. The aims were to understand the current test results review workflow, identify refinements to tailor the app's design to the QCH context, identify factors influencing the implementation of the app, and suggest implementation strategies to support the pilot trial and future implementation.

2 Methods

2.1 Study design

The study was conducted at QCH, a specialist paediatric hospital in Brisbane, Australia, and manages over 70,000 ED presentations annually. Semi-structured interviews and focus groups were conducted with clinicians in the ED of QCH to understand their current workflow for test results review and explore their views on using an app to support this process. During the sessions, participants evaluated the app prototype using simulated scenarios and provided feedback on its usability and potential workflow integration.

Researchers were given a tour of the ED by an ED manager and an introduction of the work infrastructure and electronic medical record systems by a QCH project champion. The interview sessions were conducted in office areas and adjacent to participants' usual workspaces. Participants were able to log into electronic medical record systems to show researchers how they conducted test result reviews and navigated various medical record systems. Conducting interviews within the clinicians' work environment enabled researchers to make direct inquiries into the clinicians' test result review practices and engage in interactive discussions to gain a deeper understanding.

2.2 Participants

ED Clinicians involved in the test results review process were invited by the project champion to participate either through verbal or email invitations. For those who agreed to participate, an interview or

focus group session was scheduled by the project champion. The timing and location of the sessions were arranged according to participants' availability and preference. A print-out of information sheet was provided to each participant and written consent was obtained before the commencement of the sessions.

2.3 The prototype

The prototype was a digital health standards-based decision support application intended to support antimicrobial stewardship during ED test result review. It prioritises cases by reconciling microbiology findings and antimicrobial susceptibility information with antibiotics documented in ED discharge summaries [6]. Abnormal or actionable microbiology results are identified using a trigger-based algorithm, and antibiotic mentions in the discharge text are detected using keyword-based text mining informed by clinical terminology semantics and mapping. These natural language processing and knowledge-based AI techniques underpinned the rule-based reconciliation logic that flagged cases where the prescribed antibiotic was reported as resistant, untested, or not prescribed, indicating a potential need for clinical follow-up. The prototype was designed for future integration with hospital systems using Fast Healthcare Interoperability Resources (FHIR) standards to support interoperability. Figure 1 shows the initial prototype used in this study.

Key functions of the prototype included:

- A prioritised patient list highlighting cases where a finalised microbiology result may warrant clinical action after ED discharge.
- Cross-referencing of antimicrobial susceptibility test (AST) results against antibiotics prescribed at discharge.
- Visual flagging of potential drug-bug mismatches (e.g. an organism reported resistant to the prescribed agent).
- Display of a structured summary of the microbiology result (organism and antibiotic sensitivity panel) derived from the underlying pathology report.
- Display of the World Health Organisation Access/Watch/Reserve (AWaRe) classification for tested antibiotics to provide stewardship context.
- Filtering and search controls to narrow displayed results by review status, date range, and other categories.

2.4 Data collection

Interviews and focus groups were conducted face-to-face in the ED over a three-day period in August 2025. The sessions either involved a single participant or multiple participants depending on participants' availabilities. Each session lasted approximately 60 minutes and was conducted by three researchers. Two of the researchers were on site and the third researcher joined remotely via Microsoft Teams. The sessions were audio-video recorded using Microsoft Teams.

Interview questions focused on three key areas. First, participants were asked about their current test review process and the challenges they faced. After this, participants were presented with the app prototype and simulated scenarios from a study laptop to prompt discussions about the app design. Finally, the interview explored potential barriers and enablers to integrating the app into clinical practice as well as suggestions for a pilot study and evaluation.

During the discussion on app design, researchers presented scenarios, such as drug-bug mismatches, using the app's built-in dummy patient data. Participants either interacted directly with the app and the patient cases when seated next to the study laptop or observed the researcher navigating the interface when direct interaction was not feasible (e.g., in the focus group session), verbalizing their thoughts on its functions, features and usability.

2.5 Data analysis

Audio recordings were transcribed using an AI-assisted qualitative data analysis tool, AILYZE [23]. One researcher (JL) reviewed the transcripts against the audio recordings, corrected errors, and clean the data. The transcripts were then exported into Microsoft Excel for thematic coding conducted by two researchers (JL, AD). The analysis focused on three components: current workflow, app design refinement, and factors influencing the implementation of the app.

2.5.1 Current Workflow and App Design Refinement

Based on the key interview focus areas, AILZYE was initially instructed to identify themes in three categories: test result review workflow, technology design feedback, and implementation suggestions. Text segments related to workflow and app design feedback identified by AILYZE were then used to guide manual coding (Fig. 2).

Workflow-related text segments were manually coded using AACTT framework (Action, Actor, Context, Target, Time) to generate detailed activities and steps. AACTT is commonly used in implementation science and healthcare research to unpack specific actionable practices and behaviours [24]. Relevant policy and procedure documents, such as the paediatric empirical antimicrobial guidelines and other antimicrobial stewardship guidelines published on the QCH website, were also used to guide the analysis. These findings informed the development of a workflow diagram.

The app evaluation section of each transcript, together with other design-related text identified by AILYZE, were manually coded. AILYZE-generated themes and subthemes were used as references for the manual coding. One researcher conducted the coding, which was then reviewed by a second researcher. Each subtheme identified were related to a specific design aspect. Design implications and recommendations were then developed for each subtheme and discussed with the technical design lead. After this, recommendations were then prioritised based on the importance and feasibility within the project scope.

2.5.2 Factors Influencing Implementation and Implementation Strategies

This component of analysis comprised three overarching phases: cleaning and calibration, AILYZE analysis, CFIR-ERIC mapping.

CFIR (Consolidated Framework for Implementation Research) [15, 16] is a widely used implementation science framework which offers a structured approach to examine implementation across multiple domains, including intervention characteristics, inner setting, outer setting, individuals and process. ERIC (Expert Recommendation for Implementation Change) is a tool developed to provide a refined taxonomy of implementation strategies to support intervention uptake [17, 25]. The approach of mapping CFIR constructs to ERIC strategies has been useful for guiding the implementation and evaluation of complex digital health interventions [19, 20].

In the first phase, a single interview transcript (participant 4) was manually coded by two researchers. CFIR 2.0 and a virtual care expansion pack developed by CSIRO researchers [26] was used for manual coding. A CFIR codebook tailored to the test result review context was developed. Directed content analysis was conducted on the transcript, with initial CFIR coding completed by one researcher and subsequently reviewed by a second researcher. Consensus discussions were held to ensure coding consistency and generated a list of CFIR constructs. This process served as a baseline for checking and calibrating the results generated by AILZYE.

In Phase two, the same transcript was uploaded to AILZYE for analysis without any instructions. The results were carefully assessed by the two researchers, and the generated subthemes were mapped to the manually coded CFIR results. The mapping showed consistent alignment between AILIZY outputs and manual CFIR coding from the first phase. Following this validation, all the transcripts were uploaded to AILZYE, and the themes and subthemes generated were manually checked, modified or regrouped where required. Interpretive statements were then generated for each subtheme, which were mapped to relevant CFIR constructs. After the CFIR construct list was finalized, a prioritisation exercise was undertaken to identify the top influencing factors, based on the cumulative majority (> = 5 participants mentioning).

In Phase three, the top CFIR influencing factors were mapped to the ERIC framework [17, 18, 25] to facilitate the generation of recommended strategies that could support the pilot trial and future implementation of the test result review app. Figure 3 provides an overview of the CFIR coding and strategy development process.

3 Results

3.1 Participant Characteristics

Five interviews and focus groups sessions were conducted. Two sessions involved individual participants, and three sessions included two participants each. A total of eight clinicians participated, including five nurse practitioners (NPs) and three paediatric emergency senior medical officers (SMOs). Table 1 presents the characteristics of the participants.

Table 1
Characteristics of participants

Item		N
Role	Nurse practitioner	5
	Senior medical officer	3
Years at QCH	11 (since QCH established in 2014)	7
	10	1
Years of professional experience	15–20	5
	20–30	2
	> 30	1

3.2 Current Practices and Workflow Mapping

The workflow analysis using AACTT framework identified key activities involved in test results management, covering the steps from test ordering, test result review, and patient follow-up. These activities were visualized in a workflow diagram (Fig. 4), which was reviewed and validated by the champion clinician to ensure accuracy.

The process began with clinicians (treating doctors or nurses) ordering tests and, where available, checking historical results before the patient's ED visit. Once test results (preliminary or final) became available in ieMR, they were reviewed through a structured, shared workflow: treating doctors assessed their individual result pools during shifts; nurse practitioners work from Monday to Friday supported the review through a shared pools containing all treating doctors' results; senior doctors could access their own pools and may also provide oversight to the shared pool if needed. Following review of final results, clinicians undertook follow-up actions, including contacting patients, coordinating with inpatient teams, general practitioners or pharmacies, and ensuring appropriate treatment changes were implemented.

Key activities within the test result review included: checking and assessing results; escalation and consultation; reviewing or changing antibiotics; documenting in pools and ieMR; and completing sign-off. Clinicians prioritised abnormal results, consulted laboratory systems or microbiology staff for clarification if needed, and interpreted findings in the context of the patient's clinical condition. Antibiotic management was closely integrated into this review process, with clinicians checking current prescriptions and deciding whether to initiate, adjust, or stop antibiotics based on test results, clinical

guidelines, patient-specific factors, and input from senior staff or multidisciplinary teams. Documentation and clear communication across teams were critical throughout the review process.

3.3 Design Feedback and Refinements

Participants were positive about the overall functions of prototype, particularly its visual flagging of potential drug-bug mismatches. Five key design themes identified covered the areas of integration need, clinical content, feature, user interface and usability. Table S1 in the Appendix presents the details of each theme, subthemes, associated statements, and the corresponding design considerations.

Table 2 below outlines the themes and selected examples of design feedback. Participants highlighted the need of integrating the app with ieMR to avoid duplicate review work if the app were introduced. There was also a clear demand to display more clinically relevant information, including detailed discharge antibiotic data and additional microbiology data, to better support decision-making. Effective prioritisation, filtering and clear visual cues were considered as helpful to focus attention on critical cases and improve efficiency. Participants also highlighted the importance of a simple, intuitive interface with easy navigation and minimal cognitive burden to support use in a busy clinical environment.

Table 2
Key design themes

Design theme	Summary	Key Design Feedback (selected examples)
The need of integration	A concern that clinicians would still need to clear and sign-off in the Integrated Electronic Medical Record (ieMR), as the lack of integration could lead to double handling.	The current app duplicates effort by creating parallel action lists that must be reconciled manually.
		Need to link to external pathology and radiology service, personal health record and other systems in the future.
Clinical content and decision support	Useful to include drug-bug matching, display of discharge antibiotics, additional microbiology data and patient-specific clinical information to support interpretive decision-making.	Need to see medications in discharge letter and Orders.
		Need to see additional microbiology data such as count of the bacteria growth, MRSA and MSSA.
Scope and prioritisation	Useful to keep automatic result prioritisation, improve filtering features, and avoid overly broad and unused options.	The need for automatically ordering patient list by urgency (e.g., notifiable diseases, mismatches, untreated cases) to help focus on what matters first.
		Prioritisation and filters must reflect clinicians' practical needs.
Visual cues and clarity	Color-coding with clear legend, and visual flagging will enhance the clarity.	Clinicians rely on an ordering mechanism to create a queue of actionable results, and clear color-coding and flagging can further support quick prioritization.
		The need for consistency and explicit legends so users understand what colours mean across views.
Usability in busy environments	A streamlined interface that requires minimal navigation, and a two-screen setup for concurrent app and ieMR viewing as a solution before integration is available.	Need to be simple to use and simple to learn as clinicians' cognitive burden, fatigue, and hesitation may impact on their adoption.
		Consolidation of information and the resulting reduction in clicks.

Each design consideration generated was assigned a priority level (high, medium, or low) based on technical constraints and feasibility within the scope and timeframe of the project (Table S1, Appendix). These were provisional and would need to be further revised in consultation with the technical team and key stakeholders at QCH to ensure alignment with evolving requirements and resource availability.

3.4 Influencing factors and implementation strategies

3.4.1 Inductive Coding - Themes and subthemes

Three key themes were identified through AI-assisted inductive coding and researcher review: results management and clinical workflow, antimicrobial stewardship and clinical decision making, and the app and workflow integration. These findings highlighted challenges in current practices and provided a foundation for the mapping of subthemes to relevant CFIR constructs and the generation of ERIC implementation strategies. Detailed themes, subthemes, associated statements and illustrative quotes are presented in Tables 3–5.

- **Theme 1. Results Management and Clinical Workflow**

Test results management relied on a collaborative review processing involving treating doctors and nurse practitioners. However, support gaps during weekends, public holidays, and staff leave created challenges. High result volumes, information overload, and limited prioritisation tools increased cognitive burden and the risk of missed critical findings. Challenges were also compounded by inconsistent clinical documentation, variable discharge plan and difficulties accessing relevant patient information. Participants also highlighted the importance of clear accountability and robust sign-off processes to ensure timely follow-up. Improved triage and access to integrated clinical information were viewed as key factors in supporting safe and efficient test result management.

Table 3
Theme 1 Result management and clinical Workflow - subthemes and exemplar quotes

Theme 1. Results Management and Clinical Workflow
Test Result Review and Prioritization
The process by which clinicians identify, review, and action patient test results, particularly pending results. This included checking, prioritizing, and ensuring follow-up for appropriate antibiotic prescriptions.
“Part of our role is to look through that results process, to look for those results when they've been finalized or not finalized…Or it may just be that we look at the results list…and then look back into the patient's notes...so I've got a urine that's grown E. Coli, but it's resistant to Keflex that they've been put on. So we would change it to Bactrim. And then we would obviously phone the patient.” [P4]
Shared and individual pools and Safety Netting
Nurse practitioners acted as a safety net by screening test results, taking actions, and escalating concerns, supporting clinicians in managing their individual pools, balancing individual and shared clinical responsibilities.
"With any clinician, if they order a test, it is their responsibility to chase themselves off. What we were finding in our emergency department, though, was that there were a lot of results sitting in the pool that weren’t checked. And so as a safety netting and kind of back up, it was asked if us as nurse practitioners could do it in our rapid review clinic." [P3]
Information Overload and Cognitive Burden
Challenges included high result volume, time spent reviewing, and risk of missing critical results due to information overload and inefficient prioritization tools.
"From a rapid review clinic where we can sometimes get a bit overwhelmed…you can filter through and sort the results by category, but you do worry that you might miss something that important when you have 400 there. It isn't solely the responsibility of the nurse practitioners. The consultants on the floor are also responsible for going through results in their downtime. But at times like this in winter when our departments under pressure, it's difficult." [P3]
Follow-up and Accountability
Processes ensure follow-up on pending or abnormal results through responsibility assignment, team communication, and patient calls to adjust antibiotics.
"I'm certain that I would have results that would disappear in that pool that have been checked off by them that I may not have checked off because I've been away…I had seven results that I checked off this morning, one of which was under the paediatric team and I called them about that result." [P4]
Result Sign-Off and Validation Processes
Workflows of signing off reviewed results, and challenges associated with user error, incomplete documentation, inconsistent follow-up practices, and managing result pools with validation responsibilities.
“So you go, what have I done? And then you're not sure, like, did I sign something off? I should have signed off. Does that need to be action…I am a little bit cautious with it at times, like some of those preliminary ones, I might just write prelim results. So when you actually go into the Action lists…you

Theme 1. Results Management and Clinical Workflow
Test Result Review and Prioritization
can see who's done what on them…and if someone's pre signed it off down the bottom, it will say what's happened." [P5]
Triage and endorsement
The high volumes required NPs and doctors to review and sign off, highlighting the need for filtering and triage strategies to ensure follow-up and prevent missed actions.
"So we've got a way now finally where they can at least flag ones that are positives out of the book [list] because otherwise they're just mixed into a pile. And clearly it's something that machine learning could work quite well in terms of sifting a large list and working out things that have actually got clinical significance because what we're currently being fed is just a pile which is actually very marginally filtered into this positive now." [P8]
Data access and clinical note quality and consistency
Clinicians used ieMR for clinical notes, Orders, actions and lab data during test review; inconsistent notes and discharge plans could disrupt follow-up and care continuity.
"Because not all like it would be great if every person, every treating clinician wrote, prescribed, you know, oral antibiotics and then wrote what they prescribed in the dose they prescribed, but sometimes they just write prescribed antibiotics, so you don't know. So you have to go into the orders to check what's actually being prescribed." [P2]

- **Theme 2. Antimicrobial Stewardship and Clinical Decision Making**

Clinicians made antibiotic decisions based on culture results, sensitivities, patient factors, and guidelines, but often had to rely on their clinical judgement to prescribe empirically, act on preliminary test results or consult specialists. While antimicrobial stewardship guidelines and principles were helpful, challenges existed in antibiotic administration due to issues such as palatability and dosing in children. Once final results were available, follow-up with discharged patients or wards where patients were admitted was performed to ensure proper antibiotic treatment adjustments. Communication with patients, GPs, and pharmacies was also important to enhancing safety and providing reassurance.

Table 4
Theme 2 Antimicrobial Stewardship and Clinical Decision Making- subthemes and exemplar quotes

Theme 2. Antimicrobial Stewardship and Clinical Decision Making
Antibiotic decision-making and preliminary results
Clinicians selected antibiotics based on culture results, sensitivities, patient age, diagnosis, and guidelines, but may act on preliminary test results or consult specialists.
"And the swab result, well it actually wasn't available…So I rang the lab and spoke to the microbiologist, 'cause you know, sometimes they can kind of look at it before it's actually finalized. And they told me it was, there was some resistance to Cefalexin. but it was showing sensitivity to Bactrim. So based on that, then I've rang the family, had a chat to them how the patient's doing…told him that we needed to change the antibiotic" [P1]
Antimicrobial Stewardship and Treatment Guidelines
Clinical decisions on antibiotic aligning with stewardship principles and guidelines in prescribing for paediatric patients.
"I guess at the point where we don't have the microbiology finalized, we use our antibiotic card to guide our decision making on antibiotic choice, plus or minus reviewing like if it's a child with frequent UTIs (urinary tract infections), if they've grown a specific bug previously and it's been treated with something, then we'll try and align that as we can." [P6]
Patient Follow-Up and Reassurance
Discharged patients follow-up on antibiotics when final results arrived, and GPs and pharmacies communications to enhance patient safety and trust, especially in paediatrics.
"So then I would give that family a call…if we've done a test result…then we would like the family to know that test result and explain to them that while this will change the treatment options for your patient, these are their expectations of what's going to happen over the next few days. And these are the risk factors that we would want you to re-present back to the emergency department. So that gives them reassurance." [P1]

- **Theme 3. The App and Workflow Integration**

The efficiency of test result review workflow relied on minimizing extra steps and duplication, requiring seamless integration of the test result review app with existing processes. App design such as colour coding, sorting, searching, and automated flagging of actionable results were viewed as valuable features. Future opportunities for interoperability with systems such as ieMR and external pathology providers would support smoother access to data. While experiences with AI in current practices were mixed, there was a generally positive attitude toward digital transformation and the use of AI-supported technologies. To overcome adoption barriers, pilot trial, staff training, champion models, and intuitive design would need to be considered to ensure successful implementation.

Table 5
Theme 3 App Usability and Workflow Integration - subthemes and exemplar quotes

Theme 3. App usability and Workflow integration
Workflow Integration and Efficiency
Minimizing extra steps and duplication to ensure the app streamlines and integrates into workflow, especially during high-volume test result periods.
“The summary…pulling the discharge letter and current prescriptions...and that the coloured flag as far as saying…nothing's been prescribed or this is kind of your ideal, I think that's helpful...If we're needing…more of those finer clinical details, we will go into the chart anyway...I think it [the app] is pretty straightforward. You don't want it to be too much information either.”[P5]
User Interface and Visual Indicators
Features such as colour coding, sorting, and search features could improve usability and reduce cognitive load.
"Green for me makes sense because it's they're on treatment and it's the right treatment and you don't need to do anything…So that's kind of go a red would flag, there's a potential problem…And I guess having some sort of key for the colours of what they actually mean, because colours are one thing, but nobody knows what they mean...I don't know whether you could integrate that sort of thing." [P1]
Integration of the app with clinical systems
While the test result review app could pull data such as discharge summary and test results etc, the lack of integration between the app and ieMR could create inefficiencies.
"The biggest challenge at the minute would be…the fact that it will involve a little bit of doubling up, in the fact that they don't talk to each other. And inevitably you will get people that will probably whinge about that a little bit. The fact that, I can't just click off a patient on here and it automatically, I've still got to go into the results pool system and actually clear them off the results pool." [P1]
Integration and Interoperability of various systems
Opportunities and challenges of integrating systems (e.g., ieMR, external pathology) for seamless access in the future.
“Now, nowadays, the pathology companies are being forced by federal government to move those pathologies into the My Health Record. So the obvious other thing…helpful would be to have an integration ideally or some which sort is of pulling from that. And I know there's been, there's so many different pathology companies and this is what we have a nightmare with outside of here." [P8]
App-enabled Automation for Checking and Flagging
Potential benefits of the app for improving efficiency, e.g., automating the flagging of critical or actionable results, reducing manual checking, and integrating with existing systems.
"If you roll it out to...the ones that they need to action… they're jumping on it straight… because naturally, as clinicians…if I'm looking at the results, I'll stream it by type and I'll go straight to the urines and I'll go straight. " [P8]
Artificial Intelligence in clinical practices

Theme 3. App usability and Workflow integration
Workflow Integration and Efficiency
Experiences with AI in current practices were mixed, with some negative, but there has been a generally positive attitude towards digital transformation in hospitals.
"My attitude to AI is very positive because I use it in my private [service] telehealth. We have an AI system that generates our notes and generates our letters and all sorts of things for it. And I found a very positive experience. "[P4]
Pilot Implementation and Change Management
Change management, pilot implementation strategies, staff training, champion models and intuitive design will be key to overcoming adoption barriers and delivering immediate value to encourage uptake.
"So if you're actually going to implement a system like this from a rollout and barriers point of view, I would just target the nurse practitioners…because if you're going to use it for this extra use case that we're talking about here, it will be very useful. But that would limit you to about 10 people. And that's going to be so much easier than to try and get 40 SMOs, some of whom are 0.125 [FTE] to try and get the new system, they may not want to do it." [P7]

3.4.2 Top CFIR Influencing Factors

All subthemes of the three key themes were mapped to relevant CFIR constructs (Table S2, Appendix). The top ten CFIR constructs, defined as those mentioned by the majority of participants (> = 5), were identified. These key influencing factors and their associated context-specific definitions for test result review in ED are outlined in Table 6 below.

Table 6
Top CFIR influencing factors

Top CFIR Influencing Factors	Participants (N)
Innovation Suitability • The degree to which the app is clinically appropriate or useful as delivered to the ED clinicians at QCH.	8
Innovation Adaptability • The degree to which the app can be easily modified, tailored, or refined to fit local context or needs.	8
Innovation Design • How well the app is presented and packaged, e.g., user interface, features, steps.	8
Information Technology Infrastructure • How well the hospital IT and electronic record systems support ED work and practices.	8
Work Infrastructure • How responsibilities of individuals and teams and staffing levels support ED work practices.	8
Innovation Relative Advantage • The degree to which the app is better than other similar technologies or the current practice.	6
Local Conditions • How well the local political and technical conditions enable the hospital in adopting digital technologies like the app.	6
Communications • The quality, frequency and clarity of communications internally.	6
Innovation Complexity • The degree to which the app is complicated, e.g., its overall scope, connections with other systems.	5
Tension for Change • The degree to which stakeholders perceive the current test result review practices as needing change.	5

3.4.3 ERIC Strategy Mapping

The top influencing factors were mapped to the ERIC tool to generate implementation strategies. Detailed CFIR-ERIC mapping can be found in Table S3 (Appendix). We drew upon recommended

grouping of ERIC strategies [18, 25] and triangulated these activities with specific research findings to provide guidance for future pilot implementation of the app. The summarised strategies and recommended approaches included: adapt and tailor to context, develop stakeholder interrelations, and use evaluative and iterative strategies, as outlined in Table 7. These strategies will need to be further discussed with hospital stakeholders to ensure that they are delivered in an acceptable, appropriate and feasible manner within the QCH contexts.

Table 7
Implementation strategies

Clustered strategies	Practical recommendations
Adapt and tailor to context (Innovation design, suitability, adaptability and complexity)	**Identify the ways in which the test result review app can be tailored to meet local needs and clarify which elements of the innovation must be maintained to preserve fidelity**. E.g. For future studies, ensure that any updated versions of the app incorporate feasible changes based on feedback. Map the current workflows and provide specific app features presented in a user-friendly format that aligns with existing roles and responsibilities. E.g., Tailor the filtering and prioritization design to the existing practices of the primary users of the app.
Develop stakeholder interrelations (Work infrastructure, Local conditions, Communications, Innovation relative advantage, Tension for change)	**Identify and prepare individuals who dedicate themselves to supporting, and driving through an implementation, overcoming any challenges or resistance that the app may provoke in the ED.** E.g. Ensure there are people experienced in undertaking digital health implementation lead engagement efforts in ED and assist in identifying site champions. Prepare site champions with the tools they need to promote the app implementation. **Include IT and management stakeholders in discussions to address whether the technology requirements can be met.** E.g. Coordinate with local IT department to explore options for accessing data such as Notes, Orders, and more details of microbiology results. The concerns about double handling due to not being able to be integrated into ieMR indicates that establishing an appropriate setup to minimize this challenge for the pilot trial is needed.
Use evaluative and iterative strategies (Innovation relative advantage, adaptability, complexity, design, and Tension for change)	**Collect and analyse data related to the need for the app.** E.g. Engage with clinicians, researchers and stakeholders to conduct local needs assessment such as collecting clinical performance data and other relevant data to determine whether the challenges in test result review need to be addressed and whether the app to address these is appropriate. **Implement the app in the test result review workflow in a cyclical fashion using small tests of change before taking changes system-wide** E.g. Conduct a small-scale pilot trial of the app with primary clinical users to collect feedback. Use the insights from the study to develop appropriate clinical workflow of using the app and to identify the outcomes measures for future evaluations.

4 Discussion

4.1 Overview

This study presents a qualitative exploration conducted as part of a co-design effort to inform the development and implementation of a clinical decision support tool for antimicrobial stewardship during ED test result review. A key strength of this study is its use of contextual inquiry and co-design, which provides a comprehensive understanding of local workflows and supports the development of an AI-enabled solution tailored to the ED environment. Furthermore, the study contributes to the research of clinical decision support and digital health by demonstrating the use of implementation science frameworks to enable identification of implementation strategies and support the integration of decision support technologies within existing clinical ecosystems.

4.2 Workflow and Challenges

Our findings unpacked the workflow and role responsibilities in test result reviews within the ED, and importantly, and revealed challenges that impeded efficient clinical decision making and appropriate antimicrobial stewardship. These insights highlighted the importance of understanding how responsibilities and information flows were structured and the complexity of integrating new digital tools into existing clinical processes.

The workflow analysis outlined key activities in the test result review workflow, including checking and assessing results, antibiotic review and adjustments, escalation and consultation, documentation in result review pools and ieMR, sign-off and patient follow-up. Our study leveraged AACTT framework and process mapping to identify responsibilities and identify critical points of process vulnerability during the workflow. Process mapping is an often overlooked (and under reported) step in the process of embedding digital technology into usual care [8, 11]. The process results enabled a shared understanding between researchers and clinicians by visualizing representing workflows, which in turn provided a foundation for the identification of implementation strategies. This aligns with previous study emphasizing the important steps of problem assessment and clinical workflow design along with the technology (e.g., AI model) and infrastructure development [12].

The inductive coding results revealed several challenges in existing test result reviews, including high cognitive burden, limited prioritisation support, and inconsistencies in documentation and effort required in follow-up. The results also highlighted the complexity of antimicrobial decision-making, requiring clinicians to balance guidelines with clinical judgement, patient-specific factors, and communication across teams and departments. Workflow fragmentation, information overload, and limited system integration were also identified as major barriers to efficient practice. These insights are consistent with previous studies that report persistent bottlenecks in emergency and acute care settings, such as time lags in testing processing, handovers, and specialist review, and these issues often persist or worsen following digital system implementations [1–3, 27]. Our results highlighted that research of digital solutions in this space requires not only improved usability and automation, but also needs alignment with existing workflows, clinician needs, and organisational support.

4.3 Design considerations

The study identified key design considerations for the test result review app. These included the need of seamless integration into existing hospital information systems, provision of relevant clinical content and antibiotic decision support, appropriate scoping and prioritization features, and intuitive interfaces suitable to the busy environment. These findings align with reported design principles identified in the research of decision support systems and human-AI interaction, such as presenting contextually relevant information, clearly explaining system features, supporting sensemaking and maintaining a human-in-the-loop model rather than full automation [10, 28]. These findings are also consistent with our earlier work examining explainable AI tools for predicting patient deterioration, which highlights the importance of ensuring seamless integration with existing systems, access to meaningful clinical information to support quality decision making and triage, and the importance of streamlined user-friendly interfaces that can be easily navigated in high pressure environments[9].

The design insights of this study were generated through contextual inquiry interviews combined with prototype evaluations and discussions, which enabled participants to reflect on how the tools would operate within real-world practices. This approach is consistent with sociotechnical design principles, which emphasise grounding digital health solutions in observed workflows and eliciting feedback through interaction with tangible representations of technology [13, 14].

4.4 Implementation strategies

This study identified key strategies to be addressed prior to a pilot trial of the prototype, drawing on implementation science frameworks CFIR and ERIC. These frameworks are increasingly used to help identify the conditions required to support the uptake of evidence-based practices [15–18, 25] and have been proven useful in our previous work in digital health evaluation [19, 20]. Three key strategies emerged through CFIR constructs identification and CFIR-ERIC mapping in this study: adapt and tailor to context; develop stakeholder interrelations and use evaluative and iterative strategies.

Adapting and tailoring to context involves identifying how an innovation can be modified to suit specific settings. For example, other hospitals may not include Nurse Practitioners in their workflows or may use different processes for following up test results. These processes should be mapped out at each site prior to implementation to ensure fit and local acceptability. Undertaking this exercise has been shown to improve the uptake of decision support tools in clinical settings, including those supporting diagnostic accuracy and management of acute conditions in ED environment [12, 29].

Development of stakeholder interrelations is focused on the local relationships and the influence that these can have on adoption, particularly when innovations are being introduced by outside researchers or personnel. This study identified the importance of having site champions and support from multiple levels to promote adoption. Failure to this has been demonstrated to result in sub-optimal uptake of innovations [30].

The third strategy likely to assist is the use of evaluative and iterative strategies, which includes the collection of data about the performance of the prototype and clinical care provision, and the ability to

undertake pilots and do small tests of change. While earlier AI implementation studies often relied on post-implementation surveys of clinician perspective[31], more recent research emphasises the importance of understanding clinician experience during early implementation stage to improve the uptake in settings such as ED [12, 29]. Iterative insights into how these factors interact with sociotechnical contexts can inform more effective implementation strategies.

A recent systematic review of AMS decision support systems applied ERIC framework to analyze reported implementation strategies and identified the most frequently reported strategies, including developing stakeholder interrelationships, training and educating users, evaluative strategies, provision of interactive assistance, and adaptation and tailoring to context [8]. Our study provided further practical recommendations, such as supporting tangible co-design, refining the app to incorporate feasible changes, aligning workflows with current roles and practices, coordinating with IT department to accessing required clinical data, identifying and supporting clinical champions, collecting data on clinical needs and outcome measures, and using interactive, small-scale tests of change before broader rollout. These findings contribute to a more systematic understanding of how decision support and AI technologies for AMS can be implemented in hospital settings.

It is worth noting the approach of combining AI-assisted qualitative data analysis and manual coding used in the thematic analysis of this study. The themes and subthemes generated using AILYZE were manually reviewed, modified, and validated before the manual codings processes, such as the analysis of design feedback and considerations. During CFIR constructs generation, a manual pilot analysis and calibration process were conducted to confirm the alignment between AI-generated and human-coded findings. These manual checking and validation steps increased confidence in the use of this approach for subsequent qualitative analysis.

4.5 Limitations and future work

This study was conducted at a single site with specific contextual characteristics that may not be readily generalizable. Further iterative user testing will also be needed to finalize the technology design. Mapping of the current workflow and desired workflows to integrate the app will need to be further investigated through stakeholder workshops. The next phase of the study will also involve refining these recommendations in collaboration with the pilot site to develop a detailed implementation enhancement plan to support identification of key actions and supportive personnel who will drive them. We anticipate that this formative work will increase the likelihood of a successful pilot study, helping to further advance the understanding of how to support the optimization, testing and adoption of digital technologies that support optimal patient care.

5 Conclusion

This study provides a detailed understanding of ED test result review workflows and identifies critical design and implementation considerations for an AI-powered decision support app to enhance antimicrobial stewardship. Through clinician co-design and the application of CFIR and ERIC

frameworks, key workflow challenges, technology design requirements, implementation influencing factors and feasible strategies were systematically identified. The findings highlight the importance of aligning the tool with existing clinical roles, infrastructure, and follow-up practices to support clinician acceptance and usability. These insights will guide further technology refinement and inform the implementation of a pilot trial aimed at improving antimicrobial stewardship and patient safety in the ED.

Abbreviations

CSIRO
Commonwealth Scientific and Industrial Research Organization
FHIR
Fast Healthcare Interoperability Resources
CFIR
Consolidated Framework for Implementation Research
ERIC
Expert Recommendation for Implementation Change

Declarations

Ethics approval and consent to participate

Ethics approvals were obtained from Children's Health Queensland Hospital and Health Service Human Research Ethics Committee (reference number: HREC/24/QCHQ/103135) and CSIRO Human and Medical Human Research Ethics Committee (ID 2025_007_RR). The study was conducted in accordance with the Australia's National Health and Medical Research Council (NHMRC) National Statement on Ethical Conduct in Human Research. A privacy review for the project for data analysis was also conducted by a legal counsel at CSIRO. All participants completed an informed consent form prior to participation.

Consent for publication

Not appliable.

Competing interests

The authors have no conflicts of interest to declare.

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Author Contribution

AD, JL, JR, AN and NP contributed to the conceptualization of the study. AN, AD and NP led the project and oversaw all aspects of the study. AN led the technical development, while NP managed the hospital collaboration. JL, JR, AN and AD conducted the interviews. JL and AD analysed the data. JL prepared the original manuscript draft. All authors contributed to the review and revision of the manuscript.

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Data Availability

Due to privacy and ethics considerations, the datasets generated or analysed during this study are not publicly available but may be available from the corresponding author on reasonable request.

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Figures

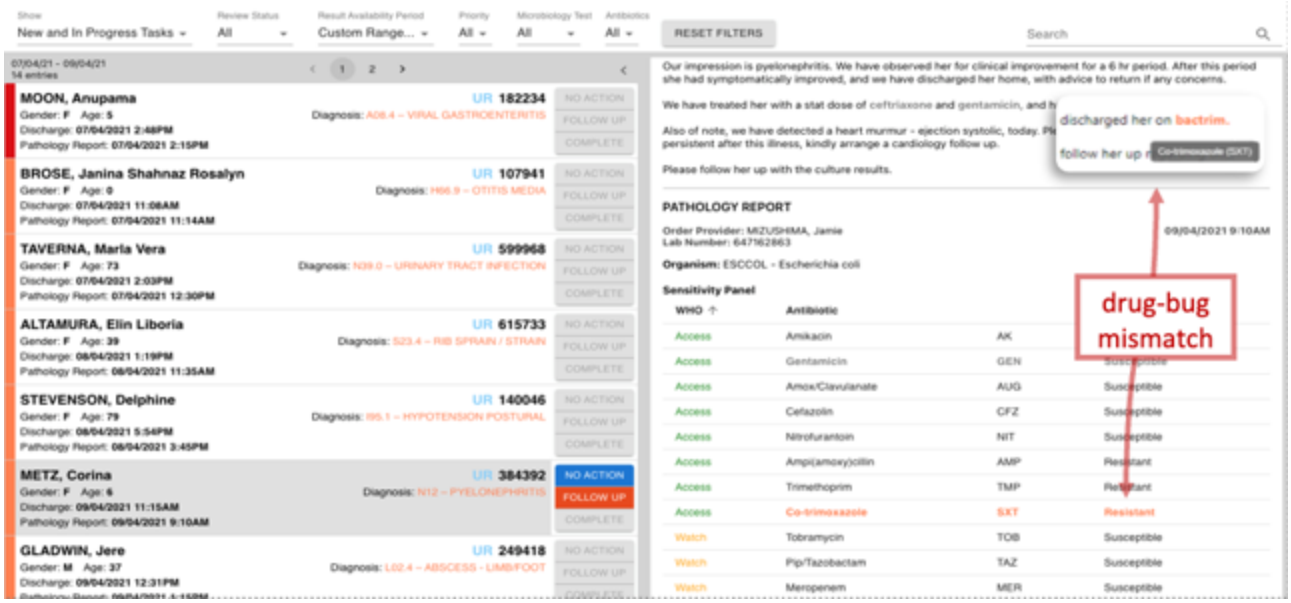


Figure 1

Initial prototype of the test result review app (with obscured patient information): identifying and prioritising patients with inappropriate antibiotic treatments due to drug-resistant infections for patient follow-up, streamlining the clinical review process in Emergency Departments.

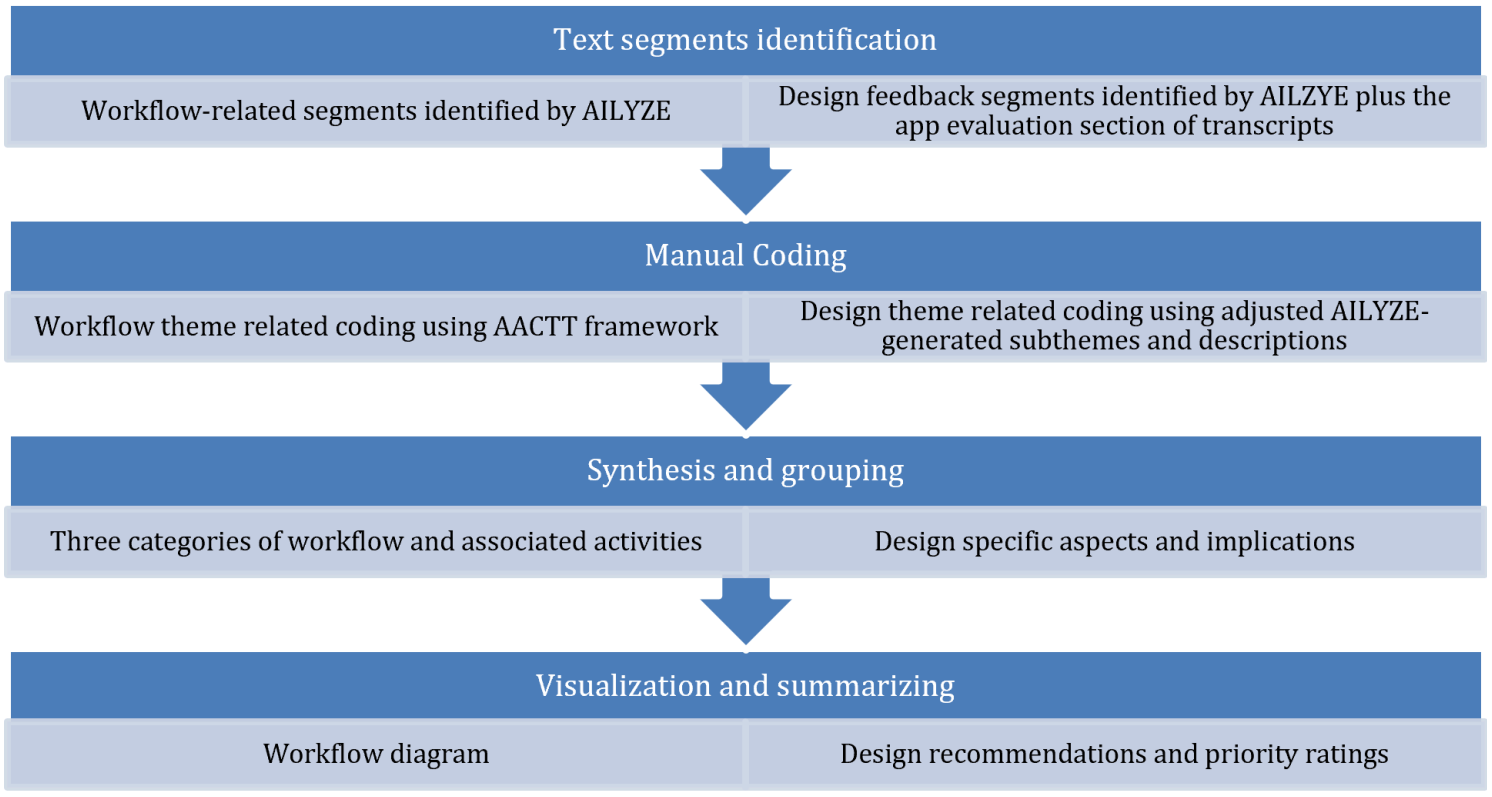


Figure 2

Current workflow and design refinement analysis process

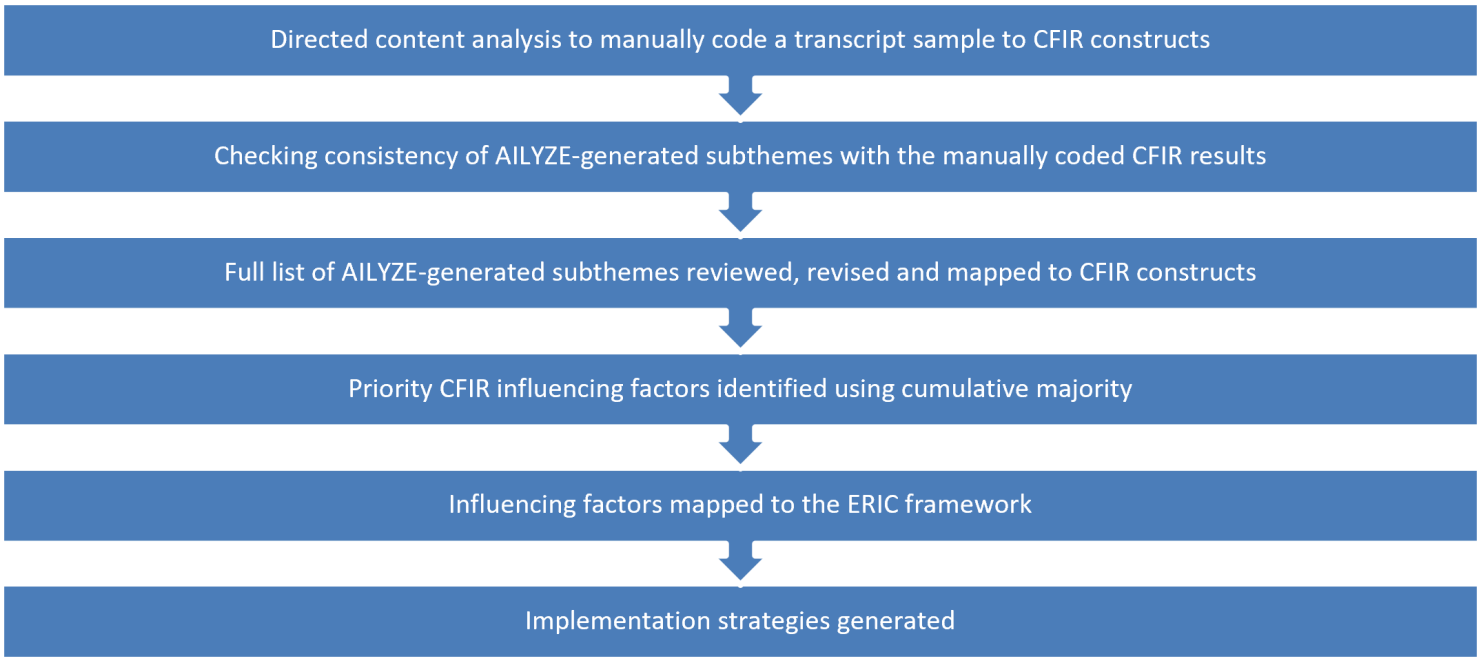


Figure 3

CFIR coding and implementation strategy development process

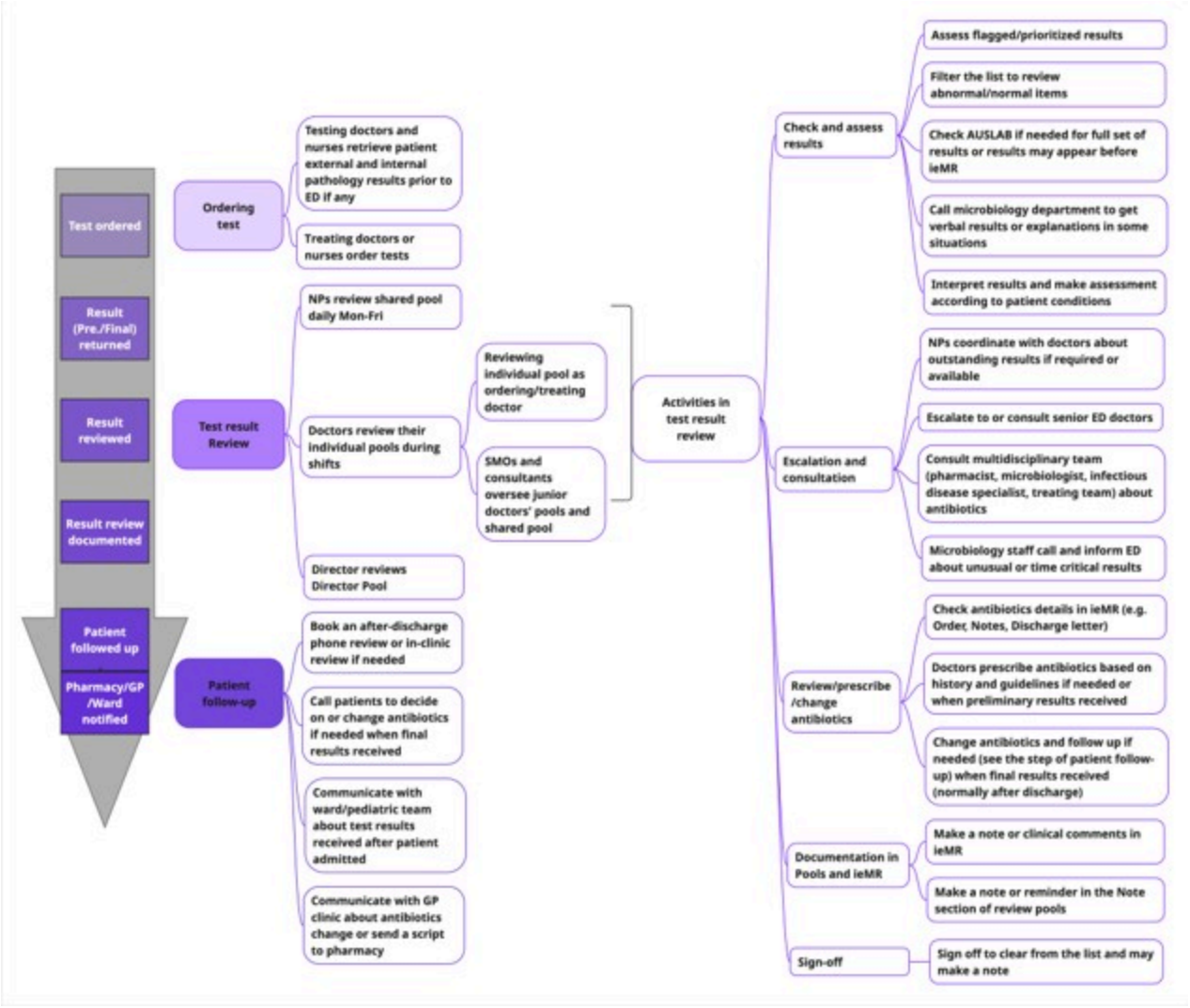


Figure 4

Test Result Management and Review Workflow at the ED

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendix.docx
- Interviewguide.docx