Supporting healthcare workers to improve the quality and safety of care through AMR stewardship

Julia Keizer

SUPPORTING HEALTHCARE WORKERS TO IMPROVE THE QUALITY AND SAFETY OF CARE THROUGH AMR STEWARDSHIP

A BOTTOM-UP PARTICIPATORY APPROACH TO AUDIT AND FEEDBACK AS A LEARNING AND IMPROVEMENT STRATEGY

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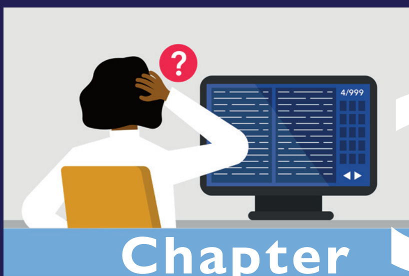
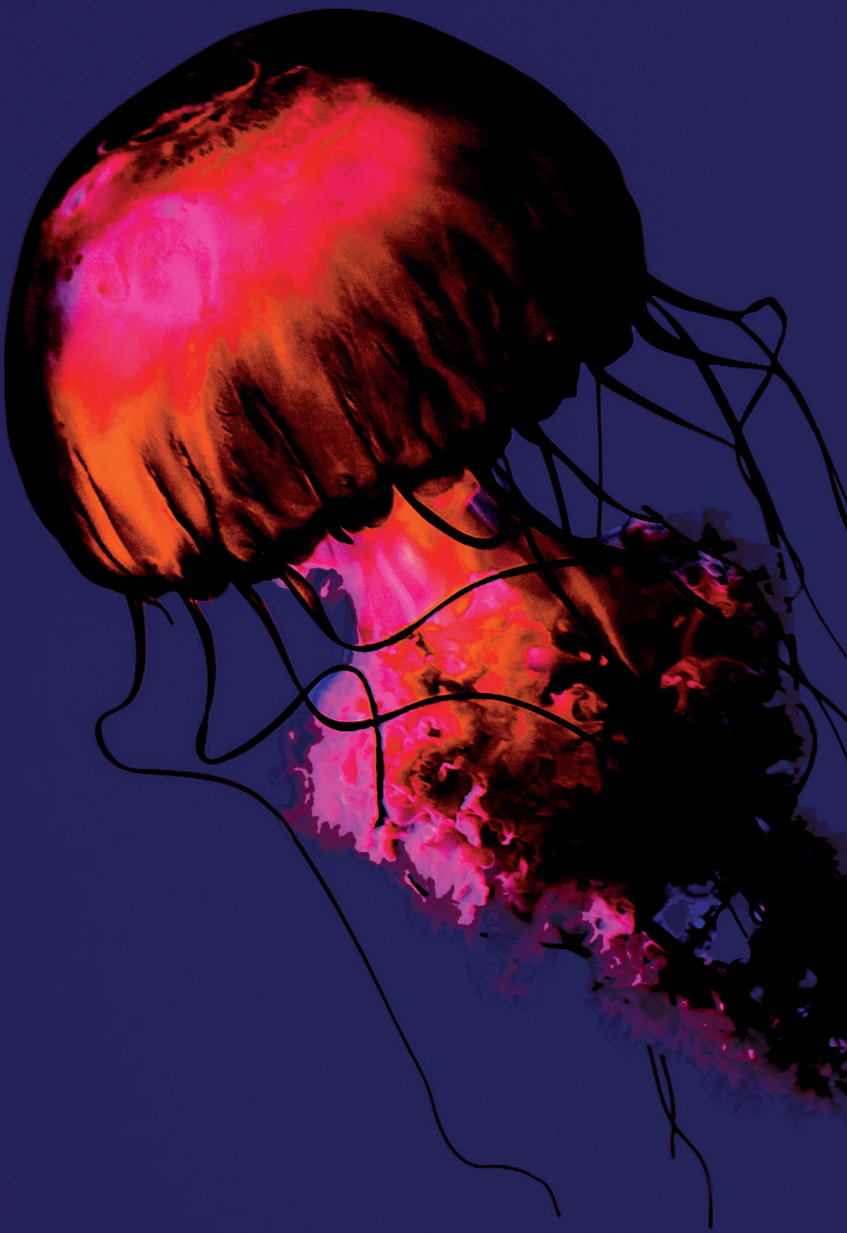
Part 1



Part 3



IT IS NOT THE STRONGEST OF THE SPECIES THAT SURVIVES,
NOR THE MOST INTELLIGENT THAT SURVIVES.
IT IS THE ONE THAT IS THE MOST ADAPTABLE TO CHANGES.

- NOT DARWIN

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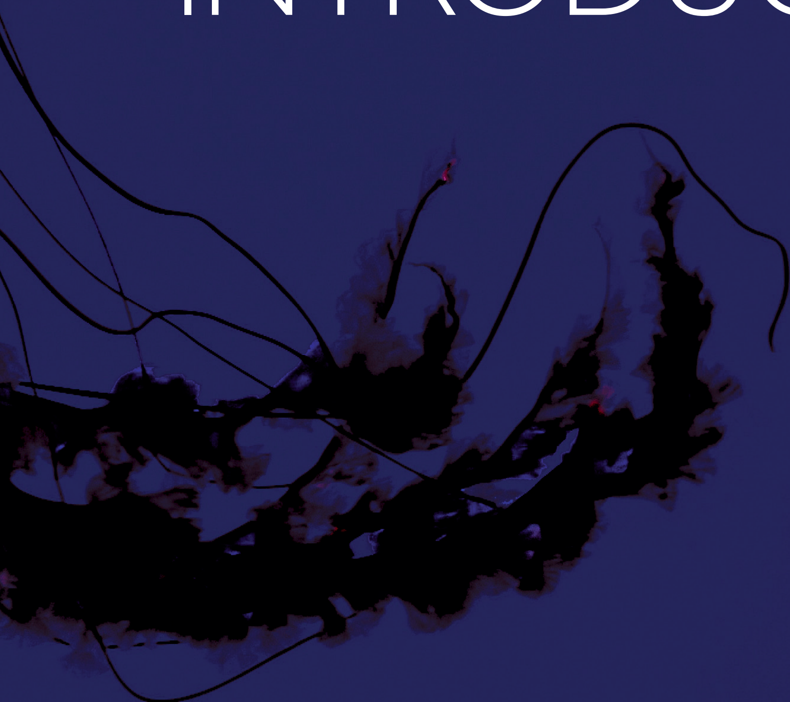
Chapter 1:

GENERAL INTRODUCTION



1. Background

1.1 The rise of antimicrobial resistance (AMR)

Let us take a quick tour through history. Millions of years ago jellyfish floated around in the oceans, accompanied by little more than microorganisms (e.g. bacteria) that have been around for much longer (1). Both have survived multiple mass extinctions due to their resilience and ability to adapt to changes in their environment (2). Fast-forward to London 1928 when Sir Alexander Fleming discovered the antibacterial effects of penicillin by chance (3). Despite publishing his findings in the British Journal of Experimental Pathology it was not until 1942 that public awareness arose for his findings after a team at Oxford University managed to isolate penicillin as a therapeutic compound (3,4). Penicillin saved the lives of many wounded people during World War II, which led to Fleming being awarded the Nobel Prize in Medicine and Physiology in 1945 (5). In his Nobel Prize lecture Fleming already warned for an evolutionary threat inherent to penicillin and other antimicrobials, namely antimicrobial resistance (AMR) (6).

AMR refers to when microorganisms (e.g. bacteria, viruses, and fungi) develop the ability to withstand the antimicrobials (e.g. antibiotics (ABX), antivirals, and antifungals) developed to kill them (7). These resistant microorganisms are also referred to as "super bugs", highly resistant microorganisms (HRMO) or multi-drug resistant organisms (MDRO) (8). Without working antimicrobials, common infectious diseases could become life-threatening once again and it may prevent the provision of complex procedures (e.g. chemotherapy and surgery) at relatively low risk (9).

1.2 AMR consequences and causes

To date, AMR still threatens human health and the quality, safety and durability of modern healthcare (9). Estimates show that at least 50.000 deaths per year can be attributed to infections caused by resistant microorganisms in the US and Europe alone (7,10), while worldwide 700.000 deaths may be attributed to AMR every year (11), although reliable evidence on the burden of AMR is scarce (12). By 2050 AMR is expected to cause more yearly deaths worldwide than cancer currently does (up to 10 million) (13). Increasing rates of AMR and the fact that the development of new antimicrobials has stagnated after the 1990s are alarming signals for the dawn of a post-antimicrobial era (9).

AMR is a natural phenomenon in microorganisms, but human behaviour in many forms accelerates the Darwinian selection process (i.e. resistant microorganisms surviving over non-resistant microorganisms). First and foremost, through the systematic mis-, under- and overuse of antimicrobials in both healthcare and agriculture (9,14). Second, because of a lack of infection prevention and control measures, and poor hygiene. Preventing infections caused by (resistant) microorganisms reduces the need for antimicrobials in the first place, while infection control can limit the spread of (resistant) microorganisms (15). Third, due to traveling, trading, and human and animal migration, the spreading of resistant microorganisms occurs rapidly and unpredictably (16). The impact of these transmissions has become very clear during the COVID-19 pandemic that is still ongoing while this thesis is written (17).

1.3 Crossing-borders

Human made borders, between healthcare institutions and between countries, are no barrier for the spread of (resistant) microorganisms. Within a country patients often move between healthcare institutions such as hospitals, long term care and primary care facilities, spreading microorganisms across them (18). Furthermore, since the 2011 EU directive on the application of patients' rights in cross-border healthcare, cross-border mobility of both patients and healthcare workers (HCWs, e.g. doctors and nurses) between European countries has steadily increased (19–21). As a result of the increased patient and HCW mobility, (resistant) microorganisms also increasingly spread in cross-border regions like the EUREGIO (i.e. north-eastern Netherlands and north-western Germany) (22). Consequently, AMR should be tackled with coordinated regional and cross-border initiatives comprising a wide range of AMR prevention measures (APM) (23). To realize a cross-border network, various consecutive European projects in the EUREGIO shared knowledge, best practices and technologies (see box 1) (24–26). The University of Twente (UT) contributed to these projects by providing input on the development, implementation, and evaluation of (eHealth) technologies with human-centred socio-technical approaches (i.e. studying the interactions between a technology and its social and technical context with an emphasis on the human perspective) (27). eHealth technology is referred to as "health services and information delivered or enhanced through the Internet and related technologies" (28). Prior UT theses on AMR have demonstrated the importance of including stakeholders in the development, implementation and evaluation of eHealth technologies, and the importance of persuasive design to optimize the technology's user-friendliness and usability, so that users are supported and motivated to actually use the technology in their work (29–32). These theses all contribute to tackling AMR with eHealth technologies that support HCWs at point of care (POC) (e.g. online guidelines and clinical decision support systems (CDSSs).

1.4 About this thesis

This thesis builds upon the aforementioned theses, but focuses on how eHealth can support HCWs through reflective learning cycles (i.e. not at POC). We describe how a human-centred socio-technical approach can inform and guide the participatory development and implementation of an APM learning and improvement strategy. Specific attention is paid to 1) how a bottom-up participatory approach (i.e. involving HCWs and other relevant stakeholders from the start of the development process) can improve the persuasive design of the eHealth technology, while simultaneously supporting HCWs' ownership of the learning and improvement strategy, and 2) the interdisciplinary theoretical underpinning for informed choices, and comprehensive and transparent reporting on the development and implementation of an APM eHealth technology. Thereby, this thesis has both added value for clinical practice and scientific merit.

In the next sections, we will elaborate on AMR and APM in the hospital setting, and introduce the learning and improvement strategy supported by data-driven eHealth technology.

Box 1. Cross-border AMR network projects and the contributions of the Centre for eHealth and Wellbeing Research of the University of Twente.

In 2006, the Interreg III EUREGIO MRSA-net project formed the basis for a regional network to improve the implementation of prevention and control strategies for a specific resistant microorganism (i.e. Methicillin-resistant Staphylococcus aureus or MRSA) (22,24). In this project, Verhoeven et al. studied how paper-based MRSA guidelines could be translated into a web-based MRSA information tool (29).

In the subsequent Interreg IVa EurSafety Health-net project the cross-border network cooperation was continued with a broader focus on all hospital-acquired infections (HAI), in which harmonization of the Dutch and German infection approach was strived for and in which healthcare institutions could acquire Euregional quality and transparency certificates (25,33,34). In this project, three UT theses highlighted various socio-technical aspects. Wentzel et al. focused on participatory strategies for developing, implementing and evaluating online AMR and infection control guidelines and tools for MRSA-patients, the general public, and nurses (30). Van Limburg et al. focused on the implementation of antimicrobial stewardship programmes (ASP) and supportive technologies (31). Beerlage-De Jong et al. focused on how eHealth technology can support physicians in ASP by studying the participatory development, persuasive design, and evaluation of ASP eHealth technologies (32).

The latest continuation of the cross-border network started in 2016 in the form of the Interreg Va Health-i-Care and EurHealth-1Health (EH1H) projects, (26). The UT contributed to the EH1H project with studies on clinical and spatiotemporal risk factors for infections and the transmission of microorganisms (35,36), and with the studies presented in this thesis (37–41).

INTERREG Deutschland Nederland | Europäische Union Europese Unie | eurhealth1health | HEALTH i CARE Innovations for safer healthcare | Centre for eHealth & Wellbeing Research

2. Audit and feedback as an APM learning and improvement strategy

2.1 Fighting AMR in hospitals

As you may have noticed by now, AMR is a very urgent and "wicked" global problem; it involves multiple stakeholders with varying (sometimes conflicting) views on what the problems and solutions are, making an evaluation of implemented solutions difficult as well (42). No single solution will be sufficient to solve AMR by itself; cooperation between stakeholders on international, national, and local institutional levels is required to create multiple series of complex synergetic interventions and strategies to address AMR emergence, transmission and burden (43).

This thesis focuses on AMR in a specific setting, namely hospitals. Hospitals have been regarded as hotspots for AMR because of the high density of vulnerable patients, the high volume of antimicrobial use, and the high level of interactions between many HCWs and patients that fuel the emergence and spread of AMR (36,44). Estimates from 2016/17 show that 3.8 million patients acquire an infection in European acute care hospitals each year (45), and between 14% and 78% of in-hospital empiric antibiotic use in patients with severe infections is inappropriate (46). Even though AMR has spread to other healthcare settings and the community, hospitals are still the main source for AMR emergence and spread (47).

To limit the emergence and spread of AMR in hospitals, AMR stewardship is advocated by various healthcare authorities and professional societies (e.g. World Health Organization (WHO) (48,49), European Centre for Disease Prevention and Control (ECDC) (50,51), and European Society of Clinical Microbiology and Infectious Diseases (ESCMID) (52,53)). AMR stewardship comprises three interrelated stewardship programmes. First, antimicrobial stewardship programmes (ASP) that aim to promote the prudent use of antimicrobials (54). Alongside ASP, infection prevention and control programmes (ICP) aim to prevent the spread of resistant microorganisms that cause difficult to treat infections (49). Last, diagnostic stewardship programmes (DSP) complement ASP by improving the appropriate use of microbiological diagnostics to guide therapeutic decisions (55). As the three programmes are intertwined, an integrated approach of AMR stewardship (comprising ASP, ICP, and DSP) is needed to reduce and slow down AMR in hospitals, while prioritizing patient safety and quality of care (56).

AMR is a problem prompted by the behaviour of HCWs and patients (e.g. by prescribing and/or using antimicrobials incorrectly and not adhering to hygiene guidelines) (57). Therefore, AMR stewardship mostly focuses on influencing the behaviour of HCWs with a wide variety of AMR prevention measures (APM) (58). Examples are providing local diagnostic and therapeutic guidelines, interfering with antimicrobial prescriptions of HCWs, and educating HCWs and patients on AMR and infectious diseases. Furthermore, in most European countries hospitals are required to establish antimicrobial stewardship teams (A-teams) and surveillance of antimicrobial consumption and AMR (52). However, even though improvements have been realized by implementing APM in hospitals over the past years, there are still considerable opportunities and an urgent need for improvement (59). In this thesis, two promising opportunities that may improve APM in hospitals are combined.

2.2 Improving AMR prevention measures (APM)

The first promising opportunity for the improvement of APM is the emerging shift from the usual top-down approach to an approach where HCWs are involved in developing and implementing APM in their daily working routines so that they feel supported to take ownership (or individual accountability) of APM (60,61). This is especially important for APM, as all HCWs encounter APM in their daily working routines (e.g. HCWs of all specialities treat patients with antimicrobials and all HCWs need to perform adequate hand hygiene), yet APM are not the "core business" of HCWs (62). In the top-down approach, APM strategies were developed and implemented by and with AMR experts (e.g. clinical microbiologists, infectious disease specialists, infection control professionals and pharmacists), and predominantly aimed to educate HCWs to fill a presumed AMR knowledge and awareness deficit (63). Thereby, HCWs are overlooked in the development and implementation process of APM and their required behaviour change is more assumed than accounted for (64). This in turn, has been shown to contribute to a poor fit between APM, the needs and skills of HCWs and their clinical practice (i.e. context) leading to suboptimal APM effects (29,30,32).

Another promising opportunity for the improvement of APM is the increased use of a wide range of (eHealth) technologies for various APM goals and target groups (also see box 1) (65). The increased use of electronic health records provides many and rich data, which in turn could be transformed into useful insights using data-driven eHealth technologies to improve health and healthcare (66). Examples in APM are the use of clinical decision support systems (CDSSs) and surveillance systems that can help to detect infections, advise on diagnostics and treatment, and monitor and predict AMR and treatment responses (67). Data-driven eHealth technology has the potential to tailor and personalize APM to fit with the needs of HCWs and their context (68). However, the added value of data-driven eHealth technologies is only realized if the data are analysed and transformed into meaningful and useful information and communicated to HCWs in a clear, concise, and action-oriented way (69). Data visualization (i.e. the graphical representation of quantitative information) can facilitate the transformation of data to understandable and actionable information and improve communication (70). Good data visualization practice involves studying the data, target users, their tasks and visualization expectations and needs (71).

Thus, both for APM and data-driven eHealth technologies, a fit between the APM/technology, the user, and their context is paramount in the development and implementation process; a human-centred socio-technical approach with attention for the interactions between the technology and its social and technical context is advocated (68). Involving HCWs in the participatory development and implementation of eHealth has the potential to improve the uptake, acceptance, and long-term use of APM technologies (72).

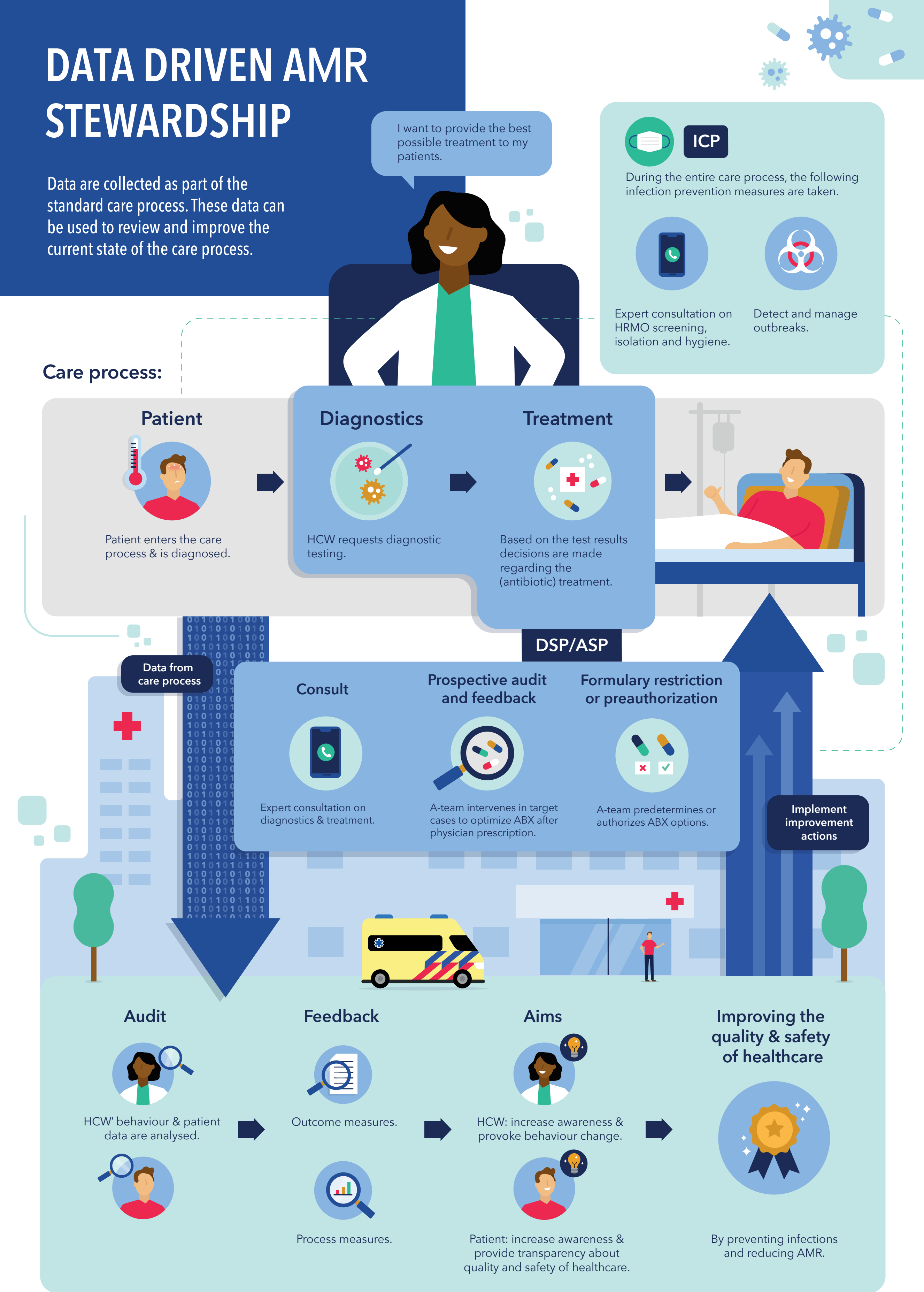
2.3 Audit and feedback for AMR prevention measures (APM-AF)

One APM in particular, which is also the focus of this thesis, especially has the potential to combine these two promising opportunities to empower HCWs to take ownership of APM by using data-driven eHealth technologies: audit and feedback (AF) systems. By measuring and analysing clinical performance over a specific period of time (audit) and providing audit results to various target groups (feedback), AF strategies intend to encourage HCWs' behaviour change (73). Audit and feedback for APM (APM-AF) has the potential to change HCWs' behaviour by learning through reflective cycles and showing them how their APM performance contributes to limiting AMR, rather than merely focusing on raising AMR urgency awareness and knowledge (as in traditional education) or influencing ad-hoc decisions (as CDSSs do) (74–76). Structural data-based feedback to HCWs can be a powerful motivator for change and provides an evidence base for action (77). Furthermore, APM-AF can be used to evaluate other APM, since it provides insight in the accomplishment of objectives and goals, and in aspects that may need improvement (49). Thereby, APM-AF combines aspects of behaviour change, learning and quality improvement, making it a potentially powerful APM to limit AMR and optimize care (78).

There is substantial variability in the design, content and delivery of AF in general, leading to inconsistent results from evaluations (73). Still, collaborative international expert groups have selected APM-AF as an essential core element for successful AMR stewardship (e.g. core elements: tracking, monitoring, surveillance, reporting and feedback) (79,80). A distinction can be made between prospective and retrospective AF. Prospective AF can be seen as a clinical re-assessment shortly after antimicrobial prescription (i.e. leaning towards (delayed) clinical decision support), whereas retrospective AF can be seen as data review sometime after antimicrobial prescription, including feedback from surveillance (i.e. leaning towards learning and quality improvement) (81). In current APM-AF, audits are mostly performed by the A-team that subsequently provides feedback to individual HCWs or teams (82). On the contrary, in this thesis we study how involving HCWs from the start of and throughout the development APM-AF process (i.e. a bottom-up participatory approach) can complement the current top-down expert-driven approach.

2.4 AMR stewardship, APM-AF, and the healthcare process

Figure 1.1 (on the next page) illustrates how AMR stewardship (i.e. the integrated approach of ASP, ICP and DSP) affects the regular healthcare process of HCWs and patients (upper part of the figure), and how retrospective AF uses data from the healthcare process resulting in improvement actions that aim to improve the quality and safety of healthcare by preventing infections and reducing AMR (lower part of the figure). Most APM directly intervene with the daily healthcare process, either by restricting the initial choice of antimicrobials (i.e. formulary restrictions and preauthorization), by reassessing and if needed adapting HCWs' antimicrobial and diagnostic choices (i.e. prospective AF), or by mandating isolation of infected pateints (i.e. manage outbreaks) (44). Contrarely, retrospective APM-AF relies on reflective learning cycles by feeding back understandable, meaningful and actionable information based on data from the care process. Note that retrospective audit and feedback should not be seen as the sole APM that will resolve the AMR problem in hospitals, nor as a replacement for other APM. As can be seen in figure 1.1, the healthcare process and AMR stewardship form a complex whole, and as described before, there is not a single solution that will be sufficient to solve the wicked problem of AMR. Therefore, multimodal strategies of complementing APM are of utmost importance for effective and efficient AMR stewardship (79,83). Although we will primarily focus on APM-AF, various recommendations are made regarding complementary actions and strategies that are preconditions for the success of APM-AF.



DATA DRIVEN AMR STEWARDSHIP
Data are collected as part of the standard care process. These data can be used to review and improve the current state of the care process.
I want to provide the best possible treatment to my patients.
ICP
During the entire care process, the following infection prevention measures are taken.
Expert consultation on HRMO screening, isolation and hygiene.
Detect and manage outbreaks.
Care process:
Patient
Patient enters the care process & is diagnosed.
Diagnostics
HCW requests diagnostic testing.
Treatment
Based on the test results decisions are made regarding the (antibiotic) treatment.
DSP/ASP
Data from care process
Consult
Expert consultation on diagnostics & treatment.
Prospective audit and feedback
A-team intervenes in target cases to optimize ABX after physician prescription.
Formulary restriction or preauthorization
A-team predetermines or authorizes ABX options.
Implement improvement actions
Audit
HCW' behaviour & patient data are analysed.
Feedback
Outcome measures.
Process measures.
Aims
HCW: increase awareness & provoke behaviour change.
Patient: increase awareness & provide transparency about quality and safety of healthcare.
Improving the quality & safety of healthcare
By preventing infections and reducing AMR.

2.5 APM-AF as a learning and improvement strategy

Bottom-up retrospective APM-AF has remained unexploited so far (84); current APM-AF were created for external accountability to for example healthcare inspectorates, where hospital level feedback is reported, but not fed back to HCWs on an individual level (85). Furthermore, few studies have addressed the APM-AF development and implementation process, since most existing studies focused on technical challenges in collecting, combining and analysing data (86–90), and selecting appropriate metrics to evaluate APM (91–95).

Undoubtedly, these are important aspects, but once again, the interrelations between HCWs, the eHealth technology and the context are overlooked. In the last decade, the importance of behavioural and social sciences has gradually been acknowledged to realize sustainable behaviour change with APM (96). APM can benefit from the numerous theories, models, frameworks, methods, and evidence-based principles from behavioural and social sciences that provide a comprehensive approach to behaviour change by considering (inter)personal, contextual, and organizational behaviour determinants (97). This wide range of determinants is especially important for APM, as it involves many stakeholders and behaviours (98).

To summarize, the potentials of APM-AF have not been fully realized in the current situation, mainly due to the top-down expert-driven approach. In this thesis, we will demonstrate how our approach can inform and guide the bottom-up participatory development and implementation of APM-AF.

Now that the most important concepts and current pitfalls have been introduced, the research questions of this thesis are presented, followed by a clarification of our approach and the theoretical lens through which we view APM-AF.

3. Research questions

This thesis focuses on the following main research question:

How can audit and feedback systems support healthcare workers to improve the quality and safety of care through AMR stewardship?

Various aspects and sub-questions were addressed to answer this overarching question. First, the central role that HCWs (e.g. doctors and nurses) and AMR-experts (e.g. clinical microbiologists, infectious disease specialists and pharmacists) play in limiting AMR in hospitals. Therefore, part 1 focuses on the following sub-questions:

- *How do HCWs perceive the AMR problem and their contribution to APM?* (Chapter 2)
- *What are HCWs' needs and expectations for (future) APM-AF?* (Chapter 3)

Furthermore, this thesis focuses on how the persuasive design of APM-AF systems can be improved by describing a bottom-up participatory development approach and studying commonly used data visualizations in AMR research by answering the following sub-questions in part 2:

- *How can a bottom-up participatory development approach improve the persuasive design of APM-AF systems?* (Chapter 4)
- *How can data visualizations fit the visual habits of AMR professionals and scientists?* (Chapter 5)

Last, this thesis focuses on the lessons learned, and the integration of theories, models, frameworks and best practices from a wide variety of research fields to strengthen the scientific underpinning of and reporting on APM-AF systems and their development and implementation. Therefore, part 3 focuses on the following sub-questions:

- *What can we learn from current studies on the development and implementation of APM-AF regarding their theoretical underpinning and reported constructs?* (Chapter 6)
- *What have we learned from the bottom-up participatory development and implementation of APM-AF systems as a learning and improvement strategy?* (Chapter 7)

4. Our bottom-up participatory approach for APM-AF

The complexity of the AMR problem warrants the studying of a wide variety of relevant interrelated determinants (e.g. behavioural and organizational) from various disciplines (97). The notion that technology, people and context are interrelated and interdependent constructs and are all part of one complex whole system instead of separate elements, is also referred to as a holistic approach (99). The Centre for eHealth Research (CeHRes) Roadmap, a framework for the participatory development, implementation and evaluation of eHealth technologies, emphasizes this holistic approach (99).

4.1 The CeHRes Roadmap

The CeHRes Roadmap combines the approaches of participatory development, human-centred design, persuasive technology and business modelling (68,99). The Roadmap (figure 1.2) comprises five intertwined phases and connecting formative evaluation cycles that can help a development team in the planning, coordination, and execution of the development, implementation and evaluation of eHealth technologies (68,99). The CeHRes Roadmap is grounded in six principles that form the basis for this thesis and are described in relation to this thesis in the next sections.

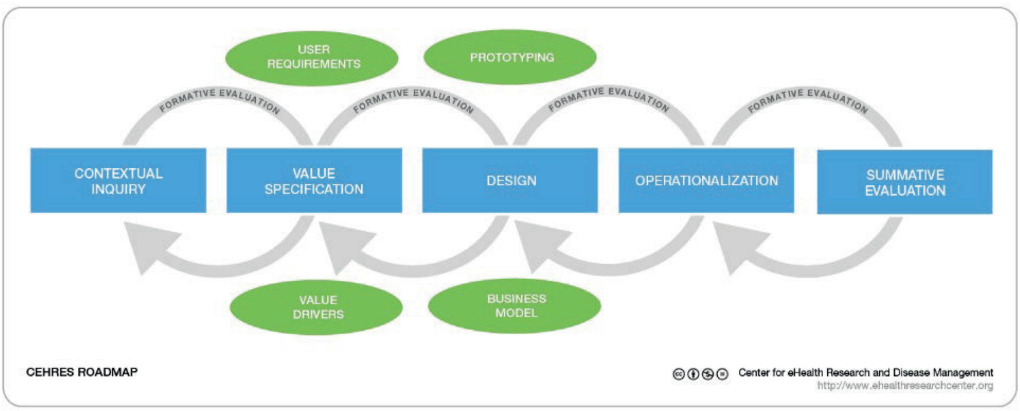


Figure 1.2. The CeHRes Roadmap (99)

1

4.1.1 eHealth technology development is a participatory process

Involving end-users and other relevant stakeholders in eHealth technology development is also referred to as participatory development (99). This starts with the interdisciplinary composition of the research or development team, consisting of both eHealth experts with knowledge on and skills for eHealth development, and domain experts who can ensure that the eHealth technology fits within their domain (100). How and when other stakeholders are involved in participatory development might range between "informant development" (i.e. stakeholders are asked for input on some products and choices, but do not make decisions and designs themselves) to "co-development" (i.e. stakeholders are seen as equal development partners) (101). Ideally, users and other stakeholders should be involved from the start and throughout the whole development process (99).

For APM-AF, HCWs are key stakeholders because they mostly execute APM in their daily working routines (e.g. prescribing antibiotics) (60). However, other important stakeholders to consider are AMR-experts for their AMR and APM expertise, the hospital administration for leadership and financial support, and ICT experts for their expertise on data, technologies and the integration of various ICT systems (102). Furthermore, protocols and guidelines should be considered as important ‘documental stakeholders’, as they describe, or even prescribe in a top-down manner, how evidence-based care should be delivered (32,103).

4.1.2 eHealth technology development requires continuous evaluation cycles

Iterative design refers to the intertwined continuous iteration of design and evaluation phases (101). Continuous formative evaluation cycles are inherent to eHealth development as it ensures the ongoing collection and use of information to iteratively improve both the eHealth technology and the development process (100). Iterative improvements originate from quality improvement science (QIS), in which the Plan Do Check Act (PDCA) cycle by Deming is one of the most influential frameworks (101,104).

In the PDCA cycle, a change aimed at improvement is identified (Plan), executed (Do), evaluated (Check), and adapted (Act) to inform a new cycle (105). Because of the characteristics of standard setting, monitoring, and assuring improvement, the PDCA cycle provides the theoretical underpinning for audit and feedback interventions (104).

4.1.3 eHealth technology development is intertwined with implementation

Because of the interwovenness of eHealth technology, humans and the context (e.g. existing infrastructure and work processes), factors for the implementation of eHealth in a real-life setting should be considered from the start of the development to ensure proper uptake and long-term sustainability (106). Business modelling can guide research activities before the start of the development process to provide value drivers that can inform and ground development choices (e.g. for the type, content and design of eHealth technologies) and implementation strategies (107). Because of the interdisciplinary nature of APM and thus the many stakeholders involved throughout the hospital in implementing and executing APM, considering and anticipating APM implementation factors (e.g. human, organisational and financial preconditions for uptake and sustainable use) from the start of the development process is crucial for successful APM in practice.

4.1.4 eHealth technology changes the organization of healthcare

The nature of human-centred participatory design entails an inherent effect of the development and implementation of eHealth technologies that might be easily overlooked by only focusing on how technologies should adapt to humans: humans and their context are also influenced and shaped by eHealth technologies (99). On a human level, this is referred to as the task-artifact cycle: humans articulate preferences and needs for the design of prototypes (or artifacts), and in turn these prototypes influence humans through adaption to consider new tasks and possibilities of the technology, thus creating new needs and preferences ("Hey Google!") (108,109). On an organisational level, the development and implementation of eHealth technologies creates new processes and infrastructures for the healthcare process, as it reshapes time, space and labour aspects of care (99). Like Eysenbach wrote in 2001: "In a broader sense, the term [eHealth] characterizes not only a technical development, but also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve health care locally, regionally, and worldwide by using information and communication technology." (28). For APM for example, this means reconsidering how APM-AF might change current APM (e.g. facilitate the integration of APM in HCW' working routines) and roles and collaborations of stakeholders involved (e.g. synergy between HCWs, AMR-experts and data experts).

4.1.5 eHealth technology development should involve persuasive design techniques

Human-computer interaction (HCI) is the scientific discipline concerned with the functionality, usability and persuasiveness of (eHealth) technologies (110). Persuasive design influences and motivates technology users by targeting their behaviour and/or attitudes, without deceiving or coercing them (111,112). As APM technologies mostly focus on influencing HCWs' behaviour, persuasive design is of critical importance for APM-AF systems (32). A prominent model for persuasive design is the Persuasive Systems Design (PSD) model, that describes various system features for persuasive eHealth technologies. These features are categorized into 1) primary task support (e.g. tailoring information to specific user groups), 2) dialogue support (e.g. suggesting the preferred antimicrobial based on guidelines), 3) credibility support (e.g. incorporating expertise and authority information), and 4) social support (e.g. letting users compare their performance with the performance of others) (113).

4.1.6 eHealth technology development needs advanced methods to assess impact

Summative evaluation (i.e. assessing the impact of the eHealth technology on the stakeholders and the context, and analysing the uptake and use of the technology) is out of the scope of this thesis as this thesis focuses on what is needed for APM-AF systems to serve as a learning and improvement strategy for HCWs and how a bottom-up participatory development approach can facilitate this. However, one prominent QIS evaluation model, the Structure, Process, and Outcome (SPO) model by Donabedian, is important for this thesis, because it can serve as a model for determining relevant audit and feedback aspects, as it forms the basis for quality indicators used in the evaluation of the quality and safety of healthcare, for example with AF (114,115). Thus, the SPO model can be used to determine relevant content for the audits in APM-AF. In the SPO model, structures refer to the setting or requirements of the organization, including all resources needed, such as material (e.g. antimicrobials available), intellectual (e.g. APM knowledge), and human (e.g. number of AMR-experts) resources. Processes refer to the activities in the delivery and receiving of care (e.g. appropriate antibiotic prescriptions) (114). Outcomes refer to the consequences of care (e.g. healthcare-associated infections and AMR) (114). While good structures increase the likelihood of good processes, and good processes increase the likelihood of good outcomes, there are bidirectional relationships between the components, and cause and effect are not always that easy to differentiate (116,117).

4.2 Interdisciplinary TMFs for APM-AF

This thesis is guided by the before described principles of the CeHRes Roadmap. However, the Roadmap is not a step-by-step prescription for eHealth development, but provides an overarching framework that guides the development team to create their own development process and select appropriate research and development methods (118). Therefore, a development process is often coloured with theories, models, and frameworks (TMFs) that complement the Roadmap and deepen relevant perspectives (e.g. from beforementioned QIS and HCI) (68).

The application of TMFs is advocated as an integral part of eHealth development and for evidence synthesis, as it identifies what works for whom, why, how and when, likely resulting in eHealth technology that achieves the desired outcomes (119). There is a clear link between (behaviour change) TMFs and the effectiveness of eHealth interventions in general (120) and for APM specifically (96,98). However, there are many TMFs that can inform choices for the development of APM-AF systems. Therefore, this thesis also focuses on how to create an interdisciplinary conceptual framework for APM-AF by synthesising information on APM-AF development and implementation.

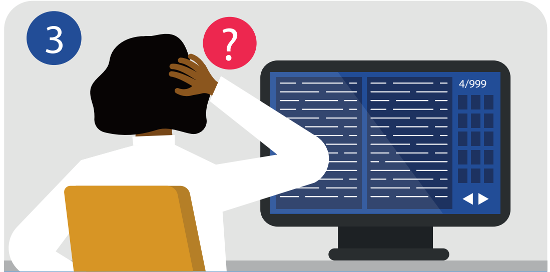
5. Thesis outline

This thesis creates knowledge, know-how, APM-AF system prototypes, and an interdisciplinary conceptual framework that can inform future APM-AF research and development and implementation projects. Thereby, this thesis contributes to the current state of knowledge on APM-AF by showing how a human-centred socio-technical approach can inform and guide the bottom-up participatory development and implementation to counterbalance the current prevailing top-down expert driven approach, and thus unlock the potentials of APM-AF as a learning and improvement strategy. On the next pages, the thesis outline is visualised (figure 1.3) and explained.

THESIS OUTLINE

PART 1 - HCWs' needs and expectations for AMR stewardship.

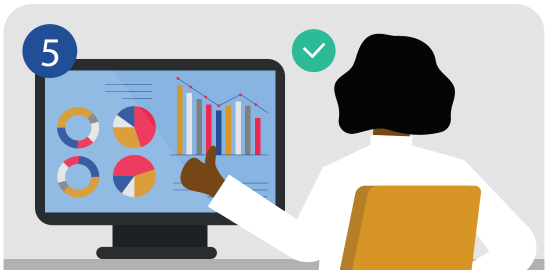
Cross-border comparison of antimicrobial resistance (AMR) and AMR prevention measures: the healthcare workers' perspective.



Finding the match between healthcare worker and expert for optimal audit and feedback on antimicrobial resistance prevention measures.

PART 2 - Developing persuasive audit and feedback systems for AMR stewardship.

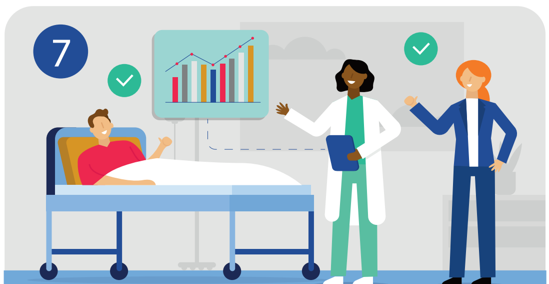
Persuading from the start: participatory development of sustainable persuasive data-driven technologies in healthcare.



The Visual Dictionary of Antimicrobial Stewardship, Infection Control, and Institutional Surveillance.

PART 3 - Towards a framework for the development and implementation of audit and feedback systems for AMR stewardship.

Improving the development and implementation of audit and feedback systems to support healthcare workers in limiting antimicrobial resistance in the hospital: a scoping review.



Developing audit & feedback: lessons learned & recommendations for practice.

In Part 1, HCWs and their needs and expectations for AMR stewardship are studied to fully understand the human side to the AMR problem, including their perspectives, behaviour, and context, before considering if and how technology can be of added value. In Chapter two, we compare German and Dutch HCWs in their perceptions of AMR and APM to create understanding of the problem urgency and to learn how HCWs perceive their potential contribution to tackle the AMR problem. In Chapter three, we identify HCWs' needs and expectations for APM-AF (in the Dutch context), thereby counterbalancing the current predominantly top-down, expert-driven APM-AF approach.

In Part 2, the development and design of eHealth technology are studied to gain insight in what we can do to match the APM-AF system with what we found in Part 1 about HCWs and their context. For that purpose, in Chapter four we describe the bottom-up participatory development approach to improve the persuasive design of data-driven technologies and simultaneously increase engagement of end-users to foster sustainable implementation. In Chapter five we focus on a specific design aspect, namely data visualizations, by creating an overview of visualizations in AMR research, including suggestions for improvement, to optimize AMR data visualization and communication.

In Part 3, we work towards a conceptual framework for the development and implementation of APM-AF. To do so, in Chapter six we provide insights on APM-AF development and implementation strategies to form a conceptual framework by synthesising evidence of information on APM-AF development and implementation. Specific attention will be paid to the integration of theories, models, and frameworks for APM, AF, and eHealth development and implementation. In Chapter seven, the general discussion, we share our lessons learned and recommendations that can guide future participatory development and implementation projects to unlock the APM-AF learning and improvement potentials.

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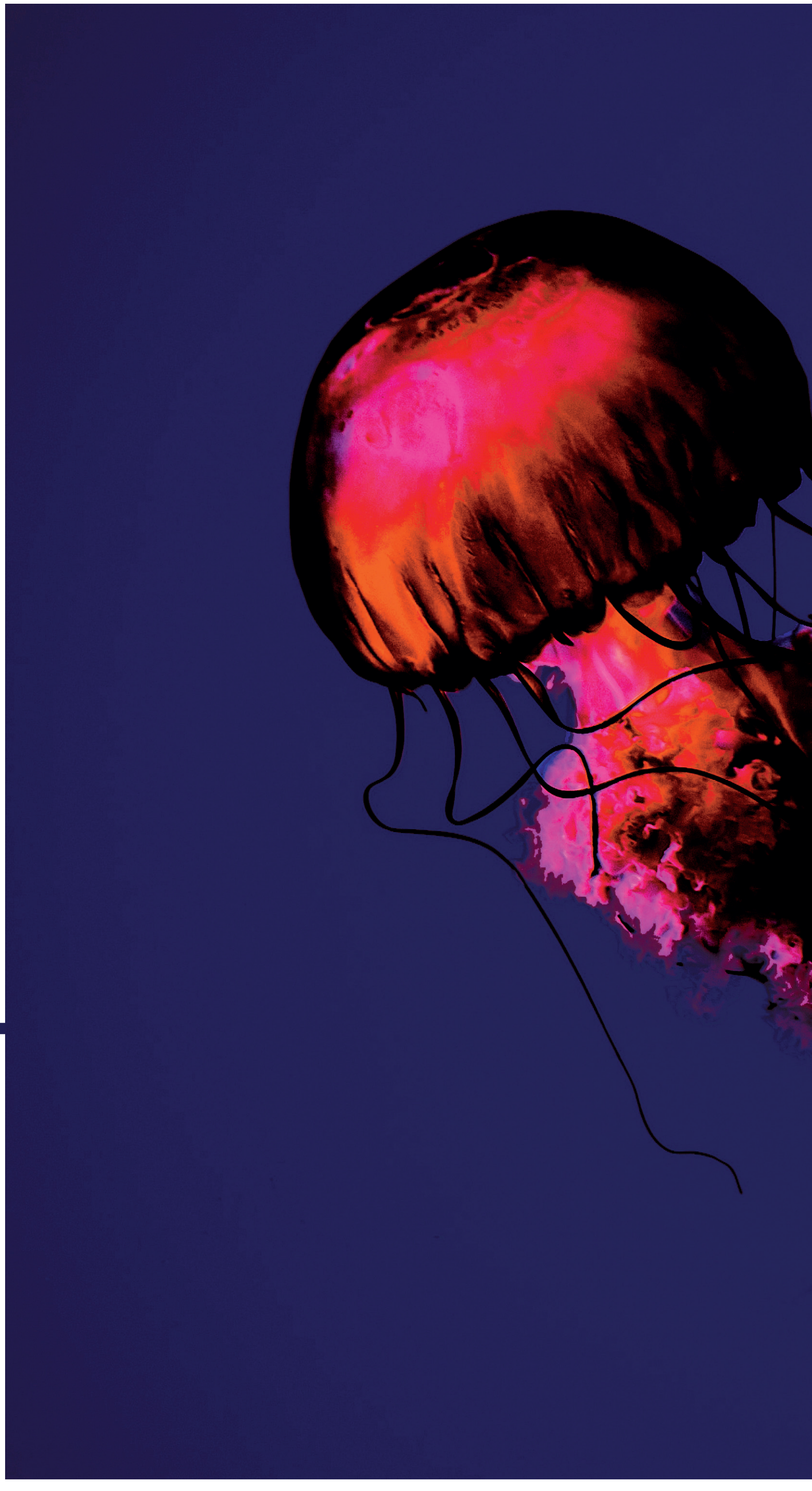
Part 1

HCWs’ needs and expectations for AMR stewardship

Chapter 2



Cross-border comparison of antimicrobial resistance (AMR) and AMR prevention measures: the healthcare workers' perspective

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Abstract

Background

Cross-border healthcare may promote the spread of multidrug-resistant microorganisms (MDRO) and is challenging due to heterogeneous antimicrobial resistance (AMR) prevention measures (APM). The aim of this article is to compare healthcare workers (HCWs) from Germany (DE) and The Netherlands (NL) on how they perceive and experience AMR and APM, which is important for safe patient exchange and effective cross-border APM cooperation.

Methods

A survey was conducted amongst HCWs ($n = 574$) in hospitals in DE ($n = 305$) and NL ($n = 269$), using an online self-administered survey between June 2017 and July 2018. Mann-Whitney U tests were used to analyse differences between answers of German and Dutch physicians ($n = 177$) and German and Dutch nurses ($n = 397$) on 5-point Likert Items and Scales.

Results

Similarities between DE and NL were a high awareness about the AMR problem and the perception that the possibility to cope with AMR is limited (30% respondents perceive their contribution to limit AMR as insufficient). Especially Dutch nurses scored significantly lower than German nurses on their contribution to limit AMR (means 2.6 vs. 3.1, $p \leq 0.001$). German HCWs were more optimistic about their potential role in coping with AMR ($p \leq 0.001$), and scored higher on feeling sufficiently equipped to perform APM ($p \leq 0.003$), although the mean scores did not differ much between German and Dutch respondents.

Conclusion

Although both German and Dutch HCWs are aware of the AMR problem, they should be more empowered to contribute to limiting AMR through APM (i.e. screening diagnostics, infection diagnosis, treatment, and infection control) in their daily working routines. The observed differences reflect differences in local, national, and cross-border structures, and differences in needs of HCWs, that need to be considered for safe patient exchange and effective cross-border APM.

Background

Avoiding antimicrobial resistance (AMR) as well as limiting the spread of multidrug-resistant micro-organisms (MDRO) through AMR prevention measures (APM) is essential for the quality, safety and durability of healthcare and societal health (1,2). Core APM are described by various international and national healthcare authorities, and comprise of both timely and adequate screening diagnostics, infection diagnosis, antibiotic treatment, and infection control measures (3–15).

2

National borders are no barrier for the spread of MDRO. Since the 2011 EU directive on the application of patients' rights in cross-border healthcare, cross-border mobility of both patient and healthcare workers (HCWs) between Germany (DE) and The Netherlands (NL) has steadily increased (16–19). As a result of the increased cross-border patient and HCW mobility, MDRO may also spread in cross-border regions, like the EUREGIO (i.e. comprising communities of north-eastern NL and north-western DE) (20,21). The INTERREG V-A funded initiative EurHealth-1Health (EH1H) combines the focus on AMR and healthcare through close cross-border cooperation (22). Close cross-border cooperation was established in particular to address comparisons of APM implemented in both countries, understand differences and find solutions for regional infection control (20).

Previous studies performed within the EUREGIO have focused on differences in the organization of healthcare (e.g. relatively more beds available (23), longer average length of stay (24), and increased connectivity of a higher number of healthcare facilities (20) in DE compared to NL), which are known risk-factors for (the spread of) infections and, thus, indirectly for the spread of AMR (25). Other studies showed differences in prevalence of MDRO (e.g. lower MRSA admission prevalence in NL) (26–28), and antibiotic prescriptions among outpatients (higher prescription prevalence in Germany) (29). Differences in AMR and APM between both countries are shaped by a complex combination of interrelated factors (20). These factors range from differences in regulations (30,31) to differences in the categorization and designation of MDRO and the recommendations for diagnostic procedures (32–34).

Nonetheless, merely focusing on organisational, regulatory, and procedural factors underestimates one of the most important aspects of successful APM, namely people and particularly HCWs (35–38). HCWs are the ones active on the work floor, diagnosing and treating patients, and are thereby largely influencing the success of APM (38–42). Furthermore, unequivocal and clear communication between HCWs is a crucial factor for effective (cross-border) APM (33,43,44). Studying AMR from the HCWs' perspective on both sides of the border will help to develop more effective APM cooperation, because it creates understanding of how HCWs perceive the AMR problem and how empowered they feel to tackle the problem through their daily work routines.

This study consisted of a cross-border survey on Dutch and German HCWs employed in hospitals of the EUREGIO. The aim of this article is to gain an understanding of the similarities and differences of AMR- and APM-perceptions of Dutch and German HCWs that need to be considered for effective cross-border AMR cooperation.

Methods

In this cross-sectional study, a survey was conducted amongst HCWs in hospitals in DE and NL, using an online self-administered questionnaire between June 2017 and July 2018. The bi-national research team consisted of researchers from various specialties, including health sciences, psychology, medical microbiology and epidemiology, infectious diseases, and infection control (see authors). The study was ethically approved by the ethical committee of the University of Twente (BCE18321).

Setting and participants

The study was performed in six hospitals, which were purposively sampled based on their location in north-eastern NL and north-western DE. The heterogeneous sample consisted of one large university hospital on each side of the border (DE: ±1500 and NL: ±1300 beds), as well as one smaller Dutch general hospital (±700 beds) and three smaller German university hospitals (±400–800 beds). Microbiological diagnostics was locally organised in all except one German hospital. In all participating hospitals, local guidelines on antibiotic prescribing were available in the form of (online) formularies. Expert consultations on medical microbiology, infectious diseases and hygiene were available by phone or in person. Because HCWs are mainly responsible to perform APM, they were selected as the key-stakeholders. HCWs consisted of physicians and nurses of relevant AMR departments (e.g. not psychiatry).

Survey and distribution

After demographic questions, the survey addressed a variety of AMR-topics, mostly based on a valid and reliable AMR questionnaire (38). First, questions about the perceived urgency of the AMR problem on various levels, the perceived causes of AMR, beliefs about antibiotic use and the perceived influence that respondents have to limit the AMR problem were asked (1: Fully disagree – 5: Fully agree). Then, we asked questions about APM, which were based on recommendations about APM from various national and international health authorities (3–15) and a study of Dik et al. (45).

APM were introduced to respondents as follows:

- Screening diagnostics: the process of finding out if a patient carries resistant bacteria (incl. asking questions about risk factors for MDRO at admission, taking cultures and testing cultures).
- Infection diagnosis: the diagnosis of an infection (present/absent).
- Treatment: the choice of antibiotics that meets both the patient’s diagnosis and the local antibiotic guidelines.

- Infection control: the implementation of suitable hygiene measures for infection and transmission prevention (e.g. antisepsis, hand hygiene, use of personal protective equipment, and cleaning of equipment and rooms).

The perceived importance of APM was questioned with one item. The perceived influence and perceived availability of resources, knowledge, and social support of colleagues and supervisor on APM was questioned with five items. The perceived influence and perceived availability of resources, knowledge, and social support of colleagues and supervisor were later combined for interpretation into a scale of "feeling sufficiently equipped" for the specific APM.

The survey was originally designed in Dutch for the regional hospital, which was used as a pilot-test for the survey. Tests that were held with a nurse and physician to ensure comprehension and clarity of the questions resulted in small adaptions in wording. After translation by an official translation service to German, the German research team members adapted wordings to better fit the clinical context and jargon. The full survey can be found in the supplementary materials.

The survey was developed and administered in Qualtrics, and consisted of 5-point Likert items (Not important–Important, Insufficient–Sufficient). Respondents were informed of the voluntary nature of their participation and confidentiality was guaranteed.

The survey was distributed by email or personal communication followed by snowball sampling with local differences due to practical matters (e.g. local restrictions of using mailing lists and managerial objections with surveys to avoid overload of work for HCWs). Reminders were sent twice, but could not be tailored to non-responders.

Statistical analysis

Descriptive analyses were performed in SPSS (v24). As physicians and nurses have different responsibilities related to AMR (46), results are shown separate per function group. Chi-square tests of homogeneity and Fisher's exact tests were used to study demographical differences between groups ((i) German and Dutch respondents, (ii) German and Dutch physicians, and (iii) German and Dutch nurses). Mann-Whitney U-tests were used to study differences on the 5-point Likert items between the before mentioned groups. This nonparametric test suits the non-normal distribution of the data, and the nominal nature of the independent variable (i.e. DE/NL) and ordinal nature of the dependent variable (i.e. 5-point Likert items) (47). Reported *p*-values for the Mann-Whitney U tests are two-tailed (asymptotic-derived p-values presented) and a p-value <0.05 was considered significant. Possible influence of demographic differences between the German and Dutch groups were considered by comparing Mann-Whitney U tests results with results of Analyses of Covariance (ANCOVA) on ranked responses for each item and scale with age, gender, and years of hospital experience as covariates.

Results

Respondents

Respondent characteristics are presented in table 2.1. Of the 574 respondents, 53% worked in German and 47% worked in Dutch hospitals. German and Dutch respondents differed significantly on all demographic variables included ($p \leq 0.001$). German physicians were significantly younger ($p \leq 0.001$). Dutch nurses were significantly more often female ($p \leq 0.001$), were significantly older ($p = 0.002$), and had significantly more experience in the current hospital ($p = 0.005$). Completing the survey took respondents 16 min on average. The respondents of the two hospitals with the highest number of responses represented response rates of less than 19%.

Table 2.1. Survey respondents' characteristics

Variable & levels		Total	All respondents		Diff. DE/NL	Physicians		Diff. DE/NL	Nurses		Diff. DE/NL
		n (%)	DE n (%)	NL n (%)	Test (*P*-value)	DE n (%)	NL n (%)	Test (*P*-value)	DE n (%)	NL n (%)	Test (*P*-value)
#	n (%)	574 (100)	305 (53)	269 (47)	–	128 (22)	49 (9)	–	177 (31)	220 (38)	–
Sex	Male	181 (32)	131 (43)	50 (19)	Chi^2 (≤0.001)	86 (67)	32 (65)	Chi^2 (0.812)	45 (25)	18 (8)	Chi^2 (≤0.001)
	Female	393 (68)	174 (57)	219 (81)		42 (33)	17 (35)		132 (75)	202 (92)	
Age	< 25 years	30 (5)	20 (7)	11 (4)	Chi^2 (≤0.001)	0 (0)	0 (0)	Fisher's exact (≤0.001)	20 (11)	10 (5)	Chi^2 (0.002)
	25–35 years	182 (32)	121 (40)	61 (23)		58 (45)	8 (16)		63 (36)	53 (24)	
	36–45 years	157 (27)	78 (26)	78 (29)		45 (35)	19 (39)		33 (19)	60 (27)	
	46–55 years	129 (22)	60 (20)	67 (25)		17 (13)	10 (20)		43 (24)	59 (27)	
	56–65 years	74 (13)	25 (8)	51 (19)		7 (5)	11 (22)		18 (10)	38 (17)	
	> 65 years	2 (0)	1 (0)	1 (0)		1 (1)	1 (2)		0 (0)	0 (0)	
Hospital	1 (general)	223 (39)	–	223 (83)	–	–	41 (84)	–	–	182 (83)	–
	2 (academic)	252 (44)	251 (82)	–		96 (75)	–		156 (88)	–	
	3 (academic)	46 (8)	–	46 (17)		–	8 (16)		–	38 (17)	
	4 (university)	23 (4)	23 (8)	–		11 (9)	–		12 (7)	–	
	5 (university)	13 (2)	14 (5)	–		9 (7)	–		4 (2)	–	
	6 (university)	12 (2)	12 (4)	–		8 (6)	–		4 (2)	–	
	Other[b]	5 (1)	5 (2)	–		4 (3)	–		1 (1)	–	
Departments[a]	Anaesthesiology	80 (11)	72 (17)	8 (3)	–	34 (19)	5 (10)	–	38 (16)	3 (1)	–
	Intensive Care	79 (11)	63 (15)	17 (6)		25 (14)	4 (2)		38 (16)	13 (5)	
	Paediatrics	77 (11)	42 (10)	35 (11)		14 (8)	1 (1)		28 (12)	34 (13)	
	Surgery	72 (10)	25 (6)	47 (15)		8 (4)	3 (2)		17 (7)	44 (17)	
	Obstetrics/Gynaecology	44 (6)	11 (3)	34 (11)		4 (2)	5 (3)		7 (3)	29 (11)	
	Internal medicine	36 (5)	20 (5)	16 (5)		15 (8)	1 (1)		5 (2)	15 (6)	
	Oncology	33 (5)	24 (6)	11 (4)		9 (5)	0 (0)		15 (6)	11 (4)	
	Orthopaedics	33 (5)	17 (4)	17 (6)		8 (4)	7 (4)		9 (4)	10 (4)	
	Emergency Department	30 (4)	17 (4)	13 (4)		9 (5)	3 (2)		8 (3)	10 (4)	
	Other	235 (33)	124 (30)	111 (36)		52 (29)	20 (11)		72 (30)	91 (35)	
Hospital experience	< 1 year	25 (4)	15 (5)	10 (4)	Chi^2 (≤0.001)	6 (5)	4 (8)	Chi^2 (0.333)	9 (5)	6 (3)	Chi^2 (0.005)
	≥1 year, < 5 years	116 (20)	84 (28)	32 (12)		49 (38)	12 (24)		35 (20)	20 (9)	
	5–10 years	132 (23)	73 (24)	60 (22)		35 (27)	15 (31)		38 (21)	44 (20)	
	> 10 years	301 (52)	133 (44)	167 (62)		38 (30)	18 (37)		95 (54)	150 (68)	

Note. Differences between nationalities are calculated with Chi-square tests of homogeneity (Asymptotic Significance (2-sided) shown) or Fisher's exact tests (Exact Sig. (2-sided) shown).
[a]Only departments with > 30 respondents in total (DE + NL) are shown. Respondents could select multiple departments (23% of the German and 9% of the Dutch HCW indicated to work at various departments) [b]Snowball-sampling included five respondents from two other hospitals, both located within the EUREGIO

Survey results

Results of the survey are presented in table 2.2 (AMR statements) and 2.3 (AMR prevention measures). Results compare (i) all respondents (DE-NL), (ii) German physicians and Dutch physicians, and (iii) German nurses and Dutch nurses. Means without standard deviations are merely used as interpretable visualisation of differences between groups (i.e. means closer to one interpreted as disagreement with item and closer to five interpreted as agreement with item) and were not used in any calculations. Full results in the form of percentages per answer category are discussed in text and can be found in the supplementary materials. Similarities and differences of tables 2.2 and 2.3 are summarized in figure 2.1.

Table 2.2. AMR statement responses of (i) all respondents, (ii) German/Dutch physicians, and (iii) German/Dutch nurses, including *p*-values of differences between nationalities

Statements		All respondents (n = 574)			Physicians (n = 177)			Nurses (n = 397)		
		DE (n = 305)	NL (n = 269)	P-value	DE (*n* = 128)	NL (*n* = 49)	P-value	DE (n = 177)	NL (*n* = 220)	P-value
		Mean	Mean		Mean	Mean		Mean	Mean	
AMR is a problem for…	the general population.	4.2	**4.6**	≤0.001	4.3	**4.5**	0.026	4.1	**4.6**	≤0.001
	nursing homes.	4.3	4.4	0.968	4.4	4.4	0.851	4.3	4.4	0.859
	our hospital.	4.4	**4.6**	0.043	4.3	4.6	0.180	4.4	4.6	0.262
	my patients.	4.2	**4.5**	0.002	4.2	4.3	0.281	4.3	**4.5**	0.017
One of the leading causes of AMR is…	the use of antibiotics in farming animals.	**4.5**	3.6	≤0.001	**4.4**	4.0	0.004	**4.5**	3.5	≤0.001
	the use of antibiotics by patients.	3.4	**3.6**	0.011	3.2	**3.6**	0.021	3.5	3.6	0.379
	the admission of nursing home patients.	**2.6**	2.4	0.006	2.6	2.5	0.254	**2.6**	2.4	0.027
I believe that…	antibiotics are prescribed at the request of patients.	**2.9**	2.4	≤0.001	**3.0**	2.4	0.013	**2.8**	2.3	0.001
	antibiotic prescriptions should be based on lab results.	**4.4**	3.9	≤0.001	**4.4**	3.9	≤0.001	**4.4**	3.9	≤0.001
	I am sufficiently informed about the diagnostic policy.	**3.6**	3.4	0.002	3.6	3.8	0.791	**3.6**	3.3	0.003
	broad spectrum antibiotics should be provided when there is doubt of an infection.	1.7	**2.2**	≤0.001	1.5	**1.5**	0.001	1.9	**2.3**	≤0.001
	I can contribute sufficiently to limit AMR.	**3.6**	2.8	≤0.001	**4.3**	4.3	≤0.001	**3.1**	2.6	≤0.001

Note. When there is a statistically significant difference between nationalities, the nationality with the highest mean is shown in bold. *DE* Germany, *NL* The Netherland

Table 2.3. APM responses of (i) all respondents, (ii) German/Dutch physicians, and (iii) German/Dutch nurses, including *p*-values of differences between nationalities

APM		All respondents (*n* = 574)			Physicians (*n* = 177)			Nurses (*n* = 397)		
		DE (*n* = 305)	NL (*n* = 269)	*P*-value	DE (*n* = 128)	NL (*n* = 49)	*P*-value	DE (n = 177)	NL (*n* = 220)	*P*-value
		Mean	Mean		Mean	Mean		Mean	Mean	
Screening diagnostics	Importance	**4.7**	4.5	**≤0.001**	**4.7**	4.4	**0.002**	**4.8**	4.6	**≤0.001**
	Feeling sufficiently equipped[a]	**3.6**	3.3	**0.005**	3.7	3.6	0.075	3.5	3.3	0.166
Infection diagnosis	Importance	**4.7**	4.5	**0.003**	**4.7**	4.4	**0.004**	4.6	4.5	0.134
	Feeling sufficiently equipped[a]	**3.6**	3.3	**≤0.001**	4.3	4.2	0.197	3.2	3.1	0.335
Treatment	Importance	**4.8**	4.5	**≤0.001**	**4.9**	4.5	**≤0.001**	**4.8**	4.4	**≤0.001**
	Feeling sufficiently equipped[a]	**3.2**	2.8	**≤0.001**	4.0	4.1	0.746	**2.6**	2.5	**0.004**
Infection control	Importance	**4.8**	4.5	**≤0.001**	**4.7**	4.3	**≤0.001**	**4.9**	4.5	**≤0.001**
	Feeling sufficiently equipped[a]	4.0	3.9	0.230	3.9	3.8	0.534	4.0	3.9	0.114

AMR problem urgency

Most of the respondents (≥59%) perceived AMR as a problem for the general population, nursing homes, their hospital, and their patients. Dutch respondents scored higher than German respondents on statements of AMR being a problem for the general population ($p \leq 0.001$), their hospital ($p = 0.043$) and their patients ($p = 0.002$), although German respondents also scored relatively high (lowest mean importance score is 4.1). Thus, both German and Dutch respondents perceived AMR as a problem on various levels, and Dutch respondents do so slightly more than German respondents.

AMR cause

German respondents scored higher than Dutch respondents on statements of the leading causes of AMR being the use of antibiotics in farming animals ($p \leq 0.001$) and the admission of nursing homes ($p = 0.006$). Dutch respondents scored higher on the statement of the use of antibiotics by patients ($p = 0.011$) as a leading cause of AMR than German respondents.

Beliefs about antibiotic use

German respondents scored higher on the statement that antibiotics are prescribed at the request of patients ($p \leq 0.001$) and on statements about antibiotic prescriptions according to guidelines (e.g. antibiotic prescriptions should be based on lab results ($p \leq 0.001$), I am sufficiently informed about the diagnostic policy ($p = 0.002$), and broad-spectrum antibiotics should *not* be provided when there is doubt of an infection ($p \leq 0.001$)).

Contribution to limit AMR

Notably, only 19% of all respondents totally agreed that he/she can sufficiently contribute to limit AMR, and 30% respondents perceive their contribution to limit AMR as insufficient. This is especially true for nurses (lower means than physicians in both countries). German respondents scored higher on the item about being able to sufficiently contribute to limit

AMR than their colleagues from The Netherlands ($p \leq 0.001$). This difference was mainly apparent for nurses, where the means differed more than for physicians (although both reached significance).

APM importance

All APM were deemed very important to limit AMR by most (≥67%) respondents (see also high importance means). German respondents scored the importance of all APM higher than respondents from The Netherlands, although scores for APM importance were high for both groups (lowest mean importance of Dutch respondents was 4.5).

Feeling equipped for APM

German respondents scored also higher on the feeling of being equipped at their hospital for specific APM (screening diagnostics $p = 0.005$, infection diagnosis $p \leq 0.001$, and treatment $p \leq 0.001$), although the mean scores did not differ much between German and Dutch respondents.

Both German and Dutch nurses scored feeling sufficiently equipped lower than physicians (lower mean scores) for most APM, although this was not statistically tested. This is less apparent when comparing the means in both groups (physicians-nurses) for infection control.

Considering demographic differences

The comparison of unadjusted (Mann-Whitney U tests) and adjusted (ranked ANCOVA corrected for age, gender and years of hospital experience) test results can be found in the supplementary materials. Of all observed differences that were significant in the unadjusted analyses, only three were not significant in the adjusted analyses (1. all respondents: AMR is a problem in our hospital, 2. physicians: AMR is a problem for the general population, and 3. nurses: one of the leading causes of AMR is the use of antibiotics by patients).

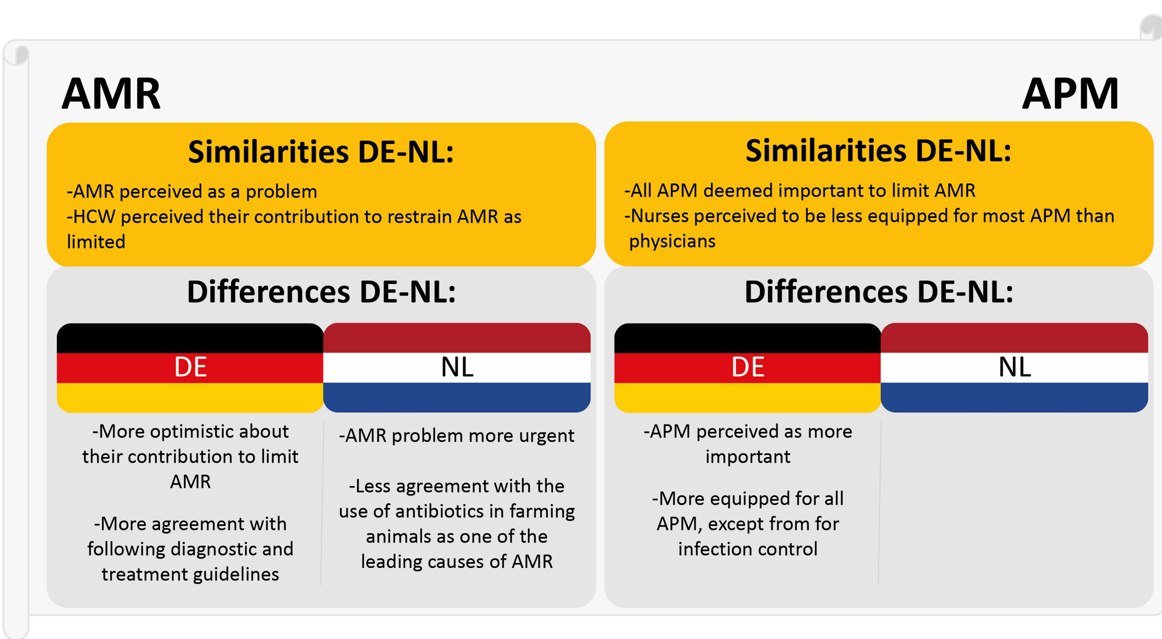

Figure 2.1. Antimicrobial resistance (AMR) and AMR prevention measures (APM): similarities and differences between German and Dutch respondents

Discussion

This study aimed to compare German and Dutch HCWs in their perceptions of AMR and prevention measures. This was done in order to create understanding of the problem urgency and to learn how HCWs perceive their potential contribution to tackle the AMR problem through daily work routines. Understanding and comparing HCWs' perspectives on AMR and APM between countries where patient and HCWs mobility is promoted, is essential for safe patient and HCWs exchange, and effective cross-border cooperation.

2

Differences in HCWs' perspectives on AMR and APM

Especially Dutch nurses felt less able to contribute sufficiently to limit AMR, as reflected in their lower mean score. The resistance rates of several MDRO are higher in German hospitals than in Dutch hospitals (e.g. proportion of MRSA/*S. aureus* from cases of bacteraemia: DE: 9.1% vs. NL: 1,5% and VRE/*E. faecium*: DE: 16.5% vs. NL: 1,4%) (28). These low MDRO rates are likely a result of the consistent MRSA 'search and destroy' policy that The Netherlands implemented early and retained since decades (15,48), while Germany has shown decreasing incidence rates for MRSA over the past few years by a 'search and follow' strategy (49). Dutch HCWs are likely more aware of the urgency of the AMR problem, because of the longstanding search and destroy policy. At the same time, German HCWs might be more optimistic about their possible contribution to limit AMR, because they handle MDRO more often in daily practice and – starting from a higher level – the incidence can be decreased more in Germany. Additionally, this powerless feeling might be attributable to the fact that, in the Netherlands more than in Germany, AMR problems at least partially also occur outside of the hospital (e.g. MDRO acquired through traveling, food chains and animals). This is also represented in the differing answers on leading causes of AMR (50–55). Thus, differences between German and Dutch HCWs' perceptions of the AMR problem urgency and potential contributions might be attributable to differences between both countries in MDRO hospital incidence and APM strategies.

AMR awareness

As the awareness in both Dutch and German HCWs in this study is considerably higher compared to similar studies (40,56), and because the ongoing EH1H network project and preceding networks (MRSA-net and Eursafety network) in this area already contribute to improving awareness (20,26), recent and future cross-border AMR prevention strategies in this region do not primarily need to target problem awareness to such an extent as is often suggested for AMR prevention strategies (4). However, continuing current efforts to retain awareness of the AMR problem in- and outside of hospitals (e.g. the German DART 2020 strategy and the European Antibiotic Awareness Day (EAAD)) (57,58) is recommended, since no short-term solutions are expected to be found for the complex AMR problems (2,25).

HCW empowerment

Astonishingly, only few HCWs from both countries perceived their contribution to limit AMR as sufficient. Although German respondents felt slightly more optimistic about their contribution to limit AMR than their Dutch colleagues, their mean score is far from optimistic (3.5).

Therefore, AMR prevention strategies in both countries should primarily focus on the awareness of how HCWs can contribute to preventing the (cross-border) spread of MDRO. Studies have shown that improved APM over time, which can only be realized by empowered individual HCWs, have led to a regional/national stabilisation or even reduction of MDRO prevalence (26,59,60).

Special attention is required for empowering nurses in APM, since nurses are less confident about their role in diagnostics, diagnosis and treatment, as also reflected in this study's results (46,61–64). Nurses are the "eyes and ears" most frequently being in contact with the patient, and can thereby fastest recognize inadequate or suboptimal APM (61,63,64). Empowering HCWs starts with promoting pro-active roles of all HCWs in all APM components (63). To empower HCWs and specifically nurses, more coordinated and innovative (e.g. problem-based learning) approaches to AMR education and communication are needed, dovetailed to the HCWs needs (65–67). Furthermore, awareness of HCWs' potential contribution to limit AMR can be improved by measuring and reporting APM performance and AMR outcomes data, according to general audit and feedback principles of quality management (68). Current surveillance efforts in both countries (i.e. PREZIES and KISS (69)) are the basis for reporting such data. Although outcomes (e.g. decreased resistance or less infections) are not easily linked to individual APM actions, incorporating measurements on APM performance and outcome data over the long-term in cyclic learning processes, has shown to improve HCWs' APM performance (59,69–71).

Cross-border AMR cooperation

Germany and The Netherlands both have very developed healthcare systems, but the two systems differ considerably from one another in organisational, regulatory and financial structures (72,73). Previous studies found that cross-border healthcare is not yet optimal according to HCWs, mainly because of communication barriers and non-supportive IT (74–76). Suboptimal and/or ambiguous communicational and non-supportive IT are known barriers within institutions (46,77), and will become even more problematic on a national or cross-border level, because of differences in language, taxonomy, and interoperability of IT.

Furthermore, AMR outcomes and APM cooperation in a cross-border setting are not only influenced by HCWs' perceptions and actions, but also by the complex interplay of organisational, regulatory and financial structures that shape a healthcare system (20). These structures are robust, and dealing with them may be done differently on the level of federal states ("Bundesländer", DE) and provinces (NL), healthcare institutions and individual HCWs. Because of these differences on various levels within both countries, it is difficult to synchronize healthcare systems for cross-border cooperation. Comprehending similarities and differences in healthcare systems and HCWs' perspectives in a cross-border region is an essential step towards successful cross-border APM cooperation.

eHealth has the potential to support and improve synchronisation AMR education, communication, and surveillance and performance feedback in a cross-border region, as has been successfully shown before in AMR studies (44,78–81). By following a participatory, holistic and human centred approach for eHealth development and implementation, eHealth has the potential advantage of being able to adapt to differences in the users' needs (e.g. nurse specific needs) and contexts (e.g. national APM strategies), which is relevant for AMR-cooperation in a cross-border setting. To fully understand the users' needs and contexts, current initiatives that compare AMR and APM from different perspectives should be continued. Thereby, knowledge and insights from best practices can be exchanged, and innovative eHealth approaches can be developed that ensure the fit between the technology, the users and the cross-border context (82).

Limitations

This study used a purposive sample of hospitals in the EUREGIO and thus might not represent other cross-border regions, since every cross-border region has its own healthcare system structure and dynamics and its own AMR biotope (17,83).

Response rates were low, even for the two hospitals that provided the most responses (≤19%). This is most likely attributable to the fact that AMR and APM are not HCWs' core business. Therefore, only HCWs with an interest in AMR/APM might have participated (i.e. selection bias), which might have influenced the results to be more positive than they actually are. HCWs that do not have that much AMR/APM experience will likely answer more negatively on questions such as feeling sufficiently equipped (see e.g.

Björkman et al., 2010 (41)). This would mean that our suggested improvements, such as empowering all HCWs in APM, are in reality even more needed to limit the AMR problem.

Furthermore, German and Dutch respondents varied significantly on nearly all demographic characteristics. However, the analyses adjusted for age, sex and years of hospital experience showed that only for a small number of questions the observed differences in HCWs' perspectives could be (partially) explained by demographic differences.

Other limitations relate to the use of Likert items. Central tendency bias might have occurred by respondents avoiding choosing the extreme response categories (scores 1 & 5) (84). We do not see this bias reflected in the answers, since respondents scored extreme responses on questions where we expected mostly positive (e.g. importance of AMR prevention measures) or mostly negative (e.g. broad-spectrum antibiotics should be provided when there is doubt of an infection) answers. Social desirability bias might always have occurred, since most people are aware that AMR should require special attention (note that this does not mean that it gets special attention in daily working routines) (84).

The survey used was based on a validated questionnaire, used elements from health authorities' recommendations on APM (1,3–8,38), and was discussed with experts in the field of AMR, but was not validated itself. To be able to use this survey as a tool to compare HCWs' perspectives between countries or even evaluate intervention effects, it should be further tested elaborately and validated (84) (see e.g. Teixeira Rodrigues, et al. (38)).

Despite these limitations, we do believe that this survey proved useful for a primary identification of HCWs' perspectives. This study can be seen as an essential step towards safer patient exchange and improved cross-border cooperation, since the cross-border AMR problem has, to our best knowledge, not been studied before from the HCWs' perspective.

Conclusion

Both German and Dutch HCWs are aware of the AMR problem, but both perceive their influence to limit AMR as insufficient. HCWs do acknowledge the importance of APM (i.e. screening diagnostics, infection diagnosis, treatment and infection control) they perform in their daily working routines to limit AMR, but do not feel sufficiently equipped to do so. Therefore, AMR strategies should not primarily focus on emphasizing the relevance of APM, but should rather focus on empowering HCWs in their working routines by providing them with the tools, knowledge, and skills they need to limit AMR.

Because of robust national healthcare structures, adaptive solutions are essential to tackle the challenges caused by AMR on a regional level. APM should be tailored to work in regional or even local settings, and need to be implemented by committed HCWs. Thus, developing and implementing (cross-border) APM requires a comprehensive understanding of the contexts in which they will be implemented and the people that will execute the strategies (i.e. HCWs). The similarities and differences between German and Dutch HCWs as found in this study, can serve as a primary identification of factors that need to be considered for cross-border APM cooperation.

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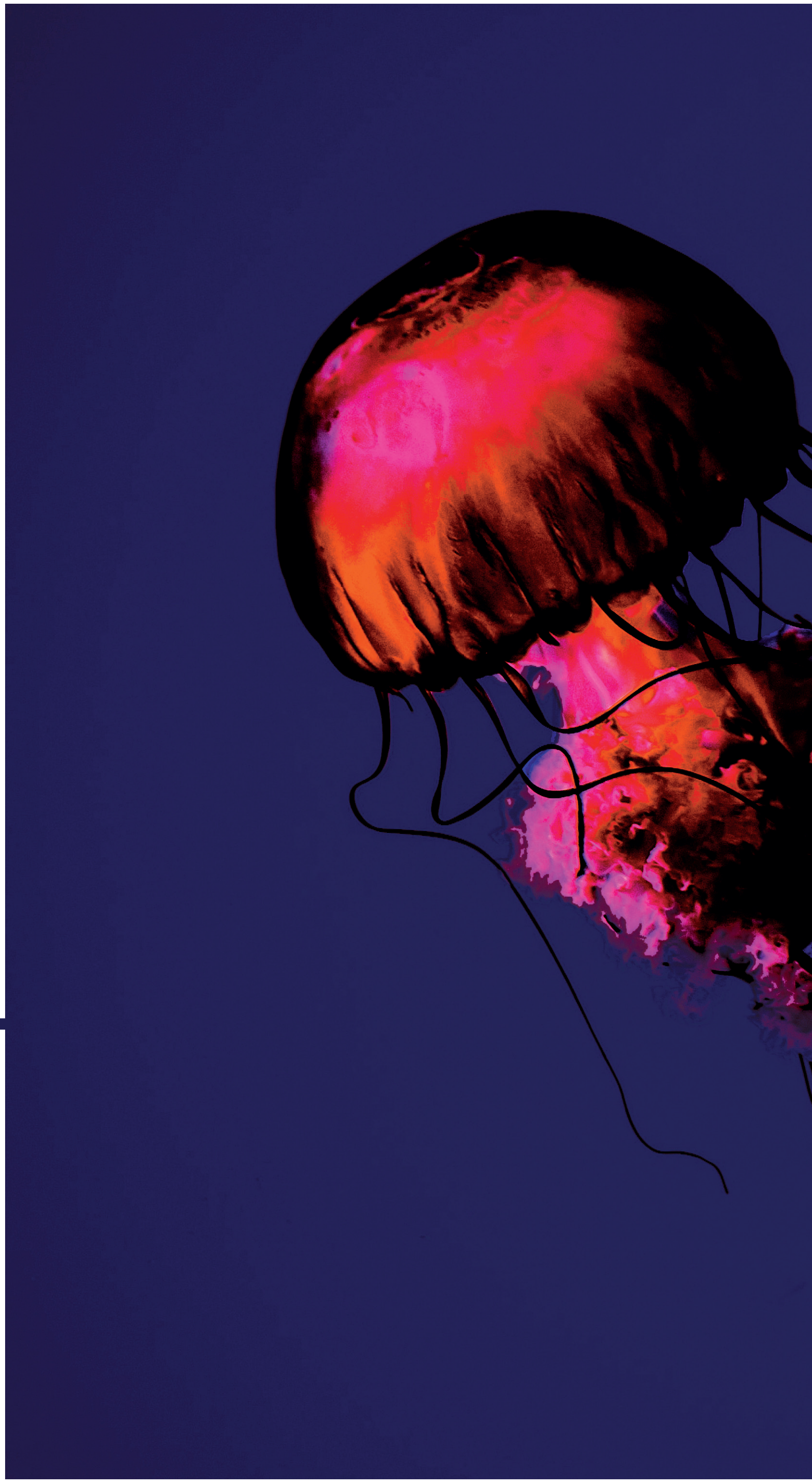
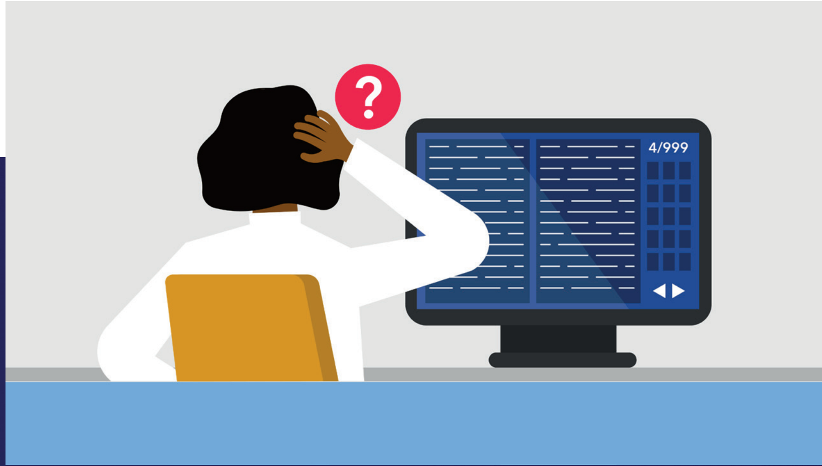
Chapter 3





Finding the match between healthcare worker and expert for optimal audit and feedback on antimicrobial resistance prevention measures

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Abstract

Background

The potentials of audit and feedback (AF) to improve healthcare are currently not exploited. To unlock the potentials of AF, this study focused on the process of making sense of audit data and translating data into actionable feedback by studying a specific AF-case: limiting antimicrobial resistance (AMR). This was done via audit and feedback of AMR prevention measures (APM) that are executed by healthcare workers (HCWs) in their day-to-day contact with patients. This study's aim was to counterbalance the current predominantly top-down, expert-driven audit and feedback approach for APM, with needs and expectations of HCWs.

Methods

Qualitative semi-structured interviews were held with sixteen HCWs (i.e. physicians, residents, and nurses) from high-risk AMR departments at a regional hospital in The Netherlands. Deductive coding was succeeded by open and axial coding to establish main codes, subcodes and variations within codes.

Results

HCWs demand insights from audits into all facets of APM in their working routines (i.e. diagnostics, treatment, and infection control), preferably in the form of simple and actionable feedback that invites interdisciplinary discussions, so that substantiated actions for improvement can be implemented. AF should not be seen as an isolated ad-hoc intervention, but as a recurrent, long-term, and organic improvement strategy that balances the primary aims of HCWs (i.e. improving quality and safety of care for individual patients and HCWs) and AMR-experts (i.e. reducing the burden of AMR).

Conclusion

To unlock the learning and improvement potentials of audit and feedback, HCWs' and AMR-experts' perspectives should be balanced throughout the whole AF-loop (incl. data collection, analysis, visualization, feedback and planning, implementing and monitoring actions). APM-AF should be flexible, so that both audit (incl. collecting and combining the right data in an efficient and transparent manner) and feedback (incl. persuasive and actionable feedback) can be tailored to the needs of various target groups. To balance HCWs' and AMR-experts' perspectives a participatory holistic AF development approach is advocated.

Background

Audit and feedback (AF) provides efficient and continuous opportunities to evaluate and improve the quality and safety of healthcare (1). AF encourages practice changes by summarizing data about specific aspects of care (i.e. audit) and reporting the findings back (i.e. feedback) to healthcare workers (HCWs). While AF is widely used, it yields modest and variable improvements in practice (2). Therefore, many studies have focused on identifying key ingredients and understanding the working mechanisms of successful AF (3–5). By now, we know that AF effectiveness depends on the targeted behaviour and the AF content, delivery, timing and context (2,3,5). Known barriers to successful AF are a lack of feedback to HCWs, feedback solely focused on what went wrong and a poor follow-up in terms of continuous quality improvement cycles (6–8). Making sense of the audit data and translating data into actionable feedback is a challenge (9). As a consequence, feedback often has little added value and HCWs perceive AF merely as a tool to comply with external obligations (e.g. accountability to healthcare inspectorate) (6,8). Thereby, the potential of AF as an improvement and learning strategy is foregone.

Colquhoun et al. (5) further supported this by postulating that the limited effectiveness of AF might be caused by neglecting feedback-recipients in the AF development process. Literature on user-centred development has long addressed the importance of including end-users from the start of the development process (10,11). Involving end-users from the early stages of development and throughout the development process ensures that the AF is functional and useful, supporting the end-users' goals, matching their working routines and fitting the organizational context (10). Studies using a user-centred approach have shown positive results with behaviour changing interventions (12). How this applies to audit and feedback strategies remains understudied. To examine how including end-users (in this case, HCWs) in the early development process can improve AF strategies, this study focuses on a specific case where the potential added value of AF is large: preventing antimicrobial resistance (AMR) in hospitals.

Antimicrobial stewardship programmes (ASP), diagnostic stewardship programmes (DSP) and infection control programmes (ICP) are part of an integrated approach of AMR prevention measures (APM) that aim to reduce or prevent the increase in AMR (13). Most APM activities directly interfere with HCWs' working routines. For example, by restricting the use of specific antibiotics or by checking prescriptions prospectively and advising to change if needed (14). Concurrently, AMR-experts are concerned about deskilling HCWs in APM as a result of restrictive interventions and an increased reliance on AMR-experts' advice (15). Therefore, studies focused on empowering HCWs to take ownership of APM in their working routines are of added value for the integrated approach of APM. Audit and feedback does not interfere with HCWs' working routines, but provides objective insights in APM to support a reflective learning approach for HCWs.

However, APM are currently developed and implemented in a top-down way (16,17). AMR-experts, such as clinical microbiologists, infectious disease specialists and infection control professionals develop and implement APM activities. HCWs are hardly involved in APM development (18). Therefore, HCWs' working routines and needs for APM support might not be sufficiently reflected, while HCWs are responsible for integrating prescribed APM in their daily working routines while handling patients. AMR-experts on the other hand, also face challenges with APM, such as a lack of dedicated time, funding or personnel, competing high-priority initiatives, and opposition by HCWs (19–21). Promoting shared ownership of APM between HCWs and AMR-experts is thus essential and could be realized by 1) improving awareness about (in) appropriate APM in HCWs (22,23), and by simultaneously 2) convincing AMR-experts of the relevance of including HCWs in APM development.

To balance the top-down AF and expert-driven APM approaches with the bottom-up perspective of the HCWs (or end-user), this study used a bottom-up participatory approach as a starting point for the development of AMR prevention measures audit and feedback (APM-AF). This paper focuses on the research question: *What are HCWs' needs* *and expectations for future APM-AF?* By answering this question, we aim to better match the APM-expert's and HCWs' perspectives to optimize future AF strategies, thereby increasing the likelihood of APM-AF uptake and easier integration and use in practice (24).

Methods

A qualitative semi-structured interview study was performed with HCWs at a regional hospital in The Netherlands (687 beds) between December 2017 and March 2018. The University's ethical committee approved this study (BCE18321).

Study population and setting

Of the wide variety of HCWs in the hospital, we focused on physicians, residents and nurses as key-stakeholders. Current AF strategies are focused on their work since they adopt APM into their daily working routines. Physicians, residents and nurses from the following departments were invited for an interview: Intensive Care, Emergency Department, Urology and Surgery. These departments handle vulnerable patients, which are often exposed to hospital admissions, invasive procedures and antibiotics, and thus are at increased risk of AMR (25).

In the regional hospital, microbiological diagnostics are locally organised and local guidelines on antibiotic prescribing are available in the form of online formularies. Expert consultations on medical microbiology, infectious diseases and hygiene are available by phone and in person.

Convenience sampling (26) was used by recruiting respondents through a previous hospital-wide survey (23). Additionally, heads of departments were asked to invite HCWs directly. No new interviews were planned when data saturation was achieved (27).

Interviews

The interview scheme was developed by a multidisciplinary research team, including health scientists, psychologists, a clinical microbiologist and an infection control professional. Themes were based on results of our prior studies on HCWs' needs and expectations in

APM support (23,28,29). The interview scheme was tested with a physician and a nurse. The interview started with demographic questions and continued with questions about specific AF for APM themes:

- current AF strategies for APM (e.g. "How do you know the quality of your APM work?", "Which feedback do you currently receive?") and expectations for future AF strategies for APM (e.g. "How could AF support in improving APM?");
- needs for future AF strategies for APM (e.g. "What would you like to know to determine your APM performance" and "How would you like to receive feedback on your APM performance?"); and
- possible barriers or preconditions for successful AF ("Could you think of reasons or situations in which AF would not improve the quality of care?").

Probing questions were asked to gain deeper insights in HCWs' experiences with current APM and expectations and needs for the content and delivery of APM-AF.

The interviews were conducted face-to-face at the hospital. Individual interviews were chosen over a collective focus group to reduce bias from social control due to respondents' functions and specialties. During the interview, open-ended, broad questions were asked to obtain rich responses. The interviewer (JK) is an experienced interviewer with understanding of (the medical terminology of) AMR. After attaining informed consent, the interviews were recorded and transcribed verbatim.

Data analysis

The transcribed interviews were coded in Atlas.ti (v8.2.30) by two researchers (JK and NBJ). Initial coding was deductive, based on the interview scheme themes as mentioned above. Within the themes sub-codes were created by open coding. Then, axial coding was performed to discover related concepts in the sub-codes. In this phase, variations within sub-codes were created if needed to explain differences within sub-codes. Analyst triangulation was applied (independent coding of 10% of the interviews by researcher

NBJ) (30). Disagreements between analysts mainly involved the use of different terminology for the sub-codes and variations. Differences were discussed until consensus was reached to increase internal validity (31).

Results

Respondents

Sociodemographic characteristics of the interview respondents (n = 16) are shown in Table 3.1 Respondents were physicians (n=6), residents (n=5) and nurses (n=5). Respondents varied in age, function and experience in their function and experience at the hospital. Interviews took 45 min on average.

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Table 3.1. Respondents' characteristics

Respondents (*n* = 16)		
Age, mean (SD)	Years	41 (12,1)
Gender, n(%)	Male	8 (50)
	Female	8 (50)
Department, n(%)	Surgery	5 (31)
	Emergency Department	3 (19)
	Urology	5 (31)
	Intensive Care	3 (19)
Function, n(%)	Physician	6 (38)
	Resident	5 (31)
	Nurse	5 (31)
Function experience, mean (SD)	Years	11,1 (8,7)
Hospital experience, mean (SD)	Years	11,7 (12,9)

Results interviews

Interrater reliability was found to be substantial (Kappa = 0.729, p < 0.001). For each interview theme various sub-codes and variations were constructed to represent the rich in-depth information that was retrieved in the interviews. The code schemes are presented below in tables 3.2 and 3.3, including frequencies of sub-codes/variations and illustrative quotes. Sub-codes and variations are further elaborated upon below the tables.

Table 3.2. Needs for future APM-AF

Code	Sub-code	Variation	n	Quote
Needs audit	Content	Insights in diagnostics	6	"Do we use the right diagnostics for our patients? In other words, do we test too much or do we take the wrong tests?" P(17.36)
		Insights in empirical and targeted treatment	4	"I would like to know for a certain clinical presentation how we start our treatment, which antibiotics we start with." P(13.29)
		Insights in infection control measures	4	"For infection control I would like to know what percentage gets clean clothes every day. And what effect that would have on the prevention of new infections. I would also like to know if hand hygiene is adequately applied and if people comply to the dress code. Also, the use of non-sterile or sterile gloves." R(04.16)
		Insights in infection outcomes	3	"I would like to see how we perform in the hospital; how often do we have resistant micro-organisms and how often are these transmitted to other patients or personnel." R(05.21)
		Insights in resistance patterns	5	"Insights in diagnostic results, resistance patterns, not for individual patients, but overall. How the resistance patterns have developed over time." P(02.16)
	Norms	Benchmark	8	"If I would be compared to colleagues for example, that might be scary, but eventually you can learn a lot from it." R(04.31)
		Trends over time	4	"You could do a baseline measurement, so how are we performing now. And then look how it evolves over time when you change things." P(17.50)
Needs feedback	Content	Simple and concrete points of improvement and recommendations	7	"Some points we might be able to change ourselves, such as poor hygiene or so. But it may also be that policies need to be adapted, that certain antibiotics may or may not be given anymore. You really have to give something back that it is not just plain facts." N(09.56)
		Feedback tailored to target group	8	"I would indeed stick to one group *[nurses or physicians]* and focus on that specific target group. Adapt the feedback to that group." N(15.23)
		Substantiated recommendations	11	"I want to be convinced with good arguments. I understand that there are rules and you must adhere to them, so I adhere to them. But I find it very annoying when people can't explain why. It seems logical and it is tangible, but if it is not scientifically proven, then I think you should thoroughly study it before you set a rule." P(08.33)
	Form	Mail/ newsletter /poster	4	"I would like to receive some kind of newsletter online". P(05.31)
		Interactive	13	"Just data is an empty shell. You have to present it, you have to discuss it, you have to work with it." R(04.40)
	Frequency	Not too often, but recurrent	14	"Oh, not every week or month, then it is way too much. I think every six months, something like that. Because otherwise it will only overwhelm you and then it seems to be a goal and not a means for something." P(17.62)
AF implementation	Approach	Positive	4	"I think positive reinforcement is better than focusing on the negative." P(14.40)
		Transparent	1	"If there are consequences from AF, you have to explain in advance clearly why it happens with what purpose, that it is linked to a standard and that there is time to improve." P(17.62)
	Ownership	Bottom-up	9	"It is also easier to hear feedback from someone you see more often than from someone who just shows up and has something to say about your work." N(15.43)
		AMR/infection experts	8	"By someone who is knowledgeable about these topics." N(09.49)
		Interdisciplinary	6	"It would be very valuable to have regularly multidisciplinary meeting with the bacteriologists and possibly infectiologists or an infection committee." P(02.24)
		Supported by supervisors and management	3	"It must be supported by the organization, so people at the top, the management." R(10.44)

P: physician, *R*: resident, *N*: nurse

Table 3.3. Anticipated barriers and preconditions for future AF strategies for APM

Code	Sub-code		n	Quote
Anticipated barriers APM-AF	Difficulties with defining and operationalizing APM quality	Contradictive APM goals	11	"Quality for me means that the patient receives proper care". R(04.05)
		APM quality determined by many aspects	4	"It is not only the person that needs to change, there might be other things. You need help from your colleagues, help from the environment; there are various sources that influence your behaviour". (P17.64)
		Linking process and outcome indicators	4	"If someone has become septic after treatment at the department, that might not necessarily be wrong, but a natural course of an illness." P(13.03)
	Difficulties with benchmarking		4	"That would also be good for departments, but then you would have to compare similar departments and that is difficult." R(04.31)
	Information overload		7	"Because there is an overkill. There is so much information, you get feedback on too many things". N(16.49)
	Registration burden		3	"For the quality it would be better if the doctor would not have to spend all the time on registering and controlling infection control measures, but if you want to do it properly, I suppose that is all in the game." R(04.06)
	Measuring for the sake of measuring		5	"Look, a lot is being measured, but that does not necessarily lead to better care." R(04.34)
Preconditions APM-AF	(Cost)-effectiveness of APM-interventions		8	"Costs also play a role, especially at this time. It should be cost-effective. Also, if it would require a lot of effort resulting in a relatively small result, then you really should consider the usefulness" P(05.59)
	Cultural safety		10	"Providing and receiving feedback is just difficult. You have to have a professional attitude". P(17.58)

P: physician, *R*: resident, *N*: nurse

Current APM audit and feedback

HCWs currently do not receive meaningful or actionable feedback on APM from audits to improve their own behaviour, nor to evaluate their working routines. Incidental audits by infection control professionals and workplace visits by the healthcare inspectorate result in general hospital-level feedback, while the audit content does not fully address the APM aims that HCWs envision.

The feedback that is received, originates from direct interactions with AMR-experts and mainly focuses on ad-hoc decisions for individual patients. Medical microbiologists are easily consulted to check and adapt the planned diagnostics or treatment. Communication with infection control professionals was described as top-down (i.e. receiving instructions rather than consulting), which was deemed acceptable for unpopular, yet necessary decisions (e.g. commissioning isolated care for a specific patient, while there is a shortage of beds).

In sum, the most pressing challenges for APM-AF are:

- Audits on APM performance are limited;
- Audit content is expert driven and does not match HCWs' aims for APM;
- Feedback is not actionable for HCWs; and
- Finding a balance between top-down and bottom up.

HCWs perceive the added value of AF for APM, because it will allow them to become more aware of AMR and of the contribution of their own behaviour and working routines to reduce the burden of AMR (i.e. reflective learning approach as opposed to ad-hoc decision-support for individual patients).

Needs for future audit and feedback for APM

Table 3.2 presents HCWs' needs for future audit and feedback for APM. Needs are organized in needs for audit (content and norms), needs for feedback (content, form, frequency) and AF implementation (approach and ownership).

Needs audit

Content: Audits should cover both process- and outcome-measurements on DSP, ASP and ICP.

HCWs were interested in audits on how many (quantity) and how well (quality) diagnostics were performed. They would also like audits to keep track of what empirical treatments are chosen for specific clinical presentations and if this was according to the local guidelines. After the start of an empirical treatment, antibiotics should possibly be adapted to match the results of diagnostic tests and HCWs were interested to see how often such adjustments were actually made. Whereas the previous mentioned AF content focuses on process-measurements (direct reflections of HCWs' behaviour), HCWs were also interested to see the outcomes (indirect and more uncertain reflections of HCWs' behaviour). They were interested in infection outcomes, such as prevalence figures of resistant micro-organisms and infections, and information about how often resistant micro-organisms are transmitted to other patients or staff. Lastly, HCWs were interested in insights in overall local resistance patterns to see if the problem is indeed worsening and to check for possible needed adaptations of (empirical) treatment.

Norms: Audits should be mirrored to reference data.

Because stand-alone data is not meaningful, HCWs would like to see their own performance data compared to some reference data. This could be a pre-agreed standard within the department or hospital, or it should allow for benchmarking between individuals, departments, similar hospitals or even regions. Another feasible alternative mentioned was to focus on trends over time to show progress. In this way, effects after APM-intervention implementation can also be evaluated.

Needs feedback

Content: Feedback should be simple, action-driven, tailored, and substantiated.

Feedback should consist of more than plain data since data are an "empty shell". Data should be analysed and translated into simple and concrete points of improvements and recommendations. Feedback should be tailored to specific target groups (e.g. physicians or nurses), so that HCWs feel that the feedback is relevant to them, unlike is often the case with current feedback.

Lastly, recommendations and planned APM-interventions should be substantiated, so that HCWs know why measures are taken and what the expected effects are.

Form: Feedback should be embodied in interactive discussions.

HCWs shared many possibilities of feedback forms. These range from informative mails, newsletters or posters to interactive presentations and education wherein the data and their implications can be extensively discussed. Two physicians suggested three additional forms of feedback: 1) analysing the data themselves (i.e. learning throughout the whole audit-feedback-cycle), 2) linking individual performance feedback to annual performance reviews and 3) direct feedback (on antibiotic prescriptions) in the form of a pop-up in the prescription system (i.e. decision-support).

Frequency: Feedback should be recurrent and requires long-term follow-up.

HCWs did not want to receive feedback too often, because of the already intense information burden. Proposed feedback frequency varied from quarterly to yearly. HCWs emphasized that AF should be recurrent and long-term to have impact, because changes in behaviour and culture take considerable time and effort. Long-term follow-up is also needed to measure the effects of APM. The preferred timing of feedback depended on its form (e.g. discussions during existing meetings).

Audit and feedback implementation

Approach: AF should positively and transparently reinforce HCWs.

HCWs indicated that a positive feedback approach (i.e. positive reinforcement) would work better than focusing on the negative (i.e. negative punishment). Positive reinforcement could for example be implemented by appraising high scores with rewards.

If consequences were to be linked to AF, then transparency and clear instructions on the full AF procedure are required beforehand.

Ownership: AF should be organically shared throughout the organization.

Various opinions were raised about who should be responsible for the whole AF process. Some HCWs indicated that it would be best to implement AF with HCWs in the leading role, because imposing AF top-down would only lead to resistance. Receiving feedback from someone familiar on both a personal level (i.e. do I know the person) and on a work level (i.e. does the person know our work processes) is believed to increase the level of acceptance of feedback and therefore its effectiveness. Other possible AF owners were experts in the field of AMR and infections, because they have the required expertise and because they can serve as an objective outsider. However, a concern was that they might not always be aware of local working routines and might miss the clinical view that is required for the full treatment of the patient (not only the AMR focus). Therefore, AF should ideally be implemented in an interdisciplinary fashion, where AMR expertise and department/patient expertise are combined in the translation of data to feedback and APM-interventions. Lastly, HCWs mentioned that the whole organization should support the AF initiative.

Anticipated barriers and preconditions for future AF strategies for APM

Table 3.3 presents HCWs' anticipated barriers and preconditions for future audit and feedback strategies for APM.

Anticipated barriers for APM audit and feedback

Difficulties with defining and operationalizing APM quality.

HCWs envisioned that a main challenge for auditing APM would be the fact that there is ambiguity about what APM quality entails. This could lead to discussions about valid measurements of APM quality. Several explanations for the ambiguity of APM quality were provided.

Firstly, ambiguity about the quality of APM is caused by contradictions in APM goals between HCWs and AMR-experts. HCWs indicated that they primarily aim their APM at providing the best possible care for individual patients. Few HCWs mentioned preventing the spread of resistant micro-organisms or limiting AMR overall as a specific goal of their daily practice. Although they understand that AMR indeed is a threat to their patients and that this threat will likely increase in the future, providing the best care for their current patients seems to be more pressing. APM activities that aim to prevent the spread of resistant micro-organisms (e.g. treating patients in isolation) or to limit the overall AMR (e.g. awaiting test results to narrow AB treatment) are sometimes experienced as unfavourable for individual patients, while these are the activities that can be measured to define APM quality.

Second, HCWs indicated that successful APM is determined by many aspects. Not only individual APM activities determine APM quality, but HCWs are also depended on others in the full APM process (e.g. cultures taken by admission at another department) and on the context (e.g. availability of sufficient disinfectants or isolation rooms).

Third, concerns were raised about linking outcome indicators for APM (e.g. number of patients with resistant micro-organisms) to individual actions, because these outcomes are outside of HCWs' control (e.g. admitting patients carrying resistant micro-organisms or sepsis as a result of the course of a disease). As a result of the complexity of APM quality, not all APM measurements are expected to have impact on their approach to individual patients and thus the feedback provided would not lead to changes in behaviours.

Difficulties with benchmarking.

HCWs also raised the concern that comparing data between regions, hospitals and departments would be difficult, because of differences in local resistance patterns and patient population. Comparing data on an individual level was mentioned as the most valuable for learning lessons, but concerns were raised about the availability of data.

Fear of registration and information burden.

HCWs were afraid of more feedback on top of the feedback that is already provided (i.e. information overload) and of a registration burden that might come with AF. HCWs described that many data are collected in healthcare, without necessarily improving the quality of care for individual patients (i.e. measuring for the sake of measuring). This belief is reinforced by the fact that HCWs questioned the usefulness of some ICP guidelines. They feel like scientific evidence is limited and sometimes common sense neither urges compliance (e.g. clothing requirements). Measuring these aspects would have no added value to them.

Preconditions APM audit and feedback

Consider cost-effectiveness of AF follow-up.

An important precondition for the success of AF was the consideration of what can and should be done based on AF findings (i.e. AF follow-up). Cost-effectiveness of APM-interventions is therefore an important precondition for improvement suggestions. Concerns about costs were about both money (e.g. taking additional cultures) and effort (e.g. washing hands all the time).

Create an open and safe culture to discuss AF.

HCWs emphasized that an open and safe culture in which you can address others' behaviour is essential in improving APM or any other behaviour-related problem. Hierarchy sometimes hinders this open and safe culture. Especially residents and nurses explained that they would not address a medical specialists' behaviour and some medical specialists acknowledged that they felt more comfortable with receiving feedback from peer specialists than from others.

Discussion

This study revealed in-depth insights into HCWs' expectations and needs for future audit and feedback (AF) strategies for antimicrobial resistance prevention measures (APM). The following discussion reflects on this study's findings, which results in specific recommendations for future (APM-)AF. To structure the discussion, we differentiate between reflections and recommendations on 1) audit and feedback itself (why, what, how) and 2) the development process of AF.

Reflection on study findings

Audit and feedback: why?

Tracking and reporting are core elements for hospital APM as defined by the Centers for Disease Control and Prevention (CDC) (32). However, this study showed that feedback in current AF strategies, if at all given, does not sufficiently support HCWs in proactively considering AMR in their daily working routines. Therefore, our findings complement the CDC's core elements, with the aim to evolve tracking and reporting into AF that serves both as a quality and safety strategy for the organization and as a learning system for HCWs. By closely cooperating with HCWs and AMR-experts from the start of the development process, we promote adopting an AMR-minded way of thinking and intrinsic motivation to take shared ownership needed for successful APM (33).

Audit and feedback: what?

An important finding of this study is the concern HCWs raised about defining and operationalizing APM quality. This concern is not new to the field of quality improvement science (34,35), yet not sufficiently discussed in the AMR-literature. A comprehensive discussion on the conceptual and operational definitions for AMR goes beyond the scope of this article, but we reflect upon three important considerations.

First, AF relies on the conceptual definition of what quality of healthcare, or in this case quality of APM, means (35). This study illustrated that the definition of APM quality depends on whose perspective is incorporated. When looking at prior studies defining quality for APM (36–41), quality seems to be defined from a narrow AMR-perspective to fulfil the aims of evaluating stewardship programmes and benchmarking hospitals. Thereby aspects that define APM quality from the HCWs' perspective are not considered, meaning that the basics of AF do not optimally fit with HCWs' needs.

Second, closely related to conceptually defining quality is the operationalization of how quality is measured. Years ago, Donabedian introduced his conceptual model for the evaluation of quality of healthcare by measuring *structure*, *process* and *outcome* indicators (42). More and more studies report on how indicators were selected in a systematic way (36–41), but far less studies have considered and scientifically tested the relationship between structure, process and outcome indicators to their clinimetric and psychometric properties (43). Because of this the transparency, reliability, and validity of the evidence-base for APM-interventions and strategies is diminished.

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Lastly, and again closely related to beforementioned aspects of defining and operationalizing quality, is Donabedian's notion that AF should be seen as an indicator rather than a definitive judgement of the quality of care (35). The HCWs' needs we found in this study closely resonate with Donabedian's reasoning: HCWs need data-driven feedback as input for more objective discussions about their behaviour and working routines. They explicitly do not need feedback presented as judgement of their work, as currently is often the case.

Further translating these three key-considerations for audit and feedback in the APM-field, and any field for that matter, is a crucial step towards sense-making AF for quality improvement (and AMR reduction).

Audit and feedback: how?

Retrieving and analysing the data are crucial steps to unlock their potential. However, little scientific attention has been paid to translating data into actionable feedback and conveying the information to specific target groups (44). We here highlight two study findings related to the translation and conveyance of actionable feedback. First, results of this study showed that HCWs prefer positive feedback, while at the same time they acknowledge the need for top-down directions on unpopular but necessary decisions. This corresponds to findings of Fitzpatrick and Riordan, who studied the "carrot vs. stick" dilemma in the infection literature. They concluded that both top-down and bottom-up approaches are required for sustainable improvement (45). Second, this study identified differences between physicians and residents on the one hand and nurses on the other hand. Whereas nurses expressed a clear need for practical "how-to" suggestions, physicians also showed interest in interactively discussing and even "playing-around" with the data themselves. Differences between nurses and physicians were also found in other studies within the context of AMR (46–49), and literature on AF also suggests other feedback recipient characteristics (e.g. intrinsic mastery goal orientation (5)) influence the success of AF. This calls for an AF system that can be tailored to fit the varying needs of various target audiences.

Developing AF (for APM)

From this study we have learned that incorporating a bottom-up approach reveals crucial aspects that are easily overlooked when following a more top-down expert-driven approach. More specifically, this study revealed gaps between different worlds on many levels:

- between healthcare workers and AMR-experts (e.g. bottom-up vs. top-down, individual needs vs. societal needs);
- between science and practice (e.g. balancing evidence-based with practice-based);
- between strict and flexible guideline implementation (e.g. pragmatic guideline implementation);
- between the fields of DSP, ASP and ICP (e.g. no integrated view on APM as reflected in the various literature sources required to highlight all aspects);
- between scientific disciplines (e.g. medical, behavioural, improvement, persuasive technology);
- between various databases (e.g. need for employing technical and data-science skills to extract and combine data from laboratory and hospital information systems).

Improving future (APM) audit and feedback

From this study several lessons and recommendations can be drawn that need to be considered in the future development of audit and feedback strategies and more specifically in AF to support HCWs in tackling the AMR-problem.

Improving audit and feedback: what?

Future studies should focus on how to balance different perspectives in defining quality of care by exploring differences in quality definitions by various stakeholders. For APM-AF, explicit attention should be paid to discuss the conceptual and operational definition of quality and to emphasize the added value for the patient, so that it better fits the HCWs' needs. To study this, research designs that explicitly consider evaluating multiple conflicting criteria in decision making (e.g. multi-criteria decision analysis (50)) and finding consensus (Delphi-studies (43)) are encouraged.

Improving audit and feedback: how?

Our study results underline the need for tailored information conveyance strategies for different target groups. This requires flexible AF, in which users can choose to what extent they would like to interact with various parts of the AF-cycle. Thereby, the required flexibility in the frequency of feedback can also be adjusted by HCWs themselves, so that the information burden can be controlled. Furthermore, tensions between top-down and bottom-up approaches could be harmonized by adequately framing the feedback through smart and persuasive visualizations (51). Here, we see a clear role for eHealth (e.g. interactive dashboards and eLearning), because it can tailor the data-representation and feedback to the demands of HCWs and AMR-experts (52–54).

Furthermore, both HCWs and AMR-experts are and always will be subjected to externally enforced directions. Therefore, the true challenge will be to explore when and how the gap between top-down and bottom-up should and can be bridged. Like many other studies, we emphasize that creating an open and safe culture is key in this process (55–57).

Future approach to developing AF (for APM)

To bridge the beforementioned gaps, future studies on the development and implementation of (APM-)AF should focus on incorporating evidence from literature in the fields of behaviour change (58), communication (59), data visualization (60,61), persuasive technology (62) and data science (63). Especially, attention should be paid to 1) collecting and combining the right data in an efficient and transparent manner (e.g. combining data from various IT-systems) and 2) communicating persuasive and actionable feedback (e.g. by using data visualizations). The CeHRes-roadmap (10) could guide the planning, coordination and execution of a participatory development process of data-driven APM-AF, since it fits well with the wicked AMR-problem because of its socio-technical and interdisciplinary-based participatory principles (64).

Limitations

The exploratory and broad nature of this study has some limitations. First, the limited number and restricted specialities of HCWs included in the interviews might raise concerns about the generalizability of the study findings. By combining findings from AF and APM literature with results from our previous studies and by including HCWs from departments that have experience with AMR (i.e. they know what AMR means for their patients and work processes), we reached data saturation with the 16 interviews. Also, the findings provided us with a strong backbone for the analysis of the results. This resulted in themes that, combined with findings from other literature, are generalizable both within the fields of AF as APM. To validate the findings, future research could replicate this study with more and other HCWs from other departments, hospitals, or settings to determine in how far findings are context-specific.

Other limitations relate to the content of the interviews. One of our initial aims was to produce concrete recommendations for the design of AF for APM. However, after analysing the transcripts, we realized that during the interviews the question of when HCWs would use AF in their daily practice was not sufficiently addressed. Because this question highly depends on the content (i.e. what is audited) and the form (i.e. how feedback is provided), this question should be addressed in a later stage of the development process. Also, we experienced that HCWs found it difficult to express their needs, especially in terms of how feedback should be provided. Similar problems were reported by Crisan et al. (61), where participants showed clearer design preferences when asked to evaluate individual design elements than when evaluating entire reports. In future studies, mock-ups or prototypes could better guide the interview by supporting HCWs to concretize and express their preferences. We have already started preparations for a next step in our research, in which this will be done.

Because this study operates on the crossroads between highly heterogenous fields, it was impossible to reflect upon all aspects of our findings. However, we believe that this paper contains important starting points for future research, both within and between the various involved fields. Therefore, this paper can be seen as an invitation to further discuss and crystallize audit and feedback, specifically for APM.

Conclusion

Current audit and feedback strategies do not sufficiently support HCWs in tackling the AMR problem. However, HCWs belief that this could be realized via AF, because AF provides a call-for-action to tackle the AMR-problem through their daily working routines. HCWs require insights into all facets of APM in their daily working routines (i.e. diagnostics, treatment, and infection control). This should preferably be provided in the form of simple and actionable feedback that invites interdisciplinary discussions, so that substantiated actions for improvement can be implemented. AF should not be seen as an isolated intervention. Rather, it should be considered a recurrent, long-term, and organic improvement strategy that balances the aims of improving quality and safety of care for individual patients with reducing the burden of AMR. To realize sense-making AF, HCWs' and AMR-experts' perspectives should be balanced throughout the whole AF-loop (incl. data collection, analysis, visualization, feedback, and planning, implementing and monitoring actions). Differences between the current linear and desired continuous situation are illustrated in figure 3.1 on the next page.

UNLOCKING THE POTENTIAL OF DATA

In the current situation, data don't have direct impact on the healthcare we provide. To add value to the audit and feedback system various changes are required.

Current situation

1. **Monitor AMR data**
   Incidental audits, e.g. for healthcare inspectorate.
2. **Analyse AMR data**
   Transform data to hospital-level.
3. **Report feedback**
   Generic hospital performance report.

Desired situation

1. **Monitor AMR data**
   Structural audits, matching HCW' APM aims and needs.
2. **Analyse and translate AMR data**
   Transforming data into actionable feedback.
3. **Report actionable feedback**
   Make use of fitting data visualizations.
4. **Plan improvements**
   Determine improvement points and action plan.
5. **Implement improvements**
   Implement improvements in care process.

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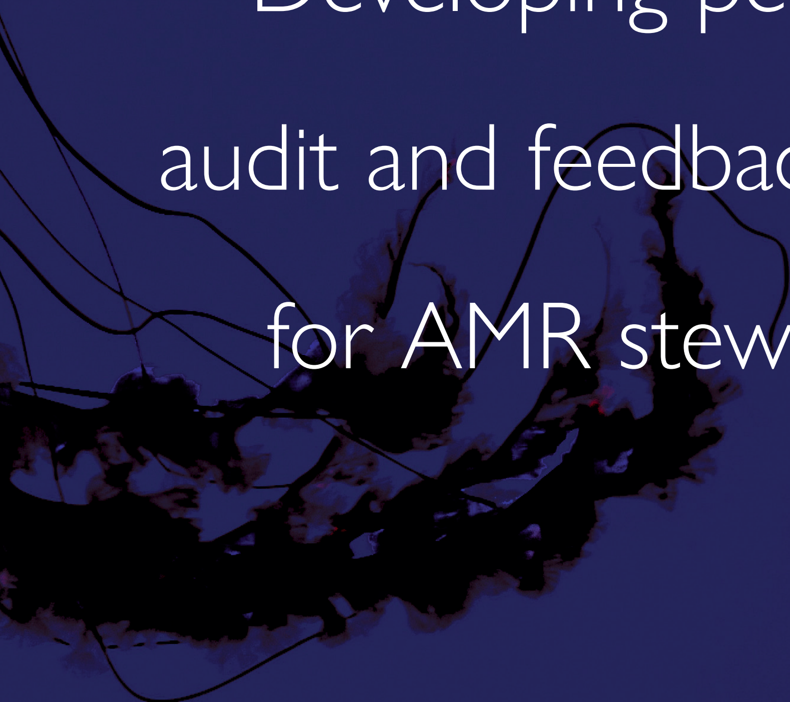
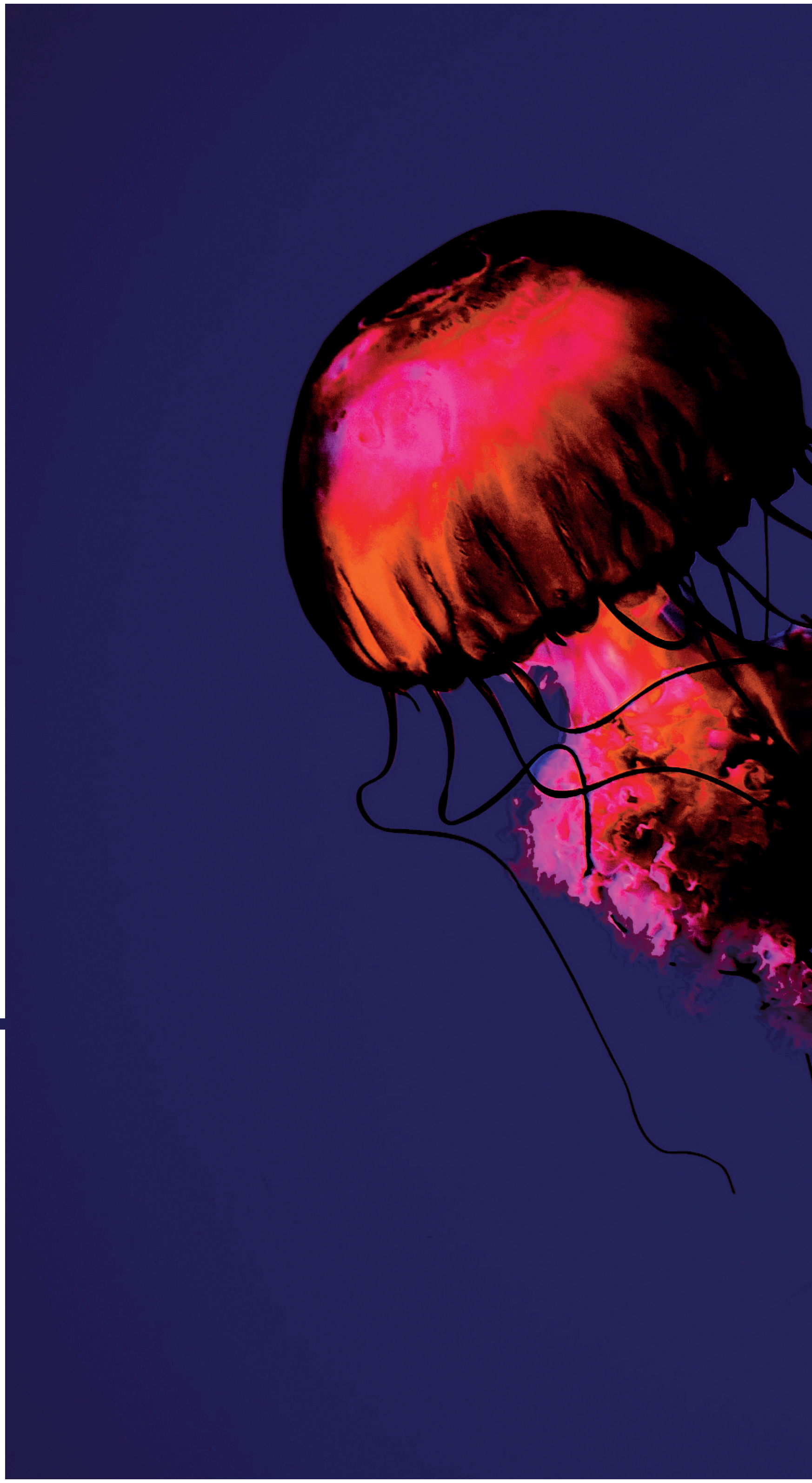
Part 2

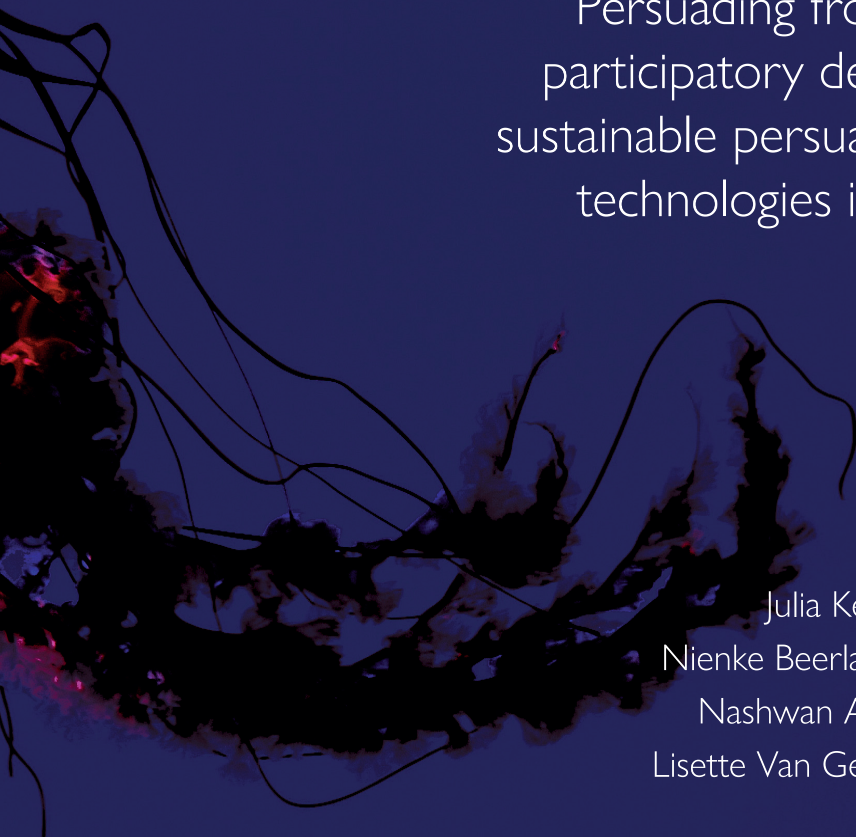
Developing persuasive audit and feedback systems for AMR stewardship



Chapter 4



Persuading from the start: participatory development of sustainable persuasive data-driven technologies in healthcare



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Abstract

Data-driven technologies can persuade humans to optimize their behaviour and context based on objective data. However, current data-driven technologies have limited persuasive powers, because of a misfit between the technology, the end-users and their context. Neglecting end-users in the development process contributes to this misfit and to limited engagement with the to-be-developed technology. This threatens sustainable implementation. Therefore, this paper demonstrates how a bottom-up participatory development approach can improve the persuasive design of data-driven technologies and simultaneously increase engagement of end-users to foster sustainable implementation.

Introduction

Society faces many wicked problems that threaten the quality and safety of sustainable healthcare and harm public and individual health (1). Humans contribute, mostly unintentionally, to these problems by behaving suboptimal (e.g. not complying with guidelines) or creating suboptimal contexts (e.g. creating a messy work environment) (2). At the same time, there is no doubt that humans and their behaviour are vital in developing and implementing successful solutions (3). However, to cope with the complexity of modern-day challenges, humans require substantial support. Persuasive technologies that take advantage of the tremendous potentials that (big)data offer are promising for efficient and sustainable solutions (4). Data-driven technologies can persuade people to optimize their behaviour (i.e. individual actions) and context (e.g. working routines) based on objective data (5).

From our previous studies in hospitals, we know that (big) data are routinely collected for each individual patient to make diagnostic and treatment decisions and to monitor the patient's status (e.g. result of diagnostic tests) (5). However, these data are not optimally used for improvement strategies (6). This relinquishes the opportunities of reflecting on one's work and work processes, disallowing healthcare workers (HCWs) to learn from mistakes and to identify good-practices (7). Especially this reflective form of reusing routinely collected data promises to be a feasible and cost-effective way to support humans: the (big) data are already available, yet not smartly combined, translated and communicated to persuade HCWs to improve their behaviour and context (5). This principle is not new. Audit and feedback (AF) has been widely used in healthcare (8). By summarizing data about specific aspects of care (i.e. audit) and reporting the findings back (i.e. feedback) to healthcare workers (HCWs), AF encourages behaviour and practice changes. Therefore, AF is an interesting case to study data-driven persuasive technologies.

Although AF is widely used in healthcare, it yields variable and modest effects in practice (8). AF is mostly organized in a top-down (e.g. audits by healthcare inspectorate (9)) and expert-driven (e.g. indicators created by quality-experts (10)) way. Thereby, feedback, often provided at hospital-level, is hardly useful for HCWs to improve their behaviour and working routines (5). Because of this misfit between the data-driven technology, the end-users and their context, current AF have little persuasive powers. The limited persuasiveness and thus added value of AF might be caused by neglecting end-users (in this case HCWs) in the AF development process (11). Making AF persuasive requires extensively studying users and their context throughout the development process. Therefore, the first aim of this paper is to demonstrate *how a bottom-up participatory development approach can improve the persuasive design of data-driven technologies* for their end-user (i.e. HCWs), and within their context.

However, this is not enough for sustainable solutions. Persuasively designed technologies do not guarantee adoption and acceptance in practice. Often, factors that determine successful implementation are studied after the design of the technology. But, implementation is not a post-design step; extensively discussing success factors for implementation from the start of the development process with end-users and other relevant stakeholders (e.g. managers) is crucial for successful implementation (12). As mentioned before, they are the ones responsible for implementing successful solutions in practice. Therefore, the second aim of this paper is to demonstrate *how bottom-up participatory development is a necessary precondition for the development of persuasive data-driven technologies that foster sustainable implementation.* We do this, by showing how our bottom-up participatory approach persuaded end-users (i.e. HCWs) from the start to get engaged by and take ownership of the persuasive technology.

Our studies have focused on the application of persuasive data-driven technologies for one of the most striking modern-day examples of behaviour-inflicted wicked problems: antimicrobial resistance (AMR) (5,13,14). AMR is a threat to global health and healthcare, that was largely caused by humans and relies heavily on human actions to be solved (15). Persuasive data-driven technologies can inform, support and persuade HCWs to optimize their diagnostic, antibiotic (AB) prescription and infection control behaviour to limit AMR (16).

In our studies we followed the CeHRes-roadmap, which guides the holistic development of persuasive technology (12). By using a multidisciplinary, socio-technical and behavioural approach, we gained deep understanding of the relevant stakeholders, their think- and work-processes and their context, including success factors for future implementation. By studying these aspects, we aim to better match HCWs' and other stakeholders' perspectives to optimally benefit from the vast amount of routinely collected data gathered in daily practice to improve the quality and safety of healthcare. Incorporating these findings into future AF strategies ensures that they match HCWs' needs and their context, thereby increasing the likelihood of uptake and easier integration and use in practice (17). Simultaneously, it builds towards a methodological and conceptual guide for good-practice bottom-up participatory development and implementation processes of persuasive technologies.

Methods

A participatory development approach requires using multiple complementary methods to grasp the breadth of aspects in wicked problems. Therefore, this study used a mixed-methods sequential explanatory design (18), in which quantitative results from a questionnaire provided input for two consecutive (qualitative) focus groups. Because the persuasiveness of a technology largely depends on the content, functionalities and design, this research focused mostly on these aspects. Additionally, attention was paid to implementation factors (e.g. what is the added value, how would you use this in practice and what are preconditions for uptake and sustainable use in practice?). In a second focus group, specific attention was paid to the bottom-up participatory research approach in relation to fostering implementation (see table 4.1 for each method rationale and the respective goals of the sub-studies).

Table 4.1. Elucidating the mixed-methods sequential explanatory design

Method	Method rationale	Sub-study goal
Questionnaire	To focus the topics for the focus groups, while integrating the AMR-expert view.	To prioritize *what* topics for AF, derived from national AMR guidelines, were most relevant to the end-users/HCWs.
Focus group 1	To realize in-depth discussions (no consensus needed).	To gain insight in *what* audit & feedback topics would be of added value and *why*.
Focus group 2		1) To gain insight in *how* audit & feedback would be used in practice and to identify *technology requirements.*
		2) To discuss *experiences* with the bottom-up participatory research approach

The study was performed in a Dutch regional general hospital (687 beds) by a research team of three health sciences/psychology researchers, a clinical microbiologist and a pharmacist. End-users, or in this case HCWs (i.e. urologists, residents and co-assistants) from a high-risk AMR department (urology) were included. The University's ethical committee approved the study (190008) and all respondents signed an informed consent prior to participating in this study.

Step 1: Questionnaire (prioritizing topics for AF content)

To prioritize *what* topics for AF were deemed most relevant, "top-down" content from the national AB stewardship guideline (19), the infection control audits of the national healthcare inspectorate (20) and key publications on AMR (21–26) were translated into a questionnaire with 27 AMR quality-indicators (e.g. "Were cultures taken before the start of empirical treatment?"). To end up with a feasible number of AF topics that could be discussed within the hour time-frame of the focus groups, HCWs answered the following questions about each predetermined indicator: "Would you like to have insight in this indicator? ("No/Yes") and "How relevant would insight in this indicator be for the treatment of your individual patients/for limiting AMR?" (5-point Likert items: "Limited relevance – High relevance").

A pilot-test was held with two AMR-experts and a urologist to ensure comprehension and clarity of the questions. All attendees of a regular weekly educational session (n=7, +/- 50% of department) filled in the questionnaire after a short presentation about the research (Jan. 2019). Descriptive analyses were performed in Microsoft Excel (v2016). Responses were summarised in means and standard deviations and the research team discussed the quality-indicators for which more than 75% of respondents saw relevance to avoid individual preferences in the small number of respondents. Through discussion, four AF topics were selected for the consecutive focus groups.

Step 2: Focus group 1 (*content* & *added value*)

The second step within this study was to determine *why* HCWs would want to use audit and feedback and *what* (kind of) AF HCWs need in order for it to be relevant and meaningful to them. Therefore, the first semi-structured focus group used the results of the questionnaire to discuss the following questions for each topic: 1) "*Why* would you want to have this insight?", 2) "Currently, *what* insight do you use to determine quality of topic X?", 3) "Which *additional insight* would you need to determine quality of topic X?". Probing questions were asked to gain deeper insight in the perceived relevance of AF and to find preconditions for successful AF.

Step 3: Focus group 2 (practical use & requirements)

The third step within this study was to determine *how* HCWs would want to use AF in practice and to identify *technology requirements* (e.g. functionalities and design) for AF, using three examples in the form of low-fidelity prototypes. The first example was the prototype based on focus group 1. For the second and third example, screenshots of existing AMR-tools were requested and attained from the first authors of published papers. The second example was an interactive open-source software app for infection management and antimicrobial stewardship: Rapid Analysis of Diagnostic and Antimicrobial Patterns in R (RadaR), developed to support AMR-experts in analysing AMR-data (27). The third example was an existing tool to measure the quality of infection control and antimicrobial use: the Infection Risk Scan (IRIS), developed to easily and transparently communicate risks and improvement areas to HCWs and managers (28).

The following three questions (and subsequent probing questions) were asked for each example: 1) "What is your first impression?", 2) "How would you use this in your work?", 3) How would you like the AF system to support you in doing so?". Furthermore, discussions were held on experiences with the bottom-up participatory research approach and expectations of how this approach might influence the persuasiveness, usefulness and effectivity of the to-be-developed technology and its development and implementation process.

For both focus groups pilot-tests were held with a urologist to ensure clarity and comprehension of the questions. All urologists and urology-residents who work at the studied Dutch regional general hospital were invited for the meetings. One hour of each meeting was dedicated to audit and feedback (April & October 2019). Participants were specifically asked not to think in limitations by data/ IT-systems. The focus groups were audio-recorded and transcribed verbatim. Transcripts were coded in Excel by researcher JK. The first round of coding was deductive based on the focus group schemes and was succeeded by open and axial coding to establish sub-codes and variations. Analyst triangulation was applied (independent coding of 25% by another researcher BB) (29) and kappa statistic were used to test interrater reliability (30).

Results

Sociodemographic characteristics of the questionnaire (QNR) respondents and focus group participants are shown in table 4.2. Completing the questionnaire took 20 minutes on average, and both focus groups took one hour. Interrater reliability was found to be substantial for focus group 1 (Kappa = 0.685, $p < 0.001$) and moderate for focus group 2 (Kappa = 0.479, p 0.017). Participants were unfamiliar with qualitative research in the form of focus groups and with participating in a participatory research project.

Table 4.2. Respondent'/participant' characteristics

	n=	Age mean(SD)	Gender n		Function n(%)		Experience mean(SD)	
			F	M	Physician	Resident	Function	Hospital
Questionnaire	7*	34,1 (12,4)	4	3	2	2	4,7 (8,3)	4,7 (8,5)
Focus group 1	5	42,0 (10,8)	3	2	3	2	8,8 (8,4)	8,2 (8,8)
Focus group 2	5	41,8 (11,0)	3	2	3	2	8,6 (8,5)	8,0 (9,0)

*Co-assistants (n=2) were excluded in the focus groups due to their limited experience in urology.
Note. Four out of five participants of focus groups 1 and 2 were the same individuals.

The results section of this paper focuses on content, functionalities and design, which are all relevant to the persuasive design of data-driven technologies (31). Results are structured in HCWs needs and contextual considerations (e.g. perceived added value, anticipated use in practice and preconditions), both relevant to the persuasive design of data-driven technologies and for fostering implementation through persuasive development. Main findings are shown in bold and illustrative quotes in italic.

Content

The Sequential Explanatory Design Enabled Prioritizing HCWs' Content Needs.

Questionnaire. Table 4.3 shows the five quality-indicators that were rated as being most relevant and that were discussed in the research team to select the final four AF topics. Indicators three and four were combined into the topic "Updating the (empirical) AB treatment plan once new information (e.g. culture results or advice from colleague) is available".

Table 4.3. Questionnaire results (most relevant quality indicators)

Most relevant quality-indicators (k=27)		Relevance Patient (n=5)		Relevance AMR (n=5)	
		Mean	SD	Mean	SD
1	Taking cultures before the start of (empirical) AB	4,43	0,79	4,43	0,79
2	Adequate AB use (e.g. quantity and duration of AB treatment)	3,86	0,69	4,57	0,53
3	Following advices from other health care professionals	4,00	0,58	4,29	0,49
4	Adapting the (empirical) AB treatment based on culture results	4,14	0,90	4,43	0,98
5	Resistance patterns (e.g. surveillance of micro-organisms)	4,29	0,95	4,86	0,38

AB=antibiotic

Focus Group 1. In focus group 1, participants expressed their need to have insights in process indicators, such as the quantity and quality of their diagnostics and AB treatment. Also, participants would like to have insight in outcomes relevant to their patients: "*Whether you used an AB that allows patients to go home sooner." (R3).* Both positive (how often do we do it right?) and negative insight (how often don't we do it right?) would be relevant. Furthermore, participants were interested to see resistance patterns for specific sub-groups to tailor their (empirical) AB treatment to individual patients. To have meaning, these insights would have to be benchmarked against some standard. This could be local policies or guidelines (e.g. trend over time) and comparisons to other hospitals. Lastly, participants expressed the need for information tailored to function groups.

HCWs Could Easily Envision The Added Value Of And Preconditions For AF.

Focus Group 1. Respondents saw clear added value of AF to evaluate and improve the status quo and consequently proactively change current policies and practices. Furthermore, AF can facilitate objective discussions about performance. Lastly, it creates room for discussions on innovations (e.g. phage therapy) that otherwise disappear in the hustle of the day. For AF to be useful in practice, respondents warned that some content was more relevant for inpatients than for outpatients (e.g. changing empirical treatments after receiving culture results). In consultation with the pharmacist and the hospital data-manager, the decision was made to focus on inpatients in the rest of the studies, because they anticipated that there would be many missing data for the outpatient population that are crucial for meaningful audits (e.g. GP cultures and AB treatment). Furthermore, participants urged the need to, from the early development phases, start thinking about practical issues and consequences for policies and working routines that insights could convey: *"What if the patient is on your OR table, you are doing the time-out and your culture results are not known yet. Do you cancel the operation? … Then we have to be honest: if the results are not in yet, you willingly and knowingly take a risk, how small that risk may be. Then you see that it might be good in theory, but in practice, well, it weakens and weakens."* (R1).

Therefore, participants wanted to extensively discuss goals to make them realistic and relevant for their patients and for limiting AMR. Also, participants mentioned data management, including their own registration behaviour, and ICT-support as a crucial precondition for successful AF. Lastly, participants urged the need for an open culture, in which quality of their work can be discussed safely.

HCWs Required Examples To Envision And Verbalize Technological Needs.

Creating The Prototype. Results of focus group 1 were translated into a lo-fi prototype together with a creative company specialized in developing serious games (see figure 4.1 for detailed description). The prototype consisted of screenshots and was not interactive. The prototype was merely used to show what an AF technology could entail to help participants to envision and verbalize their needs.

Figure 4.1. Lo-fi prototype of a quality dashboard based on findings of focus group 1

Screen 1 shows specific user-roles (e.g. physician or AMR-expert). Screen 2 offers an overview of the five topics that participants deemed important (i.e. quality & quantity of cultures/AB treatment and resistance patterns). Trends over time are shown in the graphs, as well as in coloured scores below the graphs (e.g. results relative to the past 12 or 36 months; green = positive trend, orange = negative trend). Similarly, the benchmark with other regional hospitals is shown below the graphs in coloured scores. When clicking on a specific graph, screen 3 opens, where more details and background information (e.g. reference to guidelines or justification of score calculations) is shown. Screen 4 presents the discussion mode, where HCWs can upload interesting cases, improvement plans or innovations to discuss with the group.

HCWs Could Easily Envision The Anticipated Use In Practice.

Focus Group 2. To realize the potential added value as envisioned in the first focus group, participants indicated that elaborate AF, such as the examples provided, would be interesting to use in practice. However, participants envisioned that the examples would not be used in daily practice, but could be used in three "modes":

1. during (half) yearly meetings dedicated to AMR aiming to evaluate the status quo, to discuss improvement strategies and to strive for innovation. More frequent meetings for this purpose were not deemed relevant, because resistance patterns and working routines (incl. individual behaviours) do not change fast, nor feasible, because of time-constraints.
2. in ongoing educational meetings of residents (e.g. monthly) aiming to create AMR awareness and to reflect upon one's individual impact on quality and safety of care through their own diagnostic and AB treatment behaviours.
3. as a decision-support system to make more proactive decisions both on individual patient level (e.g. choosing the right AB given the culture results) and on policy level (e.g. regularly changing empirical treatment policy).

The three modes could coexist in practice with different target groups, for whom the technological functionalities should differ.

Functionalities

HCWs Could Clearly Verbalize Functionality Needs For Each AF Mode.

Focus Group 2. Consequently, HCWs expressed needs with regards to AF content within the beforementioned modes:

1. Quality management: participants required an overview to quickly see what does (not) go well and improvement suggestions. The task force, AMR-experts and other interested HCWs should be able to dive into the data in-depth (e.g. filtering and zooming in on subgroups/-topics). Both trends over time and benchmarks with other regional hospitals were required.

2. Education: additional needs for educational purposes were the possibility to zoom in to individual cases that can be reflected upon. AF should support in reconstructing and improving the underlying reasoning of decisions (i.e. declarative information).
3. Decision-support: participants required timely advice to optimize diagnostic and AB treatments for individual patients (i.e. personalized medicine) and warnings to proactively change empirical treatment.

HCWs Could Clearly Envision Preconditions To Foster Implementation.

Focus Group 2. Participants anticipated that AF alone would not lead to improved outcomes. Additional activities are required to engage HCWs in accepting and using the AF in one or various modes, such as creating a task force, having a consensus meeting with the whole department and training on how to use AF. Participants did not want to be responsible for collecting, analysing, and interpreting data, because of time constraints, insufficient data management skills and insufficient AMR knowledge: *"I think it can be dangerous for us to look at this ourselves …, because it is difficult to assess quality. Well, the background information could help of course, but still, it is difficult to interpret."* (R3). To come to substantiated improvement strategies that fit the AF data and HCWs working routines, and that contributes to both improved individual patient care and limiting AMR, participants required help from data-, quality-, and AMR-experts.

4

Design

HCWs Could Clearly Verbalize Design Needs.

Focus Group 2. Participants appreciated a clear and structured overview, with easily interpretable graphs and an easy-to-use navigation structure (e.g. using workbook tabs per topic): "Yes, I find it nicely structured. You still have to be careful not to present too much information on one tab, but it works nice with the tabs." (R4). Participants preferred graphs over numbers, especially for scores that were more complicated and could therefore not be represented with just a single score. Furthermore, attention must be paid to coherence between visuals and scores (e.g. use green for positive and red for negative). One participant indicated that choices on for example colors and lay-out should be based on generic design rules for dashboards.

Participatory Research

Participants were enthusiastic about being part of the participatory research, because it incorporates their perspective from the start of development: *"You start from the user groups that you want to reach. From the whole process you learn if and how they are open for that and how they want to be persuaded. If you want to achieve something, it is best to do it in a way that everyone embraces it." (R5).* At first, participants had some doubts about the qualitative and open nature of the focus groups. Along the way, participants came to realize its added value, because the abstracted findings and prototype matched their needs and context. However, concerns remained regarding generalizability of the findings: *"It could well be that it does not work in other hospitals and then you have to study why. We cannot just translate our findings to the rest of the country." (R3).* Furthermore, planning the focus groups with as many HCWs as possible was difficult, reflecting the time- and resource-intensive characteristics of focus groups.

Discussion

This paper demonstrated how participatory, bottom-up development can serve as the foundation for persuasive design and simultaneously increase engagement of end-users to foster sustainable implementation. The approach allowed for continuous formative evaluations to iteratively elicit and sharpen HCWs' needs, contextual considerations and their interdependencies to design persuasive technology. Concurrently, the participatory bottom-up development persuaded end-users to remain engaged throughout the development process. By paying attention to both needs and contextual considerations from the start of the persuasive development process, a fostering implementation context was provoked.

Persuasive data-driven technologies

From the discussions on HCWs' needs and contextual considerations, persuasiveness of AF technology mostly relied on content, functionalities and design. These are well-known aspects of the Persuasive System Design (PSD) Model (32). Our bottom-up participatory approach revealed an additional layer to the PSD's design principles, thereby supporting the PSD postulates. By matching "top-down"-context requirements with bottom-up HCWs' needs from the start of the development process, credibility support elements (e.g. expertise authority and third-party reliability) are incrementally and transparently integrated in the content of the technology ánd in the end-users' perceptions. Primary task support elements (e.g. tailoring and personalization) should be adaptable to the anticipated mode of use (e.g. quality management or training), while at the same time preconditions for successful AF use required changes in current working and training schemes. Users and their context thus shape the process of persuasive development and implementation, while reversely, the process shapes its users and context (33). For each wicked behaviour-inflected problem, the users and context vary largely, thereby requiring iteratively adaptable persuasive features and implementation strategies. Therefore, the PSD should be complemented with other models and strategies from the early phases of development to increase persuasiveness and foster sustainable implementation (32). For data-driven technologies examples are principles of actionable audit & feedback (34) and the multidimensional benefit framework (35).

Bottom-up participatory approach to foster engagement/ownership

To optimize the fit between humans, their context and the persuasive technology, an agile development process is required (36). In this paper, we demonstrated why iterative phases are crucial for successful development: both HCWs and the research team needed and used several sessions to clearly envision and verbalize their needs and the direction of the project. Additionally, we believe that the iterative nature of the bottom-up participatory approach persuaded end-users (i.e. HCWs) to engage with and take ownership of the development of the persuasive technology. Engagement needs to grow, especially for subjects that are not within the primary tasks of HCWs, such as AMR (37). By pursuing the development process, we saw increased engagement with the subject (i.e. AMR), but also with reflecting on one's work (i.e. embracing quality management). The focus groups provided time to extensively discuss these matters that otherwise would have not been discussed. Also, the participatory approach created more willingness to facilitate other research activities, such as data collection and writing grant proposals. Effect on implementation has yet to be determined, but participatory research has persuaded them to be closely engaged with this research. We strongly believe that this is a crucial precondition to realize ownership and nurture local champions, which are highly recommended for successful and sustainable implementation (38). This study concretized ownership by showing that HCWs still require top-down support from data-, quality-, and AMR-experts to come to substantiated and sustainable improvement strategies. Rethinking ownership in terms of shared-ownership is thus required to embrace the true multidisciplinary nature of the complex wicked problems that the world faces today.

Professionalizing (reporting on) persuasive design

The bottom-up participatory approach allowed us to continuously adapt the persuasive design of the technology to HCWs' needs and contextual considerations. In the persuasive design field, the need to match user, context and technology is not new (12). However, very few studies explicitly report on how this match can be realized. This study adds to this knowledge base by demonstrating the dependencies between HCWs' needs and contextual considerations, and consecutively how the persuasive design can incorporate them. Furthermore, it showed how a bottom-up participatory approach can help in iteratively optimizing the user, context, technology fit. Crystallizing values and requirements from mixed-methods and transparently reporting on the taken steps are required to further professionalize the field of persuasive technology. Kip et al. and Van Velsen et al.

published some excellent guides on how to translate values and requirements into persuasive designs, and perhaps more importantly, showed how you can report on the development process in a structured and transparent way (31,39).

Strengths and limitations

A limitation to this bottom-up approach is that top-down considerations were mostly ignored. For example, only minimal efforts were taken to match Inspectorate audits that are performed because of legal obligations. Matching new initiatives to existing initiatives is one of the key-factors of implementation and we did take several actions to avoid 'discovering the wheel all over again'. We included top-down content by basing the discussions on existing quality-indicators from AMR-experts. Furthermore, top-down considerations were incorporated in the questionnaire and focus group schemes by including AMR-experts in our research team. Including the top-down perspective indirectly thus was an explicit choice within our larger development project, because we were interested in studying the bottom-up approach (i.e. letting the HCWs' needs and context guide the development process). Starting with a small and homogeneous target-group allowed us to gain in-depth insights at the cost of generalizability. This reflects a methodological issue apparent in all (pilot-) development processes and urges the need for local adaptations to the to-be-developed technology.

Conclusion

A bottom-up participatory development approach has the potential to improve the persuasive design of data-driven technologies and simultaneously increase engagement of end-users. This is a necessary precondition for the development of persuasive data-driven technologies that foster sustainable implementation.

Findings from the second focus group were used to redesign the prototypes, which resulted in lo-fi prototypes (screen shots) of APM-AF in its three envisioned modes by HCWs (figures 4.2, 4.3 and 4.4).

Figure 4.2. Lo-fi prototype of a quality dashboard based on findings of focus group 2 – mode: quality management

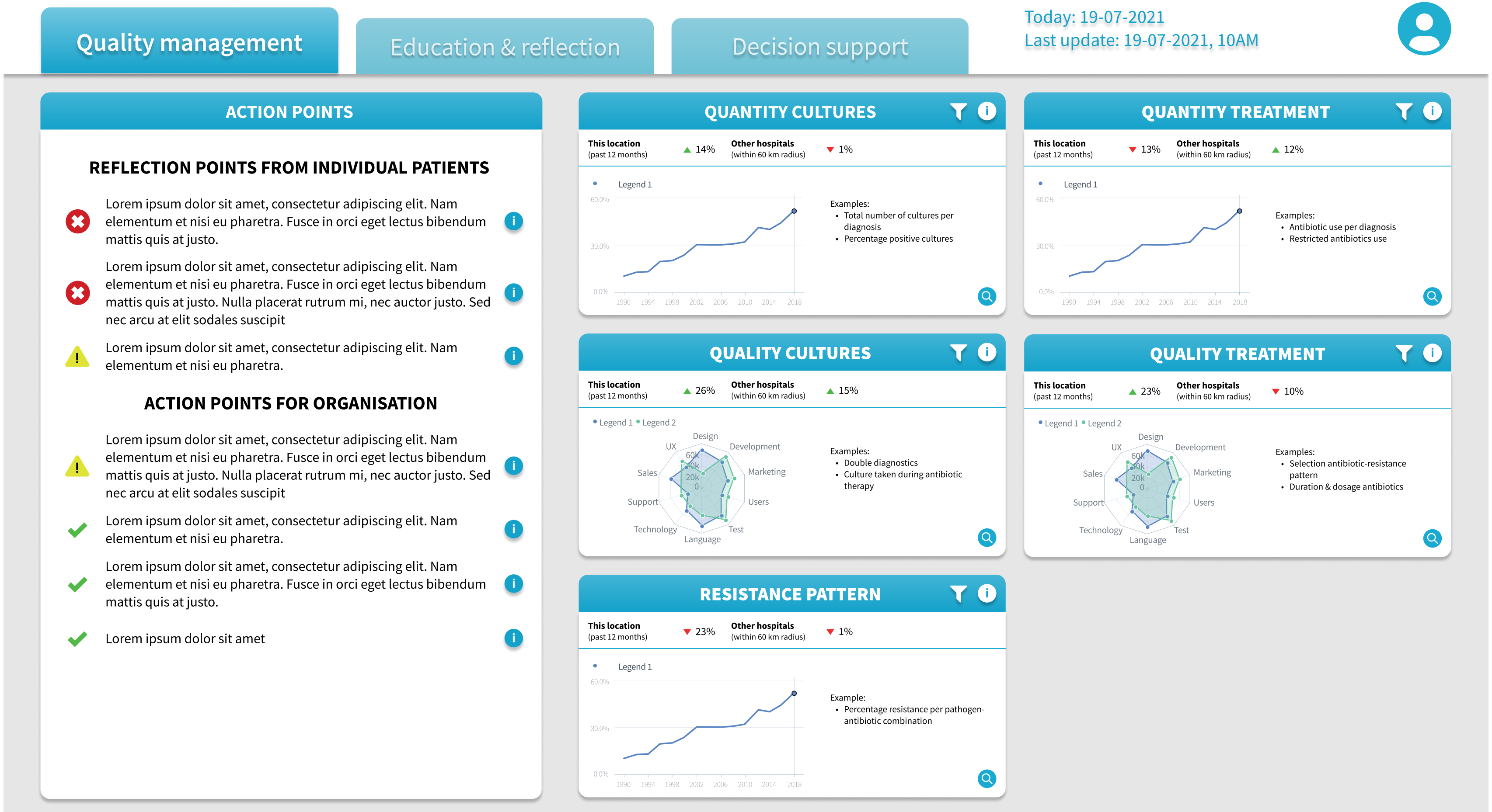


Figure 4.3. Lo-fi prototype of a quality dashboard based on findings of focus group 2 – mode: education

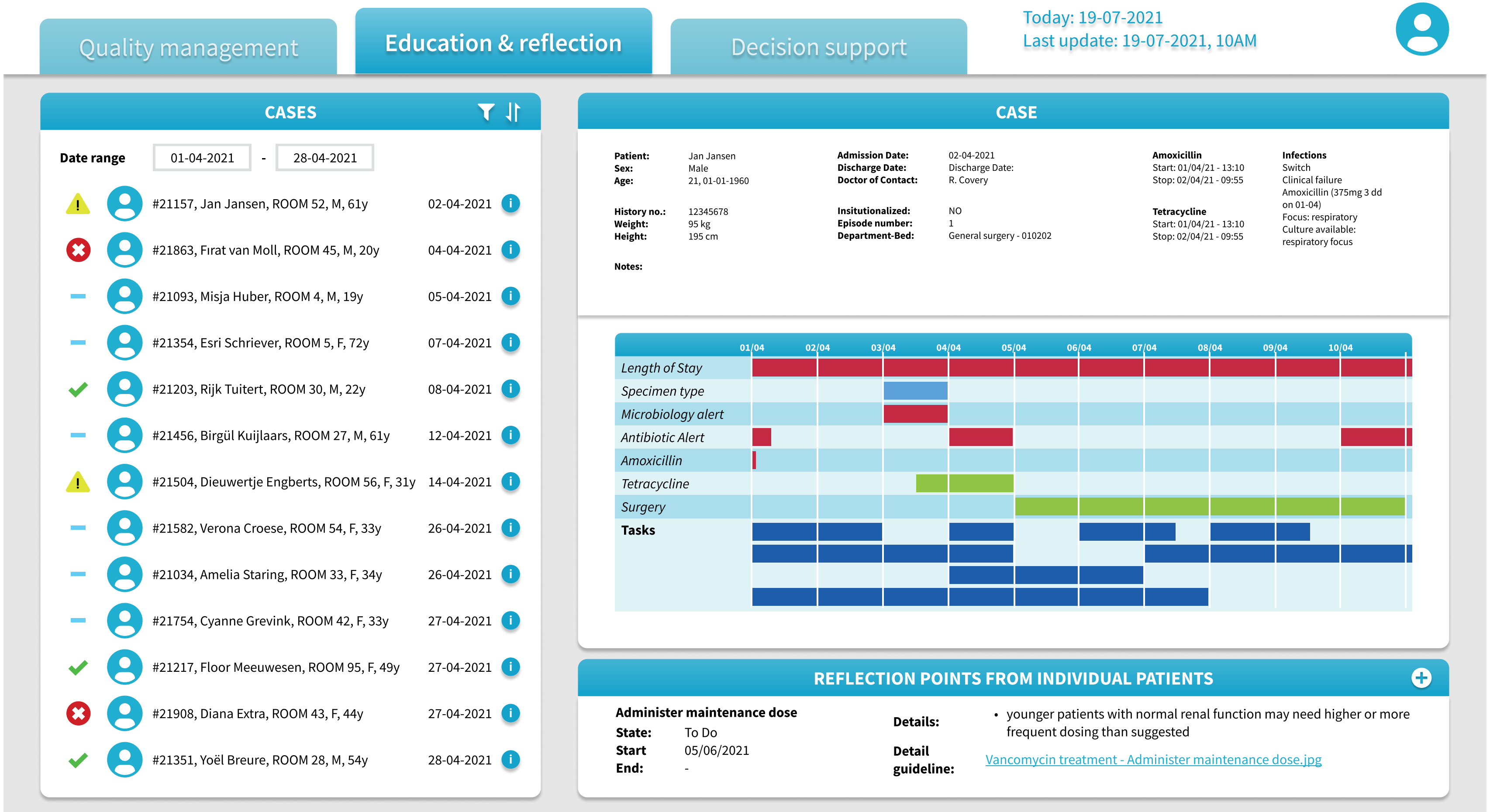
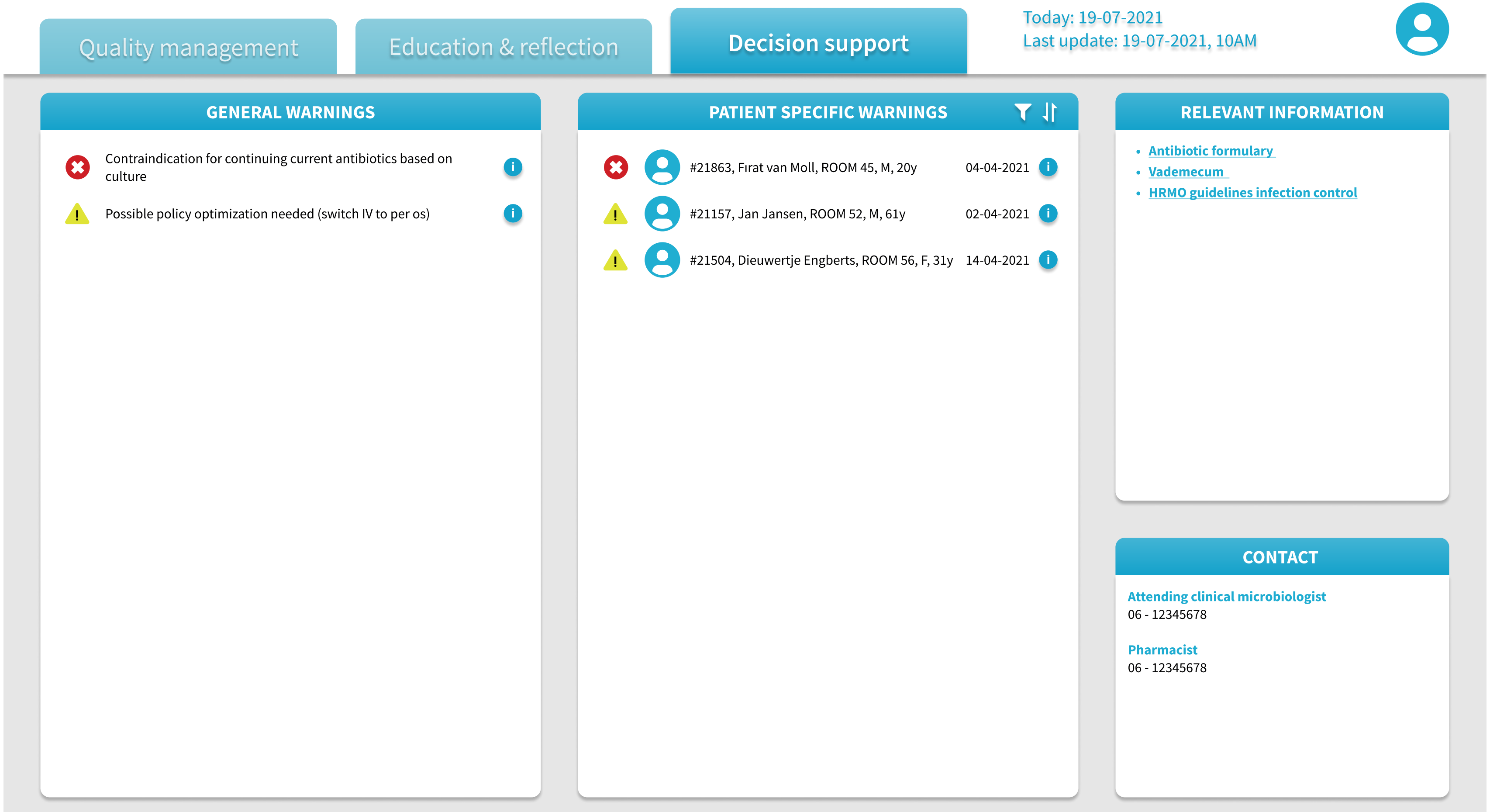


Figure 4.4. Lo-fi prototype of a quality dashboard based on findings of focus group 2 – mode: decision support



The prototypes were created by:

8D GAMES.

4

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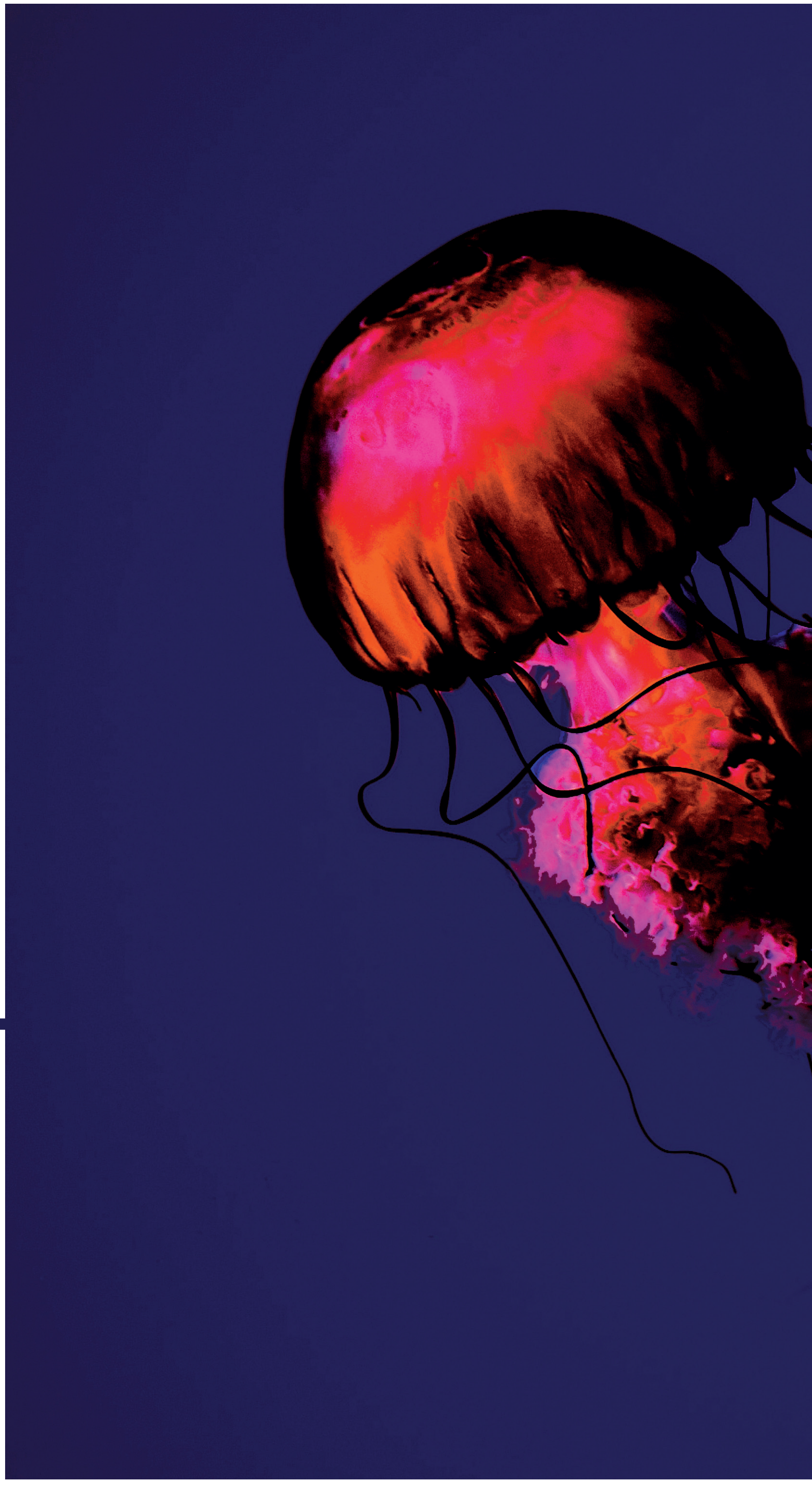
Chapter 5



The visual dictionary of antimicrobial stewardship, infection control, and institutional surveillance data

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Abstract

Objectives

Data and data visualization are integral parts of (clinical) decision-making in general and stewardship (antimicrobial stewardship, infection control, and institutional surveillance) in particular. However, systematic research on the use of data visualization in stewardship is lacking. This study aimed at filling this gap by creating a visual dictionary of stewardship through an assessment of data visualization (i.e. the graphical representation of quantitative information) in stewardship research.

Methods

A random sample of 150 data visualizations from published research articles on stewardship were assessed (excluding geographical maps and flowcharts). The visualization vocabulary (content) and design space (design elements) were combined to create a visual dictionary. Additionally, visualization errors, chart junk, and quality were assessed to identify problems in current visualizations and to provide improvement recommendations.

Results

Despite a heterogeneous use of data visualization, distinct combinations of graphical elements to reflect stewardship data were identified. In general, bar (n=54; 36.0%) and line charts (n=42; 28.1%) were preferred visualization types. Visualization problems comprised colour scheme mismatches, double y-axis, hidden data points through overlaps, and chart junk. Recommendations were derived that can help to clarify visual communication, improve colour use for grouping/stratifying, improve the display of magnitude, and match visualizations to scientific standards.

Conclusion

Results of this study can be used to guide data visualization creators in designing visualizations that fit the data and visual habits of the stewardship target audience. Additionally, the results can provide the basis to further expand the visual dictionary of stewardship towards more effective visualizations that improve data insights, knowledge, and clinical decision-making.

Introduction

The amount of and reliance on data increases with the increase of scientific publications and information technologies in healthcare (1,2). These big data raise various issues to be resolved by innovative big data analytics, including integrating, analysing, and visualizing data to translate them into meaningful information (3,4). The translation and communication to specific target groups is challenging (1). Without this translation and communication, researchers and practitioners cannot optimally use the information, so that the true value of the data remains hidden. Data visualization, here defined as the graphical representation of quantitative information, can facilitate the transformation of data to understandable and actionable information and improve memorisation and communication. Data visualization also aids in the interpretation of big data and in the understanding of sophisticated statistical models and their results - two rising trends over the last decades (5,6). The importance of data visualization can, once again, be observed in the COVID-19 pandemic with the ubiquitous presence of charts and dashboards that aim to inform and support decision-making for a wide variety of target audiences (7).

Data visualization is an active (research) field in itself and is generally part of statistical software for data analysis processes (e.g. R). Information on the data visualization process is numerous and can be transferred between research fields (8–11). However, research on the visual domain context within a research field is often lacking, i.e. what the target audience is accustomed to see and expects in terms of content and design, and how this influences the perception and interpretation of data visualizations from different perspectives (12). Common data visualization practices in a specific domain can be identified by studying the visual dictionary, which consists of the visual vocabulary and visual design space (see Figure 5.1) (13). The vocabulary represents the content in terms of visualized data attributes. The design space is “an orthogonal combination of two aspects”, namely marks (i.e. graphical elements such as points, lines and areas) and visual channels to control their appearance (i.e. aesthetic properties such as colour, size and shape) (13).

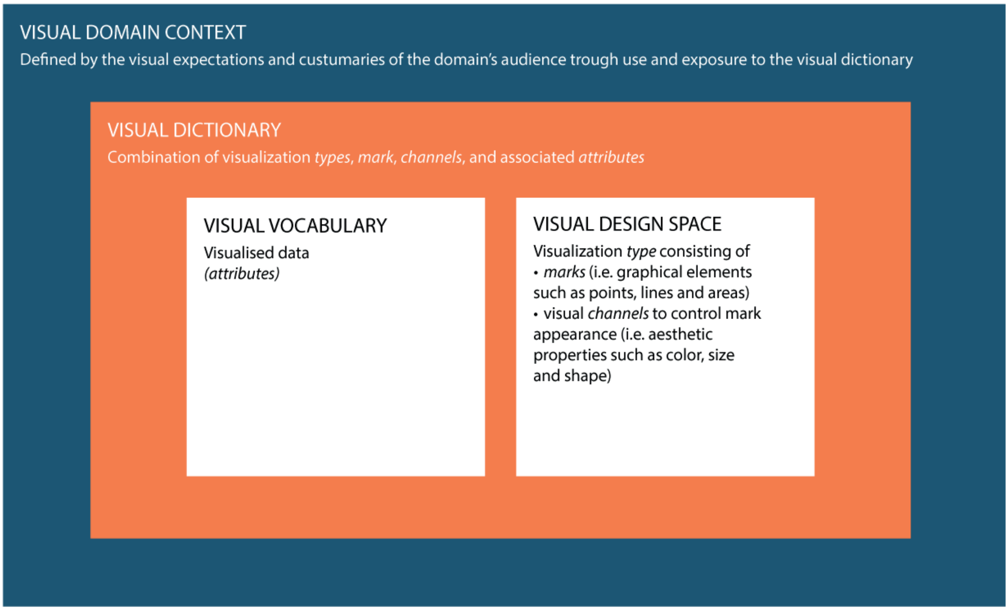

Figure 5.1. Conceptual framework used in this study to clarify the definitions and interrelations between the visual domain context, the visual dictionary and the visual domain vocabulary and visual design space. To clarify the conceptual definitions a linguistic analogy can be used: a dictionary describes language in terms of both vocabulary (i.e. the set of words familiar in a language) and grammar/punctuation (i.e. the set of structural rules and supporting marks that control the composition and navigability of sentences, phrases, and words). Similarly, the visual dictionary describes visualizations in terms of both visual vocabulary (i.e. the domain content in terms of visualized data attributes) and visual design space (i.e. graphical elements and supporting aesthetic properties). The language or visual domain context is an overarching concept that represents language/visualization in practice, i.e. expectations and customs of the target audience, and how this affects their perception and interpretation of data visualizations. The visual domain context is, just as language, subject to changes over time and subject to interpretation differences based on varying perspectives.

Data and data visualization play important parts in the field of infectious diseases and antimicrobial resistance (AMR) for the reporting on the growing burden on health and healthcare systems (14,15). Comprehensible and actionable information on antimicrobial consumption, pathogen distribution, or incidence and prevalence of (multi-) drug resistant microorganisms are vital to design interventions to tackle the AMR challenge (16). Reliable data on AMR, robust data analyses, and the correct presentation of data are essential to support crossing borders between human, animal, and ecosystem health, also known as the One Health approach. One example is the surveillance of AMR in humans, animals, and food (17). In this study, we focus on the hospital level, where antimicrobial and diagnostic stewardship, infection control, and institutional surveillance (further summarised under 'stewardship') are the core components of strategies that promote the responsible use of antimicrobials and improve the quality and safety of patient care (18,19). Data visualization is an integral part of these strategies, as it unveils the (local) situation and drivers of AMR, and can have a significant impact on the use of antimicrobials (20,21).

It has been shown how important it is to study data and data visualization experiences and perceptions in the medical domain and how this can influence the interpretation of data (22,23). Identifying the key messages from a data visualization can be substantially hindered by a suboptimal visualization type. The audience's background and its familiarity with data visualization (i.e. visual domain context) have to be considered in the design process to avoid these obstacles. Example studies that identified the visual domain context by studying the design space can be found in the field of genomic epidemiology and genomic data visualization (24,25). Although some recommendations exist that are helpful for stewardship data visualization, common data visualizations practices in the field have yet to be revealed (26,27). The visual domain context and the use of data visualization in the field are unstudied - a systematic approach to define the design space is missing.

In this study, we aim to fill these gaps by assessing and defining the design space of data visualization in stewardship and to create a visual dictionary. The results of this study can help data visualization creators, such as AMR-/data-professionals and scientists, to anticipate the visual domain context of the target audience and link it with existing recommendations for the data visualization process. This could benefit both research and clinical decision-making in the translation and communication of data to understandable and actionable information needed to tackle the AMR challenge, thereby improving the quality and safety of health and healthcare.

Methods

Study data

This study succeeds a mapping study that clustered the AMR field into 88 topics (28). The map was generated by assessing the entire body of AMR literature available on PubMed between 1999 and 2018 (152780 articles). Using a machine learning algorithm (STM), topics were identified based on the title and abstract text (29). The present study used all articles of three of the identified topics: *stewardship* (n = 3383 articles), *infection control* (n = 1687 articles), and *institutional surveillance* (n = 2176 articles). These three topics reflect the core components of an integrated, comprehensive stewardship concept in institutional healthcare (19).

For each topic, a sample of 60 articles that contained at least one data visualization was randomly drawn. Data visualization was defined as the graphical representation of quantitative data. Geographical maps and flowcharts were excluded, as geographical data have distinct visual characteristics and challenges beyond the scope of this study (see e.g. (30,31)). From the sampled articles, one visualization per article was randomly sampled resulting in 180 data visualizations. The study design is shown in Figure 5.2. To analyse inter-rater reliability, ten randomly picked data visualizations per topic were analysed in duplicate, and the joint probability of agreement was calculated by dividing the number of agreements per categorical assessment form question (i.e. visual characteristics described hereafter) by the total number of assessments (32).

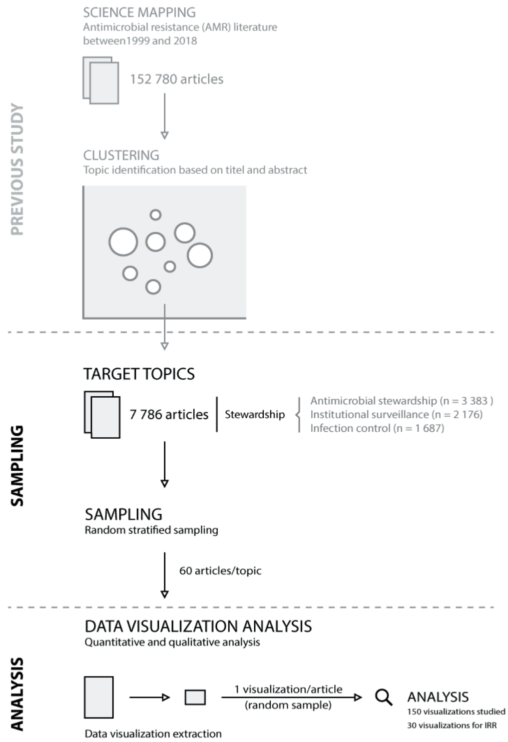

Figure 5.2. Study design. IRR = inter-rater reliability

Data visualization analysis

The resulting 150 data visualizations (supplementary materials) were analysed using the nomenclature and categorization by Munzner adapted for this study (13). This approach dissected data visualizations into visual characteristics:

- *Attributes (or variables, parameters, features)*: the underlying data labelled as categorical, ordered, or quantitative
- *Marks*: the basic geometric element (points, lines, or areas)
- *Channel:* channels control the visual appearance of *marks*
- *Position:* horizontal, vertical, both
- *Colour*
- *Shape*
- *Tilt*
- *Size:* length, area, volume
- *Channel effectiveness*

- *Magnitude:* the effectiveness to express ordered *attributes* can be ranked: position on common scale (most effective) > position on unaligned scale > length > tile/angle > area > depth > colour luminance/saturation > curvature/volume (least effective)
- *Identity:* the effectiveness to express categorical *attributes* can also be ordered: colour hue > shape

In addition, data visualizations were labelled with the visualization type used (e.g., bar chart, line chart, scatter plot, etc.) and the use of faceting (multiple linked visualizations in a design grid). Each visualization was assessed upon its interpretability without additional text (yes, if interpretable without additional information; partially, if a description was given in a caption; not at all, if a description was absent or only available in the article text).

Visualization quality was captured by rating the first and last impression during the analysis process on a scale form 1 (poor) to 5 (good). The choice of the visualization type given the underlying data was rated on a scale from 1 (poor) to 5 (good). In addition, free, written text was recorded to capture comments and remarks about the data visualization.

A structured assessment form (supplementary materials) was developed comprising all the above-mentioned elements. The form was discussed within a multidisciplinary team of data-visualization and AMR experts. The assessment form was applied to each data visualization in a two reviewer (JK, CFL) process. First, the assessment form was used for training the analysis process with ten data visualizations not part of the final study data. Next, each reviewer analysed 50% of the study data visualizations followed by a re-review through the other researcher. Consensus was reached through discussion if the first assessment differed.

Quantitative analysis

Descriptive statistics were calculated for visualization type, number of attributes, faceting, rating, and visualization type choice. *Attributes* were analysed for pairwise co-occurrence and presented if a combination occurred more than twice in total.

Visual dictionary

The visual dictionary was created based on the visual vocabulary (stewardship-related content) and visual design space (characteristics used to design the visualization). The vocabulary was analysed by identifying *attributes* and grouping the *attribute* names using inductive coding. Next, quantitative analyses of visual characteristics (*channel, marks,* etc.) were performed stratified per *attribute*, thereby adding the visual design space to the vocabulary. Linking the vocabulary and design space enabled the creation of a visual dictionary to help identify *attributes* (e.g., resistance) with associated *channels* (e.g., points and lines on a common scale).

Qualitative analysis

Comments about the visualizations were coded in Microsoft Excel by two researchers (CL and JK). An open coding round was followed by axial coding to discover related concepts in the sub-codes. Differences were discussed until consensus was reached, which increased the internal validity (33). Next to improvements, CL and JK coded remarks about chart junk (i.e. the unnecessary and/or redundant use of visualization embellishments) (11).

Results

In total, 150 visualizations were analysed (IRR: 87% joint probability of agreement). The following sections are separated into visual vocabulary (content) and dictionary with results stratified by identified *attributes*. These sections are followed by visualization ratings, identified visualization problems, and suggested recommendations for visualization creators.

Visual vocabulary (content)

In total, 48 different attributes were coded. The ten most used attributes were *time* (n=69, 46.0%), *setting* (n=43, 28.7%), *antimicrobial consumption* (n=32, 21.3%), *resistance* (n=31, 20.1%), *antimicrobials* (n=27, 18.0%), *percentage* (n=26, 17.3%), *count* (n=24, 16.0%), *incidence* (n=24, 16.0%), *numeric value* (n=20, 13.3%), and *bacteria* (n=12, 8.0%). Attributes could be grouped into objects (e.g. *bacteria*) and measurements (e.g. *percentage*). However, the following analysis focuses on attribute combinations and attributes are thus kept ungrouped.

Attributes showed different co-occurrence patterns (Figure 5.3). The ten most frequent combinations were *time* and *antimicrobial consumption* (n=21), *time* and *incidence* (n=18), *antimicrobial consumption* and *antimicrobials* (n=12), *antimicrobials* and *resistance* (n=12), *time* and *resistance* (n=12), *time* and *antimicrobials* (n=11), *antimicrobial consumption* and *setting* (n=10), *resistance* and *setting* (n=9), *time* and *setting* (n=9), and *percentage* and *setting* (n=8).

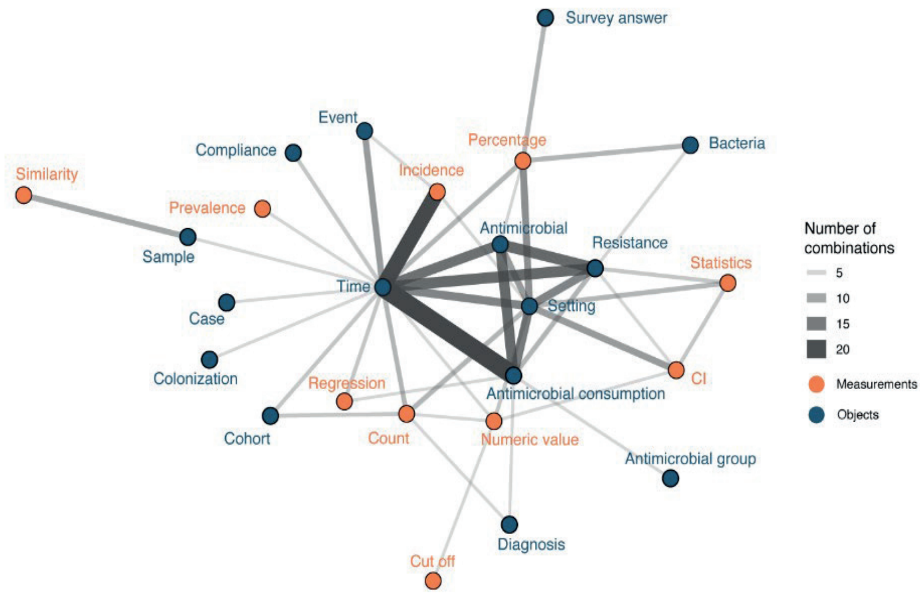

Figure 5.3. Attribute combinations in visualizations (combination count ≥ 3). Thickness of lines corresponds to combination count. Orange points and labels represent attributes related to measurements; blue points and labels represent attributes related to objects.

Visual dictionary

Visualization types

Fourteen different visualization types were identified of which bar charts (n=54, 36.0%) and line charts (n=42, 28.1%) were predominantly used. Bar charts were most frequently associated with attributes *antimicrobials, bacteria, cohorts, compliance, counts, diagnosis, errors, percentages, resistance, setting,* and *survey answers.* Line charts were predominantly associated with *antimicrobial consumption, costs, cut-off, incidence, numeric values, regression, statistics,* and *time* (detailed results available in the supplementary materials).

Different visualization types combined in one visualization were used in 10.7% (n=16) of all visualizations. In these, visualization types that were combined more than once were bar charts with line charts (n=5, 31.3%) and stacked bar charts with line charts (n=2, 12.5%). In 41 visualization (27.3%) facets were used, i.e., one visualization split into a matrix of visualizations using the same axes.

Visual design space

Different patterns of visual characteristics could be identified for different *attributes* (detailed counts and percentages in the supplementary materials).

1. Position: Horizontal axes were mostly used for *Antimicrobials, bacteria, confidence intervals, counts, cut-offs, diagnoses, events, numeric values, settings, similarity,* and *time*. In contrast, vertical axes were mostly used for *antimicrobial consumption, cases, cohorts, counts, errors, incidence, percentages, regression*, *resistance, samples, statistics,* and *survey answers.*
2. Marks, colour, shape: *Attributes* also differed in their use of marks. Some attributes had clear associations with mark types, e.g. *time* was always visualised with lines. Area marks were seldomly used, e.g. for *antimicrobial consumption, counts, cut-offs, incidence, numeric values, percentages,* and *resistance.* Colour and shape channels were frequently used in most attributes. A detailed colour and shape channel analysis is available in the supplementary materials.
3. Size: Size was most often visually reflected through length. Area to reflect size was used for *antimicrobial consumption, count, cut-off, incidence, numeric values, percentages,* and *resistance.* Volume was rarely used (for *count* and *percentages*).
4. Magnitude/ordering: Position on a common scale was mostly used in quantitative and ordered attributes reflecting the best channel effectiveness for these attribute types. Categorical attributes mostly used colour hue, which is preferred over the less effective use of shapes. A detailed channel effectiveness analysis is available in the supplementary materials.

Ratings, problems, and chart junk

Visualization ratings

Overall, 55.3% (n=83) of all visualizations were interpretable without additional text (in caption or in the manuscript text). The overall choice of visualization type was rated with a mean of 4.62 (SD: 0.9) on a scale from 1 (poor) to 5 (good). The assessment of the visualization quality (scale 1=poor to 5=good) was rated with a mean of 3.6 (SD:1.2).

Identified problems

The coding of the identified problems are presented in the coding scheme in Table 5.1, including axial codes, open codes, and frequencies. In the supplementary materials, additional illustrative quotes per code are presented.

Chart junk

Most chart junk represented text that cluttered the visualization (n=8), for example with redundant direct labels for each data point. Other chart junk was found in visualizations using unnecessary 3D (n=8), background colours (n=6), shadow (n=4), and colour/shape filling (n=4).

Examples and recommendations

To illustrate problems in data visualization, we designed a visualization that exhibits several of the identified problems based on simulated data (Figure 5.4). Figure 5.5 proposes an alternative to Figure 5.4 where the identified problems were avoided. Of note, data such as the simulated data in these figures can be visualised in many different ways, depending on the underlying research questions.

Table 5.1. Identified problems in data visualization

Code (axial)	Code (open)	Count	Subtotal
Missing labels, annotations, legend and/or abbreviation explanations	Legend/caption is missing/unclear	26	102
	Labels for lines/points are missing/unclear	23	
	Labels for axes are missing/unclear	20	
	Annotation/direct labelling overflow	14	
	Abbreviations not explained	12	
	Use of colours not explained	7	
Axes not readable	Axis intervals uneven (within visualization and between faceted visualizations)	17	35
	Axes texts not clearly readable	11	
	Too short/dense axes/intervals	5	
	Uneven bar placement	1	
	Axis intervals illogical (within visualization and between faceted visualizations)	1	
Colour scheme mismatch	Groups not distinguishable by colours	14	27
	Non-intuitive colour schemes used	6	
	Categorical colours used for ordered attribute	5	
	Groups not distinguishable from background	2	
Hidden data points by overlaps	Overlap of shapes problematic	7	7
Using suboptimal channel effectiveness	Groups not distinguishable by shapes	12	15
	Sub-effective channel is chosen	3	
Size scale indistinguishable	Differences in size not clear	10	15
	Groups not distinguishable by shape size	3	
	Contrasts between groups not clear	2	
Missing channel	Line types not used to distinguish between groups	2	4
	Colours not used to compare between visualization/groups	2	
Visualization type does not (optimally) fit data	Other visualization type preferred	21	21
Data points/lines on double axes	Double Y-axes difficult to read	11	11
Channel overflow	Double use of shape and colour	8	11
	Unnecessary use of shape sizes	1	
	Unnecessary use of colour	1	
	Too many colours	1	
Attribute overflow	Too many attributes	2	3
	Relating attributes that are not related	1	
Information sparsity	Could be text	1	1
Incoherent ordering	Data not ordered coherently	1	1
	Grand total	253	

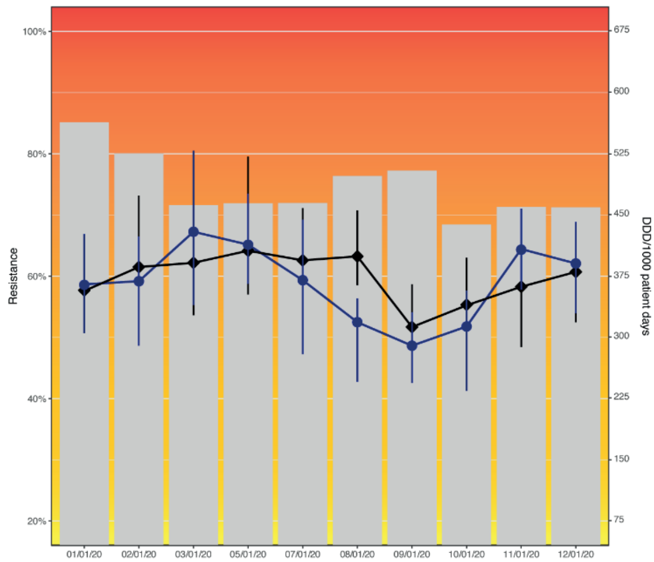

Figure 5.4. Resistance to amoxicillin in Escherichia coli and consumption of cefuroxime (black) and piperacillin/tazobactam (blue) across hospital departments in 2020. This data visualization (simulated data) shows several problems identified in this study: Axes not starting at zero, use of double y-axes, background colours, hidden data points by overlaps, colour scheme mismatch (blue and black difficult to distinguish), unequal axis steps on x-axis, missing legend, incomplete axis labels (abbreviation not explained).

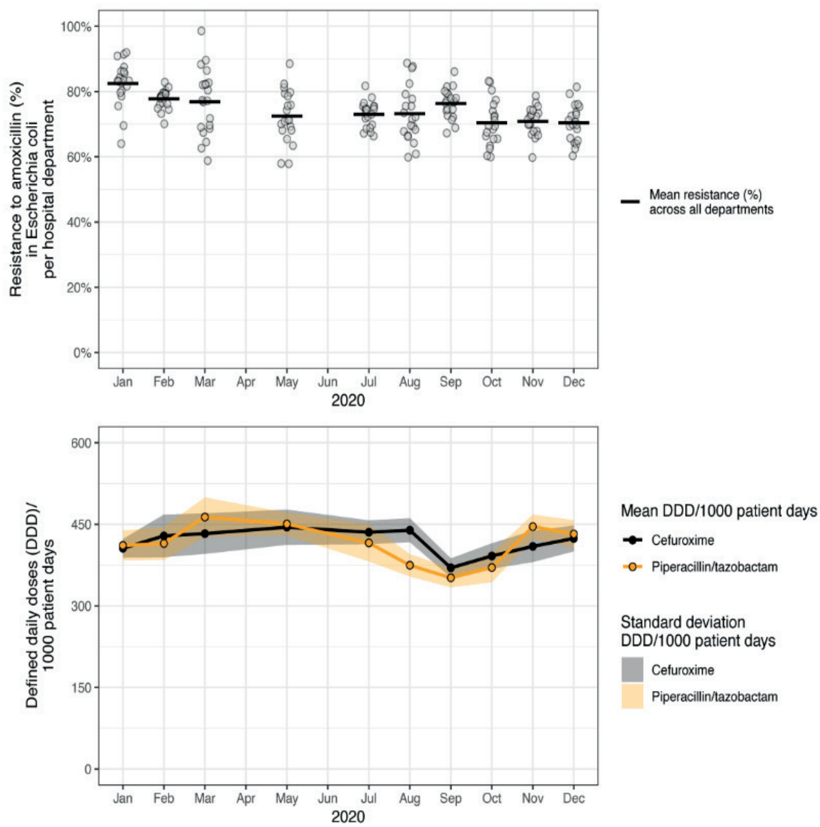

Figure 5.5. Resistance to amoxicillin in Escherichia coli and consumption of cefuroxime and piperacillin/tazobactam across hospital departments in 2020. These data visualizations use the same data as in Figure 5.4 (simulated data), but propose an improved visualization.

Figure 5.6 summarises the results of this study and presents the visual dictionary of stewardship. In addition, it provides a set of recommendations to avoid the most common problems in data visualizations as identified in this study.

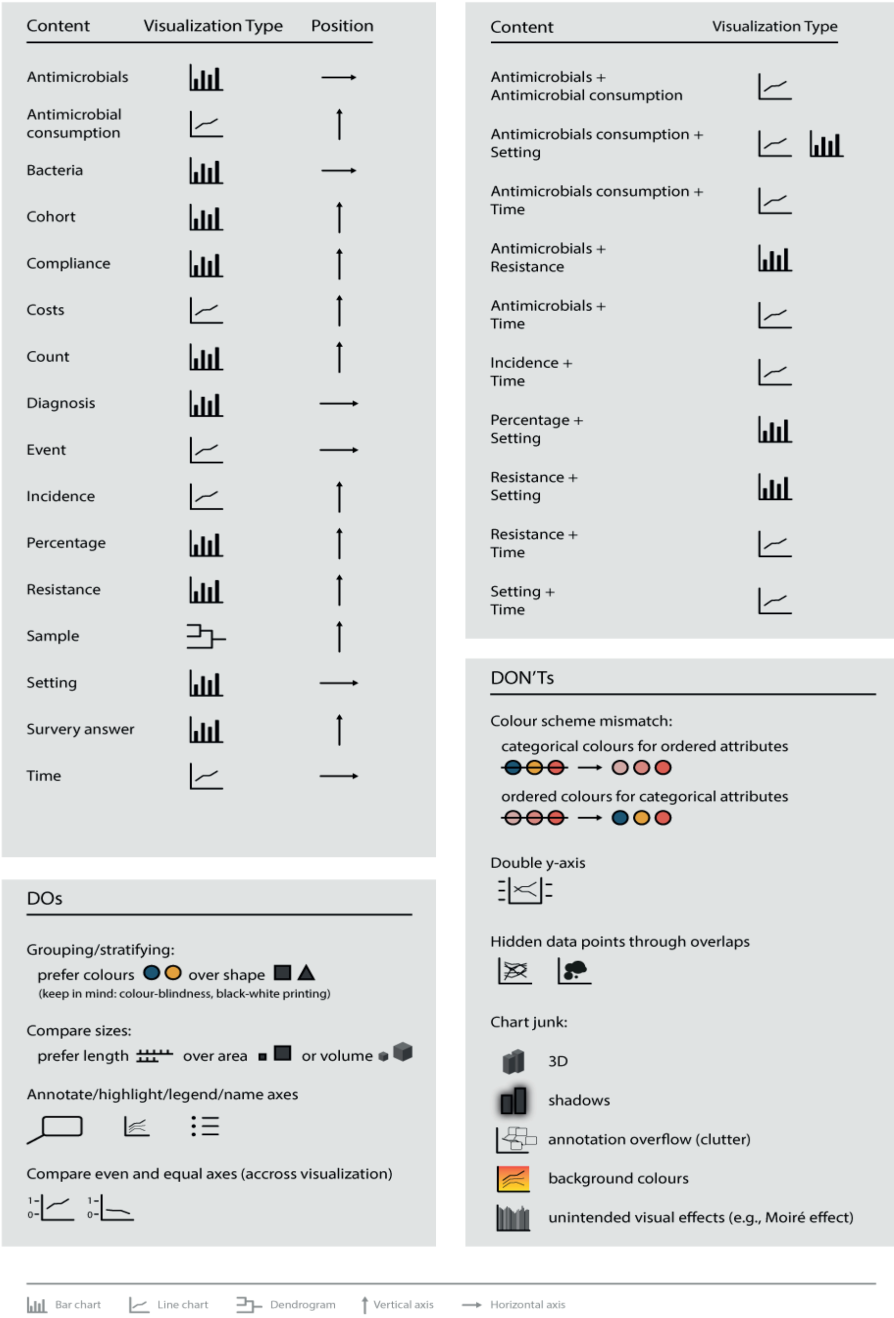

Figure 5.6. The visual dictionary of stewardship (antimicrobial stewardship, infection control, and institutional surveillance)

Discussion

This study systematically analysed the visual domain context of stewardship, i.e. antimicrobial stewardship, infection control, and institutional surveillance. Stewardship experts and scientists that create data visualizations can benefit from the revealed visual domain context, since it allows them to anticipate the visual habits of their target audience. The results of this study can serve as the basis to inform visualization creators to optimise visual communication in the field and to guide user-centred design, e.g., in clinical decision support systems.

Findings and future directions

With the systematic analysis of the visual domain context of stewardship we revealed common practices and identified problems with current implemented visualizations. In general, the use of data visualizations for communicating data is highly encouraged. It greatly supports the interpretation, memorisation, and communication of insights and knowledge gained from data. In this study, we identified 14 different visualization types used in the visual domain context of the field. However, more than 80% of all visualizations used classical (stacked) bar or line charts; quite homogenous design choices. We argue that the visualization type choice is based on tradition and habits as a systematic approach to data visualization in the field was missing until now (27). A lack of awareness and knowledge about data visualization design and design alternatives might lead to suboptimal data visualizations. Examples from our findings were the use of less effective visual channels, suboptimal plot types for the presented data, or mismatches in colour choices for different data types. Similar visualization pitfalls were identified in studies focusing on common visualization pitfalls in multidisciplinary research related to visual representations and for environmental data, emphasizing instances where data visualization creators require more support in visualization design choices (10,34). Now that we revealed common data visualization practice in the visual dictionary for stewardship by linking often used attributes (i.e. content) and associated design choices (e.g. visualization type or marks), visualization creators in the field can match their visualizations with the audience's visual expectations and habits.

However, given the wide variety of data in the field and the increased complexity that big data will add (in terms of volume, velocity, variety, veracity, validity, volatility and value), more "visual variability" might be expected and even needed in the future (3,35,36). A first step towards visual variability is informing and teaching visualization creators and users about data visualization design alternatives. We see a clear role here for data visualization experts and software developers to cocreate open-source/access tools that support visualization creators in their visualization choices (e.g. reminders for adding labels and legends, suggestions for optimal colour schemes, warnings in case of chart junk). Our results and findings from similar studies in other fields can support them in doing so by providing an overview of common data visualization practice in the field, including dos and don'ts (24,25).

Of note, academic journals play an important part in this process by providing the platform for data visualizations and should be encouraged to promote high quality data visualization practices. Furthermore, it could be worth considering standardising data visualization for often used data types and contents in the field, given the prominent patterns in the visual dictionary (e.g. time series were part of 43.3% of all studied visualizations) within the large variety of content (48 different attributes such as antimicrobials, bacteria, or time) observed in this study. For time series specifically, an overview of data visualization methods exists (37) and similar standardizing initiatives can be found in the AMR field (e.g. European Committee of Antimicrobial Susceptibility Testing (EUCAST) (38)) and other fields (e.g. the Intergovernmental Panel on Climate Change (IPCC) and standardized medical data visualization based on the ISO13606 data model (39,40)). This could help ensure high quality data visualizations for reliable insights in AMR/stewardship related data.

In the light of growing complexities and increasing data volumes, genomic data and their visualization play a special role in the field. Although genomic data visualizations were included in this study, most visualizations were simple dendrograms and phylogenetic trees. As with the a priori excluded geographical data, these complex data require dedicated research and visualization techniques which are provided in great detail by others (see e.g. (24,25)). An additional important aspect for high quality data visualization in the stewardship and AMR data field is the visualization of uncertainties. The visualization of uncertainties was not within the scope of this study and further research into the optimal display of uncertainty is highly encourage. For more information and readers are referred to the work of others (41–43).

Studying the visual domain context is as important as studying data visualizations themselves. The importance of assessing visual habits and perceptions in data visualization has been demonstrated before in other medical fields revealing that personal preferences and visualization habits might not always match with novel data visualization approaches and recommendations (22,44). Aung *et al.* published an exemplary study in the field of reproductive, maternal, new-born and child health, focusing on data visualization interpretation capacity and preferences in their target audience by combining interviews on interpretability and card-sorting of preferred visualizations (22). Thus, for data visualization in general we strongly believe that incorporating best practices is essential, but advocate that these should be carefully balanced with visual habits and expectations in the field and the message to be conveyed. Additionally, research is needed to better understand how data visualizations in general impact the viewers in terms of changes in opinions or attitudes that direct decision-making or behaviour changes (45).

Limitations and strengths

In future research special attention should be paid to matching the visual dictionary and the context in which the visualization will be used in terms of users, their tasks and current practices (e.g. studying questions like ""How do current visualizations support to do current tasks?" and "What visualizations would the target audience like to see?") (46). This also includes colour-blindness considerations, as extensively studied by others (47–49).

We see a clear parallel with user-centred eHealth design that emphasises the need for a holistic understanding of the interrelations between technology, people, and their context (50). Both qualitative (e.g. interviews) and quantitative (e.g. eye-tracking in current data visualizations) study designs can contribute to such a holistic understanding, which in turn can inform or improve the design of visualizations (or eHealth) in terms of required content, functionalities, and usability (51). Therefore, complementing research on data visualizations, as the current study and many other studies do, with research that primarily focuses on the interaction between people, their context and how data visualizations can support them, is needed (46).

This study has several limitations. Despite sampling from a comprehensive set of articles that cover the stewardship field, only a limited number of data visualizations were included. Moreover, only data visualizations from scientific publications and not from other sources relevant to stewardship data visualization creators (e.g. data systems used in practice (12,52) and AMR policy reports (53,54)) were included. Therefore, we missed data visualizations for other stewardship content, making our findings potentially more applicable to stewardship researchers than healthcare professionals. However, the observed homogeneity of data visualization types suggests saturation regarding the visual design space for stewardship. Subsequent research into the visual domain context of stewardship should include these additional sources to ensure a more comprehensive picture for healthcare professionals. Even though the extracted data visualizations were systematically analysed using a structured assessment form based on existing data visualization nomenclature and categorization (13), the analyses relied on the subjective interpretation and rating by the coding researchers. Several measures were taken to validate our findings, including discussing the assessment form and results within a multidisciplinary team of data-visualization and AMR experts, analysing the interrater-reliability, and comparing our findings to other data visualization studies. Our study is one of the first empirical studies that explores the use of data visualization in stewardship, thereby adding to the few review studies providing primers for data visualization recommendations and best practices in the stewardship field (26,27). Furthermore, our structured assessment approach can be applied in future studies in the broader One Health field to unravel the visual dictionary of the fields of human, animal, and ecosystem health, considering interdisciplinary differences in data and data visualizations and their integration and interpretation (17,55,56).

Conclusion

In this study, we analysed the visual domain context of stewardship (antimicrobial stewardship, infection control, and institutional surveillance). We successfully created a visual dictionary that can support the process of creating and using tailor-made data visualizations in the field. Thereby, our results allow data visualization creators to learn the *visual language* of the diverse field of stewardship. As data-driven solutions for stewardship are of increasing importance, effective processes of transforming this data to insights and knowledge is essential. Data visualization supports and enables this transformation and our results can guide the optimal visualization design choices that are grounded on expectations and habits in the field. In the future, our study can provide the basis to further expand the visual dictionary of antimicrobial stewardship towards more effective data visualizations that improve data insights, knowledge, and decision-making.

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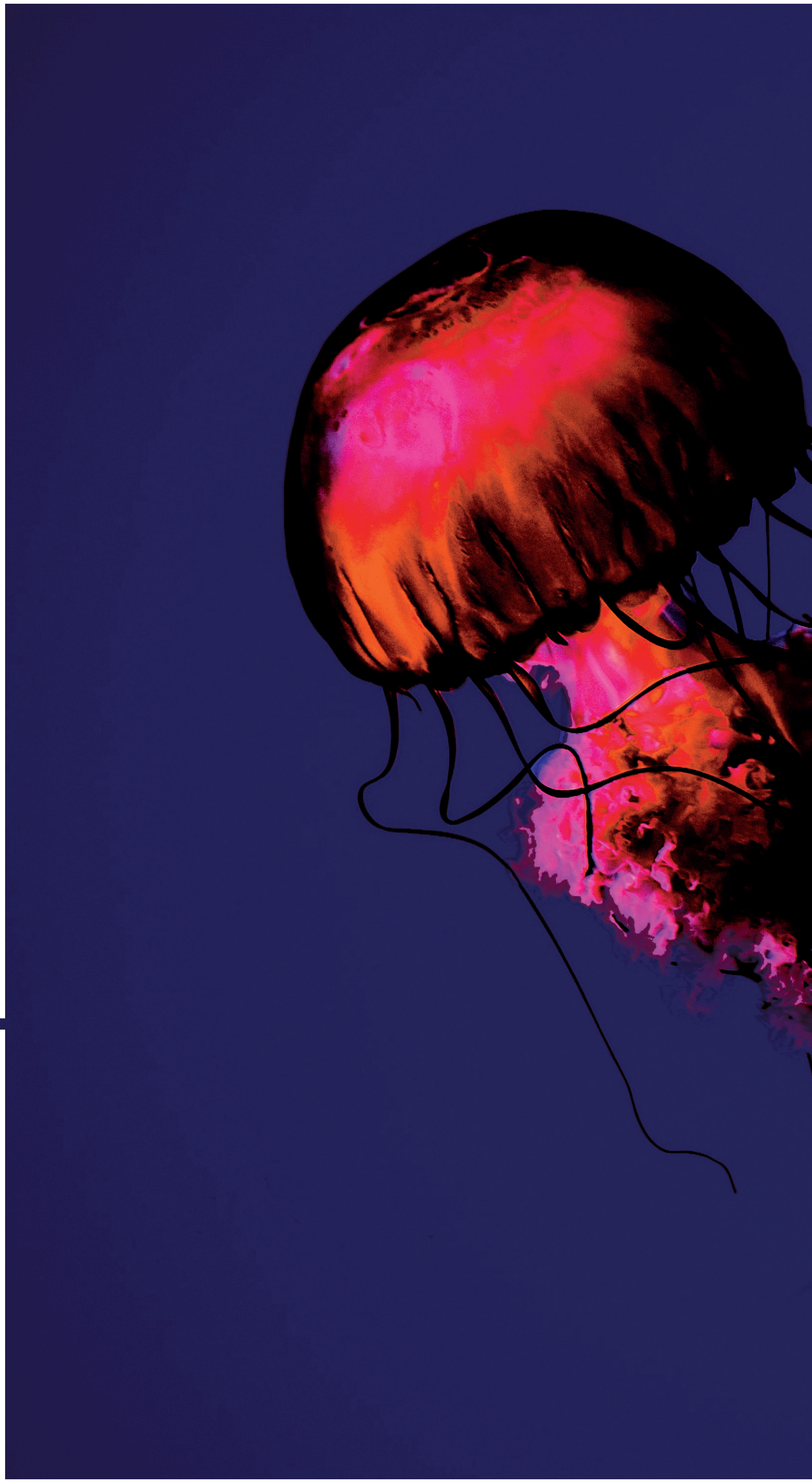
Part 3

Towards a framework for the development and implementation of audit and feedback systems for AMR stewardship

Chapter 6



Improving the development and implementation of audit and feedback systems to support healthcare workers in limiting antimicrobial resistance in the hospital: a scoping review

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Abstract

Background

For eHealth technologies in general, and audit and feedback (AF) systems specifically, integrating interdisciplinary theoretical underpinnings is essential as it increases the likelihood of achieving desired outcomes by ensuring a fit between the eHealth technology, stakeholders, and their context. Additionally, reporting on the development and implementation process of AF systems, including substantiations of choices, enables the identification of best practices and accumulation of knowledge across studies, yet is often not elaborated on in publications.

Objective

Therefore, this scoping review aims to 1) provide insights in development and implementation strategies for AF systems for a real-world problem that threatens modern healthcare care: antimicrobial resistance (AMR), and 2) provide an interdisciplinary conceptual framework that can serve as a checklist and guidance to make informed choices in the development and implementation of future AF systems.

Methods

A scoping review was conducted by querying PubMed, Scopus, Web of Science, IEEE Xplore Digital Library, and EMBASE (≥2010) for studies describing the development and/or implementation process of an audit and feedback system for AMR or infections in hospitals. Studies reporting on effectiveness or impact only were excluded. Three independent reviewers performed study selection, and two reviewers constructed the conceptual framework through axial and selective coding of often used theories, models and frameworks (TMFs) from literature on AF and eHealth development and implementation. Subsequently, the conceptual framework was used for the systematic extraction and interpretation of studies' descriptions of the AF systems and their development and implementation.

Results

The search resulted in 2125 studies screened for eligibility, of which 12 studies (2012-2020) were included. These studies described the development and/or implementation processes heterogeneously in terms of study aims, study targets,

target groups, methods, and theoretical underpinnings. Few studies explicitly explained how choices for the development and implementation of AF-systems were substantiated by the TMFs. The conceptual framework provided insights in what is reported on the development and implementation process and revealed underreported AF system constructs (e.g. AF system design, engagement with the AF system, and comparison, goal setting and action planning), and development and implementation (e.g. champions) constructs.

Discussion

This scoping review showed current heterogeneous reporting of AF systems and their development and implementation processes and exemplified how interdisciplinary TMFs can (and should) be balanced in a conceptual framework to capture relevant AF system and development/implementation constructs. Thereby, it provides a concrete checklist and overall guidance that supports the professionalization and harmonization of AF system development and implementation. For the development and implementation of future AF-systems, and other eHealth technologies, researchers and HCWs should be supported in selecting and integrating TMFs into their development and implementation process and encouraged to explicitly report on theoretical underpinnings and substantiation of choices.

Introduction

Audit and feedback (AF) is a common reflective approach for various healthcare targets, but reported effects are small to moderate (1). With the increase of electronically available data in healthcare, there is great potential for electronic AF systems (2). The effectiveness of AF systems depends on the targeted behavior and the content, delivery, and context of AF and the system (1,3–6). These constructs are often studied after AF system development and implementation to evaluate strategies and their success ingredients (7–10). In literature, less attention is paid to the development and implementation processes of AF systems (3), as is also common in the broader field of electronic health (eHealth) (11,12).

The development process of eHealth can refer to the entire, iterative process of developing an eHealth technology, from (pre-)design to implementation and (summative) evaluation (13). However, in this study we focus on the process from predesign and design (referred to hereafter as development), and implementation, including formative evaluation cycles. This allows us to focus on the early stages of implementation and development that are truly intertwined, as potential implementation issues (e.g. limited eHealth skills) should be accounted for early in the development process to avoid well-known pitfalls of stakeholder and context disregard (14). These phases are entwined by iterative formative evaluation cycles that provide ongoing information on how to improve both the eHealth technology and the development process taking (13).

Development and implementation are essential to gain a profound understanding of relevant stakeholders, their think- and work-processes, and their context (including implementation factors). Without this understanding, a misfit between technology, context and people is likely to occur, which decreases the effectivity and efficiency of eHealth in practice (13). It is crucial to consider these constructs from the start of the development and implementation process to avoid common pitfalls in current AF, such as top-down expert-driven audits with feedback on hospital-level, rather than personalized actionable feedback that supports healthcare workers (HCWs) in improving the quality and safety of healthcare (15,16).

The application of theories, models, and frameworks (TMFs) is advocated as an integral part of eHealth development and implementation as it identifies what works for whom, why, how and when, likely resulting in eHealth technology that achieves the desired outcomes (17). Colquhoun et al. and Tuti et al. reported that only 9% (n=140) and 29% (n=7) of included studies in their systematic reviews explicitly used theory to inform AF development and design (2,18). Thereby, implicit assumptions about AF working mechanisms and effective AF systems have driven AF development. Even though these assumptions might hold true, they were not informed by theory (18,19), while there is a clear link between TMFs and eHealth intervention effectiveness (20,21).

To study the development and implementation of AF, this scoping review focuses on a real-world wicked problem: antimicrobial resistance (AMR). AMR poses an increasing threat to human health and the durability of modern healthcare (22). By 2050 AMR is expected to cause more yearly deaths worldwide than cancer currently does (23). Antimicrobial and diagnostic stewardship programs and infection control programs form an integrated approach of AMR prevention measures (APM) that aim to reduce and prevent the burden of AMR in hospitals (24). Previous studies on HCWs' needs for APM support showed that changing HCWs' beliefs about their contribution to limiting AMR should be an important aim of APM strategies, rather than merely focusing on raising AMR awareness or influencing ad-hoc decisions (25,26). To do so, learning through reflective cycles provides the opportunity to change HCWs' behaviors by giving them insight in their own behavior and improvement possibilities (15,27). Therefore, audit and feedback for APM (APM-AF) is a promising strategy in the fight against AMR, although it is currently underused and understudied in the field of AMR (7).

There is a clear link between the use of TMFs and APM effectiveness (28–31), and because of the interdisciplinary nature of APM and eHealth, approaches for the development and implementation are grounded in a plethora of TMFs (32). In particular, APM-AF combines behavior change techniques (28–31), participatory eHealth development (33), human-centred and persuasive design (34–37), and improvement (38) and implementation (39) science. Moreover, TMFs have emerged for AF itself (e.g. actionable feedback and feedback intervention theory (3–6)), and in the field of AMR (e.g. integrated stewardship model (16,24,40)). Combining these TMFs into a conceptual framework that guides the development and implementation of APM-AF is challenging, and there is little guidance on how to create such interdisciplinary conceptual frameworks (41,42).

There seems to be no standardized way to (theoretically) substantiate choices for and report on the development and implementation of AF systems, which hinders the identification of best practices and knowledge accumulation (10,43). Whereas other reviews on AF have mainly focused on the effectiveness of AF systems (1,2), this scoping review focuses on the development and implementation process to further harmonize and professionalize AF system development and implementation. The aim of this study is to gain insight in the development and implementation strategies for APM-AF systems by answering the following research questions (RQs):

1) What studies have been conducted so far to study the development and implementation of APM-AF systems?
2) What theories, models and frameworks are used and described in studies on the development and implementation processes of APM-AF systems?

3) What information is reported on APM-AF systems and how are choices substantiated?
4) What information is reported on the development and implementation processes of APM-AF systems and how are choices substantiated?
5) What are lessons learned for the development and implementation of APM-AF systems?

To allow for an evidence synthesis of information on the development and implementation of APM-AF, and because of the explorative aim and research questions in this study, a scoping review is preferred over a systematic literature review (44,45). This scoping review provides an interdisciplinary conceptual framework that supports researchers, healthcare workers and policymakers to make informed choices in APM-AF system development and implementation, with the aim to reduce the burden of AMR and improve the quality and safety of healthcare.

Methods

The PRISMA extension for Scoping Reviews was used to report on this scoping review without prior registered review protocol (46). The current scoping review was designed by a multidisciplinary research team comprising of AMR and eHealth experts.

Eligibility criteria

Studies were included if 1) they describe the development and implementation process of an AF system (incl. monitoring and surveillance systems), 2) the system provides feedback to HCWs, and 3) the system targets AMR and infections in hospitals. A more elaborate description of development and implementation is provided in the supplementary materials. We define AF systems as any system that comprises both audit and feedback, wherein at least one of them (audit and/or feedback) is delivered or enhanced through the Internet and related technologies (47). Because reporting on eHealth development and implementation processes is highly heterogeneous, there were no requirements for specific TMFs, methods, or eHealth technologies. Reviews and poster abstracts were excluded, as were studies outside the hospital setting. Evaluation studies that only reported on APM-AF effectiveness and impact without reporting on development and implementation were excluded. However, constructs of formative evaluation (defined as "activities throughout the entire development process that provide ongoing information on how to improve the development process, outcomes of activities and eHealth technology" (13)) were included, since it is intertwined throughout the eHealth development and implementation process. A full list of eligibility criteria can be found in the supplementary materials.

Information sources, search, and selection of evidence

A comprehensive and systematic literature search in PubMed, Scopus, Web of Science, IEEE Xplore Digital Library, and EMBASE was conducted without language restrictions. Only studies published in and after 2010 were considered, as both eHealth development/implementation and AMR/APM are rapidly advancing fields. Databases were queried by JK on November 2, 2020, except for EMBASE, which was queried on January 28, 2021. Together with an information specialist, AMR experts, and eHealth researchers, a structured query was constructed consisting of the terms: audit OR monitor OR surveillance AND feedback AND develop* OR implement* AND infection OR antib* OR antimicrobial OR resistance. Results were uploaded to the Covidence Web-based software platform (Veritas Health Innovation Ltd), where duplicates were removed. Sources of evidence were selected in a thorough screening process including title and abstract screening, and full-text screening by three researchers independently (JK, BB and NBJ). After each round, conflicts were discussed until consensus was reached.

Data charting process

To chart the data, JK created a data extraction form (supplementary materials) in Microsoft Excel. General study characteristics extracted were first author, year, journal, country, study aims, targets and target groups, study design and method(s), and theoretical underpinning. Given the heterogeneous study approaches and theoretical underpinnings of the included studies a comprehensive overarching conceptual framework was needed to systematically analyze relevant constructs. The conceptual framework was grounded in often used TMFs and best practices from various scientific perspectives on AF (3–5,18), and for the description, development and implementation of eHealth interventions in general (2,43,48–50). These TMFs and best practices were merged via an iterative axial and selective coding process by JK and NBdJ. Thereby, overlapping and complementary constructs from the various scientific perspectives were revealed. To structure all constructs, a distinction was made between constructs for APM-AF systems (n=41, RQ3), and constructs for development and implementation (n=35, RQ4).

The data extraction form was discussed within the research team, piloted, and iteratively refined throughout the assessment process. Note that this conceptual framework should be merely seen as an analytic frame for an organized way of thinking about and reporting on APM-AF systems from various perspectives, and not as a theory explaining or predicting possible interrelations and outcomes.

Synthesis of results

The main researcher (JK) read all full texts and systematically extracted data using the data extraction form. Studies were scored with a "+" for a comprehensive, a "~" for an incomplete, and a "-" for a missing description for each data field. Descriptions were copied from the studies and further summarized per data field by describing variations between studies (i.e. axial coding). In this process, data fields described by none of the studies were omitted (supplementary materials), and other overlapping fields were combined. This reduced the number of data fields for APM-AF systems to n=29. The translation and summarization of extracted data into results were discussed in various rounds within the research team. Because of the heterogeneity and qualitative nature of included study designs, the richness and relevance of the (contextual) information was believed to be more important than study quality. Therefore, no quality appraisal was performed (51).

Results

Study selection

The literature search resulted in 3592 potentially relevant abstracts. After removing 1467 duplicates, 2125 unique titles and abstracts were assessed (figure 6.1), which resulted in eligibility assessment of 58 full texts. Main reasons for exclusion were a lack of information on development/implementation and evaluation studies (without reporting on development and implementation).

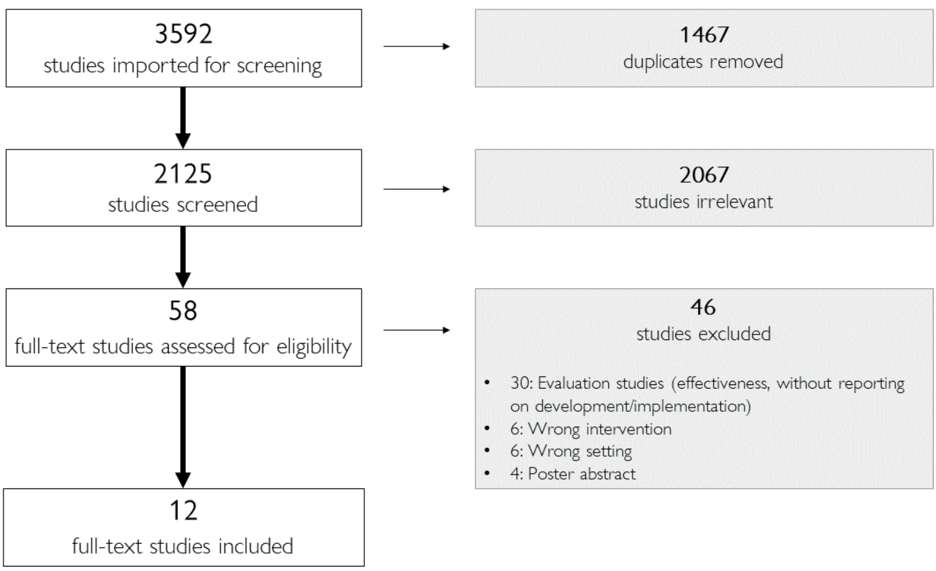

Figure 6.1. PRISMA flowchart of in- and excluded studies including reasons for exclusion

Current state of literature addressing APM-AF development and implementation (RQ1)

Study characteristics

In total, 12 papers were included in this review (2012-2020), mostly from PubMed, Scopus, and Web of Science. Publications came from Northern-American (n=6) or European (n=4) countries, and Australia (n=2). Included studies stemmed from journals in various research fields (e.g. infections or implementation science). Studies described APM-AF systems that were either in (preparation of) development or already implemented in practice, resulting in a wide variety of study aims, study targets, target groups, study designs, and used methods (table 6.1).

Study aims

Four studies primarily focused on development, four studies on implementation and four studies described both development and implementation. However, development and implementation appeared to be undefined concepts, with "implementation" studies describing development and design constructs, and "development" studies paying attention to implementation constructs. Studies aimed at describing APM-AF system development focusing on 1) the integration of TMFs (e.g. Feedback Intervention Theory), 2) AF content and presentation (e.g. feedback gamification), or 3) technical aspects (e.g. suitable badges for hand hygiene monitoring). Additionally, studies focused on implementation barriers and facilitators.

Study targets and target groups

Eleven studies focused on one of the APM (i.e. diagnostic stewardship program, antimicrobial stewardship program or infection control program), while one study targeted multiple APM. The target groups consisted of a variety of HCWs (both frontline staff and AMR experts; n=8), and in some studies also administrators and/or managers (n=4).

Study design and method(s)

Most studies (n=10) used multiple methods, complementing quantitative (e.g. questionnaires) with qualitative data (e.g. observations, interviews and focus groups). Two studies were fully qualitative relying on interviews and focus groups.

Table 6.1. Study characteristics (continued on next pages)

Author, year, country	Journal	Study aims	Study targets	Target group	Study design and method(s)	Theoretical underpinning
Boscart 2012 Canada (52)	Implementation Science	To identify nurses' and administrators' perceived barriers and facilitators to current HH practices and the implementation of a new electronic monitoring technology for HH.	ICP/HAI: Hand hygiene (improving HH compliance).	Nurses & administrators	Qualitative: • Semi structured key informant interviews	Theoretical Domains Framework
Conway 2014 USA (53)	The Joint Commission Journal on Quality and Patient Safety	To describe the implementation of an automated group monitoring and feedback system for promoting HH among healthcare professionals and report its impact on the frequency of HH at a community hospital.	ICP/HAI: Hand hygiene (increase HH frequency).	HCWs (e.g. nurses & respiratory therapists), administrators & managers	Multiple methods: • Quantitative: before-and-after study on HH events per patient-hour (outcome) • Qualitative: focus groups	Model of Actionable Feedback
Edmisten 2017 USA (54)	American Journal of Infection Control	To describe the implementation of an electronic HH monitoring system in 3 community hospitals, including the challenges and drivers of success and the maintenance activities needed for continued improvements in compliance with HH practices.	ICP/HAI: Hand hygiene (improving HH compliance).	HCWs, staff, unit/ department directors & facility management	Multiple methods: • Quantitative: after study (outcome measures on HH compliance after implementation) • Qualitative: direct input from users/department and facility leaders, direct observation, and analysis of system-generated data, sharing of best practices between facilities	-
Hysong 2017 USA (55)	BMJ Quality and Safety	To describe how feedback intervention theory can be systematically applied in healthcare settings to design better feedback interventions.	DSP/HAI: To improve internal medicine resident and long-term care personnel's capacity to distinguish between asymptomatic bacteriuria and catheter-associated urinary tract infection.	HCWs (e.g. nurse practitioners & staff physicians)	Multiple methods: • Quantitative: Smither and colleagues' 11-item scale for recipients' reactions to feedback • Quantitative chart monitoring (adherence to the treatment algorithm, specifically, rates of urine culture) of orders and inappropriate use of antibiotics	Feedback Intervention Theory
James 2015 Australia (56)	The Journal of antimicrobial chemotherapy	To design an audit tool that was appropriate for use in all Australian hospitals, suited to local user requirements and included an assessment of the overall appropriateness of the prescription.	ASP: to improve the quality of patient care by reducing inappropriate and unnecessary use of antimicrobials (national level focus).	HCWs (e.g. pharmacists & nurses)	Multiple methods: • Quantitative: inter-rater reliability and validity tests, and web-based questionnaire • Qualitative: teleconference and direct input from users	-

Author, year, country	Journal	Study aims	Study targets	Target group	Study design and method(s)	Theoretical underpinning
Jeanes 2020 UK (57)	American Journal of Infection Control	To develop and implement an infection control performance and quality improvement data collection tool to meet the needs of a large, acute health care provider and to improve the credibility and use of infection control performance monitoring.	ICP/HAI: to improve the credibility and use of infection control performance monitoring (beyond HH).	Not clearly described; ("auditors" & managers)	Multiple methods: • Quantitative: questionnaires and intermittent validation • Qualitative: day to day contacts with auditors, feedback from users via the IC-CQI data input system, discussion groups, and IC-CQI training sessions &	Pronovost Knowledge Translation Cycle & Barriers and Mitigation tool & double loop learning cycle & Hexagon tool framework
Keizer 2020 NL (58)	Lecture Notes in Computer Science	To describe how a bottom-up participatory development approach can improve the persuasive design of data-driven technologies for their end-user (i.e. healthcare workers), and within their context. To describe how bottom-up participatory development is a necessary precondition for the development of persuasive data driven technologies that foster sustainable implementation.	DSP/ASP/ICP: to optimize HCWs' diagnostic, antibiotic prescription and infection control behavior to limit AMR.	HCWs (e.g. urologists & residents)	Multiple methods: • Quantitative: questionnaire • Qualitative: two focus groups (last focus group prototype based)	CeHRes roadmap
Marques 2020 Portugal (59)	BMC Medical Informatics and Decision Making	To develop a gamification solution that can provide healthcare workers' real time feedback on personal HH compliance.	ICP/HAI: to create awareness regarding HCWs' HH compliance, while trying to change their behaviors and optimize their performance.	Nurses	Multiple methods (two work iterations): • Qualitative: preliminary experiments, simulations, field studies and focus groups	Design Science Research Methodology & Gamification
Pakyz 2014 USA (60)	American Journal of Infection Control	To identify the factors related to the implementation of ASP strategies.	ASP: to optimize use of antimicrobial agents, decrease antimicrobial resistance, and decrease rates of Clostridium difficile infection.	ASP pharmacists & physicians	Multiple methods: • Quantitative: survey • Qualitative: semi structured telephone interviews	-

Author, year, country	Journal	Study aims	Study targets	Target group	Study design and method(s)	Theoretical underpinning
Parker 2020 Australia (61)	Journal of Clinical Nursing	To provide insights into the experiences of clinicians in implementing a multifaceted bundled urinary catheter care intervention (of which AF is a considerable component).	HAI: The study aimed to reduce catheter use and duration of catheterization.	Clinicians (e.g. nurses & resident medical officers)	Qualitative • Post-implementation focus groups	Intervention Description and Replication framework
Patel 2012 USA (62)	Inter-disciplinary Perspectives on Infectious Diseases	To describe the development and implementation of our audit and feedback intervention using a theoretical framework.	ASP: to promote the judicious use of antibiotics.	HCWs (e.g. neonatologists & pediatric residents)	Multiple methods: • Quantitative: retrospective observational study of antibiotic use and clinical vignette study • Qualitative: ethnographic workflow study and two focus groups	Model of Actionable Feedback
Power 2014 UK (63)	International Journal for Quality in Health Care	To set up a low-cost pragmatic system to provide monthly data on four harms across care settings and produce measures that could be used locally for improvement but also aggregated to determine the burden of harm nationally.	HAI: to reduce four high volume harms (safety outcomes), pressure ulcers, falls, urinary tract infection in patients with catheters and venous thromboembolism.	HCWs (e.g. nurses & junior doctors)	Multiple methods: • Quantitative: questionnaire survey (professional satisfaction) • Qualitative: paper-based prototyping, formative evaluation by interaction with testers, web forum (incl. mail queries), regional leads, face-to-face meetings, regional measurement workshops	Project Plan Framework & Plan, Do, Study, Act Method

USA: United States of America, UK: United Kingdom, NL: The Netherlands, HH: hand hygiene, ICP: infection control program, HAI: hospital-acquired infection, DSP: diagnostic stewardship program, ASP: antimicrobial stewardship program, HCWs: healthcare workers, CeHRes: Centre for eHealth Research.

TMFs for APM-AF development and implementation (RQ2)

Theoretical underpinning described by studies

Most studies (n=9) described the theoretical underpinning of their APM-AF system and/or study approach (table 6.1). Two studies explicitly mentioned the use of Feedback Intervention Theory and the Model of Actionable Feedback to guide choices in the development and implementation in their study aims (55,62), while others mentioned TMFs in their introduction or methods section. AF TMFs (n=3, e.g. Model of Actionable Feedback) (53,55,62) were used, as were TMFs for developing, implementing and evaluating interventions or technologies (n=5, e.g. CeHRes roadmap) (57–59,61,63), and for identifying implementation barriers/facilitators (n=1, e.g. Theoretical Domains Framework (TDF)) (52). Substantiations of choices on APM-AF systems were scarce; few studies substantiated their choices, which were either theory-informed (e.g. providing group-level feedback) or based on findings from the studies themselves (i.e. revisions based on formative evaluation).

Conceptual framework for APM-AF development and implementation

The conceptual framework, which is based on often used TMFs and best practices for AF and eHealth interventions, is shown in tables 6.2 (APM-AF system constructs) and 6.3 (development and implementation constructs), and in the supplementary materials in more detail.

The construction of the comprehensive overarching conceptual framework revealed the added value of including multiple perspectives, as 48% of constructs were complementary (i.e. covered by one of the three perspectives). Overlaps in coverage of constructs between AF, eHealth and implementation indicate the integrative nature of development and implementation of APM-AF system. Overlapping constructs occurred more often for APM-AF systems (n=4) than for APM-AF development and implementation (n=2). In the former, most constructs (72% and

66%, respectively) came from AF and eHealth literature, while in the latter, most constructs (74%) came from the implementation literature. Constructs underpinned by all three perspectives (darker grey) are not necessarily described by more studies (e.g. goal setting (n=5)).

Table 6.2. Conceptual framework: APM-AF system constructs

Construct	Subconstruct (s)		1) Audit & feedback				2) eHealth & interventions			3) Implementation		# of studies (n=12)
			(17)	(3)	(5)	(4)	(47)	(42)	(2)	(48)	(49)	
Audit	Auditees						+			+		10
	Main "input"							+				9
Feedback	Feedback recipients						+		+	+		8
	Main "output"		+					+	+			8
	Level of individualization/ specificity	Feedback provided to individual, groups, or both	+		+		+	+				11
		Feedback is about the individual/ team's own behavior(s)	+	+	+	+						10
		Feedback level specificity	+		+	+		+				8
	Comparison, goal setting & action planning	Comparison	+	+		+		+	+			8
		Goal setting	+	+		+			+	+		5
		Action planning	+	+		+		+	+	+		4
	Feedback framing and incentives	Punitiveness			+	+						6
		Attack on self-identity				+					+	4
		Intrinsic/extrinsic reinforcement and/or incentives				+				+		4
	Timing	Delivery timing	+	+		+		+				8
		Timeliness (frequency and continuous cycle)	+	+	+	+	+	+	+			11
		Reminders				+		+				3
APM-AF system	Technology & materials	Key features of the technology						+	+		+	11
		Access						+				12
		Materials					+	+	+			8
	Human-system interaction	Modes of feedback delivery	+	+		+	+	+	+			9
		Level of human involvement						+			+	9
		Engagement				+						6
	Design	Visual presentation strategies and cognitive load	+	+	+				+	+		9
		User-guided experience	+	+	+	+	+	+	+	+		4
	Data validity & trust/ credibility	Data validity		+		+						9
		Trust/credibility		+		+				+		11
APM-AF as learning strategy	Learning opportunities	Reflective learning	+			+				+		5
		Learning climate				+				+		7
	Additional strategies/procedures						+	+	+			12
% of constructs theoretical underpinned by literature on…			72%				66%			41%		

Overlapping constructs are indicated with grey shadings (dark grey: constructs represented in all perspectives, light grey: constructs represented in two perspectives) and unique constructs (i.e. where the various perspectives complement each other) are in white.

Table 6.3. Conceptual framework: APM-AF development and implementation constructs

Construct	Subconstruct(s)		1) Audit & feedback				2) eHealth & interventions			3) Implementation		# of studies (n=12)
			(17)	(3)	(5)	(4)	(47)	(42)	(2)	(48)	(49)	
Stakeholders & roles	Developer/research team						+					5
	Pilot-testers & involvement in development and implementation process					+	+			+		11
	Leadership Engagement									+	+	6
	Opinion Leaders									+		3
	Formally appointed internal implementation leaders									+		2
	Champions									+		3
Target behavior & added value	Target behavior, problem, and intervention	Nature of the problem									+	12
		Description of underlying behavior and decision processes	+			+						12
		Relevant sociocultural factors and comorbidities									+	8
		Perceived need for behavior change	+							+		4
		Targeted behavior is likely to be amenable to feedback	+	+		+						6
		Self-efficacy		+		+				+		3
		Justify need for behavior change	+			+					+	10
	Rationale and added value	Rationale for using APM-AF	+				+	+				12
		Desirability, efficacy, safety, and cost effectiveness				+				+	+	10
		Relative advantage								+		10
Embedding in practice	Implementation complexity & compatibility with target behavior and work processes	Complexity of implementation process								+	+	8
		Technology supply model									+	8
		Compatibility				+				+	+	11
		Remove barriers				+		+			+	11
		Opportunity costs (incl. additional efforts to use technology)				+				+	+	3
		Available resources								+	+	6
	Inner & outer setting	Structural characteristics								+	+	1
		Networks & communications								+	+	2
		Culture								+		3
		Patient Needs & Resources								+		1
	Implementation	Planning								+	+	6
		Executing								+	+	5
Formative evaluation	Intended use						+	+				1
	Actual use						+					3
	Development process and formative evaluations							+		+		12
	Harms or unintended effects							+				4
	Trialability									+		9
	Revisions and updating						+			+	+	6
	Replicability/digital preservation									+		1
% of constructs theoretical underpinned by literature on…			32%				24%			74%		

Overlapping constructs are indicated with grey shadings (dark grey: constructs represented in all perspectives, light grey: constructs represented in two perspectives) and unique constructs (i.e. where the various perspectives complement each other) are in white.

APM-AF system constructs (RQ3)

Table 6.4 shows APM-AF system constructs (more details in the supplementary materials). Constructs could be categorized into four main codes: 1) audit, 2) feedback, 3) APM-AF system and 4) APM-AF as a learning strategy and are elaborated upon below. The table also shows to what degree, and by which studies these constructs were described.

Audit

Auditees

The ones audited, or auditees, were described by most studies (n=10), and consisted of frontline HCWs (52–56,58,59,61–63).

Main input

Five APM-AF systems relied on automatically collected input (e.g. electronic hand hygiene monitoring system) (52–54,59,62), while other systems (n=4) relied on manual input (e.g. audit survey tool) (55,56,61,63).

Feedback

Feedback recipients

Feedback recipients were described by most studies (n=8), and consisted of auditees (i.e. frontline HCWs) (55,59,61), and managers/administrators (53,54,58,62,63).

Main output

Eight studies described APM-AF output in terms of specific content (e.g. process, structure and outcome indicators) (53,54,57,59,61), or gave a general description of output (e.g. quality of antibiotic treatment) (55,58,62).

Level of individualization/specificity

The level of feedback individualization was described by most studies (n=11). Feedback was provided on individual (55,60) or group level (53,61–63), or on both (i.e. option to choose) (52,54,56,58,59). Two studies explicitly justified their choice to provide group-level feedback only, because individual feedback could be perceived as too threatening (53,62). Feedback was provided to the auditees only (55,59–61), to the auditees and managers/administrators (52,54,58,62,63), or to managers/administrators only (53). Feedback specificity was described by most studies (n=8). Feedback was provided on individual patient cases (mostly diagnostic and antimicrobial stewardship studies) (55,60), on aggregated group level (mostly infection control studies) (53,54,59), or on both individual and aggregated level (58,61,63).

Comparison, goal setting & action planning

Eight studies described data comparison, either in terms of trends over time and/or benchmarks between groups and with other hospitals (52,56,58,59,62). Four studies briefly mentioned goal setting and action planning. Goals were either derived from literature (52), based on current data (53,54) or described in terms of a HCW' need to discuss goals (58), but were not substantiated. Five studies mentioned action planning after feedback, but mostly in general terms (e.g. feedback as a tool from which participants could make an actionable plan) (55,60,61), or as a separate follow-up strategy besides the APM-AF system, requiring additional information and human involvement (57,58,60,61).

Feedback framing and incentives

Some studies mentioned feedback framing in terms of punitiveness (n=6) or attack on self-identity (n=3), but few specified if and how these constructs were incorporated in AF system design (53,55,57–60,62). Two studies incorporated these constructs in their decision to focus only on group-level feedback (53,62), while two studies emphasized nonconfrontational and informal language (59,60). In- and extrinsic reinforcement and incentives were addressed in general terms (52,55,60), and more specifically by one study (e.g. competition, win state and rewards), including how these were implemented in the system (e.g. presenting the highest score with a distinct color) (59).

Timing

Five APM-AF systems made use of feedback at point of care. This was provided via visual and auditory signals (for hand hygiene monitoring) (52,54), and/or a real-time performance dashboard (54,59,63). Retrospective feedback was provided in ten systems, with variable frequencies (daily, monthly, half yearly, and yearly) (52–59,61,62), sometimes with the possibility to continuously access the performance dashboard when needed (53,58,59). Reminders were mentioned by three studies (52,53,58).

APM-AF system

Technology & materials

All studies described their (envisioned future) technologies, which ranged from audit tools (e.g. Excel or SurveyMonkey) (56,57,60,61,63) to electronic monitoring systems (for hand hygiene) (52–54,59), interactive PowerPoint presentations (55,62) and prototypes (58). Access to the APM-AF systems was realized in interactive dashboards or PowerPoint presentations with the possibility to send customized reports via email (54,58,59,63), while in four studies feedback recipients relied on managers or the research team (via email or face-to-face) for access to the APM-AF system (53,55,61,62).

Human-system interaction

Two studies solely provided feedback via the APM-AF system (59,63), while other studies (n=7) also provided face-to-face feedback (52,53,55,58,60–62). Additionally, studies described a need for additional human involvement, for example for (educational) meetings with AMR-experts (53,56,58,61,62), and support in data processing (55,57,58,60,63). Half of the studies described how they would engage the user with the APM-AF system via interactive feedback presentations (55,63), gamification (59), or with additional strategies (e.g. creating an AF task force) (58,61,62).

Design

Design details about included graphs were described by four studies (53,55,59,63), while other studies (n=5) described the APM-AF system design broadly (52,54,58,61,62). One study used theory-informed design to ensure that their design matched with task- and user-characteristics (55). Four studies described an interactive and customizable AF system, wherein personalization was used to customize feedback to match end-users' needs (55,58,59,63). However, this was often not further specified (e.g. which parts customizable), nor focused on user-guided experience (i.e. how is usability ensured).

Validity & credibility

Data validity was addressed in terms of raised concerns by study participants (52–54,60), (planned) data validation activities (55–57,63), or technical constructs (59). Trust in and credibility of the APM-AF system was addressed by describing study participants' perceptions (52,53,57–61) or (planned) activities to improve the trust in and credibility of the system (55,56,62,63).

APM-AF as a learning strategy

Learning opportunities

Four studies described reflective learning (i.e. personal reflections on one's behavior and APM performance) as a result and as a strength of APM-AF systems (55,58–60). Furthermore, APM-AF systems (n=6) were described as a (potential) facilitator for interactive discussions and communication between HCWs and AMR-experts, mostly in existing meetings (55,57,58,60,61,63).

Additional strategies/procedures

All studies described additional strategies, both for the study (e.g. webinar to explain how to use the tool), and for the APM-AF system in practice (e.g. creating an AF task force) (52–63).

APM-AF development and implementation constructs (RQ4)

Table 6.5 shows the APM-AF development and implementation constructs (more details in the supplementary materials). Constructs could be categorized into four main codes: 1) stakeholders & roles, 2) target behavior & added value, 3) embedding in practice and 4) formative evaluation and are elaborated upon below. The table also shows to what degree, and by which studies these constructs were described.

Stakeholders & roles

Research team

Five studies described their research team, consisting of multidisciplinary stakeholders (e.g. HCWs, AMR experts, biostatisticians and researchers) (53,55,56,58,60). The research team compositions were substantiated (e.g. having a multidisciplinary mix in the team (53,55,56,58,60) and experience with specific research methods (53,55,60)).

Pilot-testers & involvement in development and implementation process

Pilot-testers were described by eleven studies (52–56,58–63) and were predominantly selected for their occupational function (52,55,56,58,59,61–63), while other details about stakeholders' expertise and background were hardly described (52,53,56). Stakeholder involvement was realized by including stakeholders (e.g. HCWs, AMR experts) in the research team (61,62), and by involving them in pilot-tests and formative evaluations (56,58,59,61–63). Leadership engagement was mentioned by half of the studies as facilitator for successful implementation

(54,57,60–62), while stakeholder engagement through champions or opinion leaders was mentioned less often (n=4) (52,57,60,61).

Target behavior & added value

Target behavior, problem, and intervention

The nature of the problem and relevant sociocultural factors were addressed by all studies (52–63). Most studies (n=8) gave a description of underlying behavior and decision processes, either shortly in the article's introduction (53,56) and/or in a prior study (52,55,57,58,61,62). Some studies paid attention to whether there was tension for behavior change (52,53,55,59), if the targeted behavior is likely to be amenable to feedback (52,53,55,59–61), and self-efficacy of feedback recipients' (i.e. feeling capable and responsible for behavior improvement) (52,53,56). The need for behavior change was justified by pointing out flaws in current behaviors (52–55,57–61,63).

Rationale & added value

All studies described the rationale and added value of APM-AF (52–63). Seven studies described recommendations from health authorities (e.g. World Health Organization) or AF as a widely used intervention in healthcare in general as reasons to develop and implement an APM-AF system (53–56,58,60,62). Other studies (n=5) explained how APM-AF could solve problems and inefficiencies in the current situation (52,57,59,61,63). The added value was described both in terms of expectations (e.g. improve efficiency of audits) and experiences (e.g. feedback motivated to change behavior) (52,53,55–61,63).

Embedding in practice

Implementation complexity & compatibility with target behavior and work processes

Most studies (n=8) described constructs related to implementation complexity, including required organizational configurations and dependability on supplier for customizations, in terms of expected or experienced implementation barriers (53,54,57–63). One study specifically reflected upon the duration and efforts of the whole implementation process (57). Almost all studies (n=11) described constructs regarding the compatibility between the APM-AF system and stakeholder's needs and existing workflows, and expected or experienced implementation facilitators/barriers (52,54–63). Opportunity costs were described by few studies (n=3) (57,59,61), including negative experiences with the required additional efforts to use the APM-AF (incl. for example education and collecting data) (59,61). A lack of resources was described in terms of staffing, time and materials (56,57,60–62).

Inner & outer setting

Few studies (n=4) paid attention to the inner setting, expressing the need for a collaborative environment and open culture, in which the quality of their work can be discussed safely (58,60,62). One study described increased patient involvement as a result of visible APM-AF systems (54).

Implementation planning and execution

Six studies addressed implementation planning of which five also reflected on execution (54,57–59,61,63). Studies mostly reported longer implementation processes than initially planned, due to hospital workflow conflicts, personnel availability, and other confounding factors (incl. technical problems and resistance from stakeholders).

Formative evaluation

APM-AF system use

Intended and actual use of the APM-AF system were hardly (n=3) described, either as the maximum time HCWs should spend on filling out the audit tool (63), or as how often and complete the audit tool was filled in (57). Additionally, one study used Google Analytics to measure users' interaction with the gamification parts (59).

Development process and formative evaluations

The development process and methods used for the formative evaluations were described by all studies (52–63) and elaborated upon in this paper's study characteristics section.

Harms or unintended effects

Four studies described if and how harms and unintended effects were monitored during the development and implementation process (in general terms or with specific examples) (54,60,62,63).

Trialability & revisions and updating

Nine studies described trialability, and revisions and updating in terms of several testing rounds (52–56,58,59,61,63). However, only six studies subsequently described, either specifically (56,59,63) or broadly (52–54), how the findings from the testing rounds were incorporated in the design or implementation of the APM-AF system (e.g. use of better beacons).

Replicability/digital preservation

One study published their APM-AF system online with additional information (e.g. web forum) (63).

Conceptual framework

(Tables 6.4 & 6.5)

Table 6.4. Constructs of APM-AF systems

Constructs	Subconstructs		Described by % of studies			References
			+	~	-	
Audit	Auditees		83	8	8	(52–56,58,59,61–63)
	Main input		75	25	0	(52–56,59,61–63)
Feedback	Feedback recipients		67	25	8	(53–56,58,59,61–63)
	Main output		67	25	8	(53–59,61,62)
	Level of individualization and specificity	Feedback provided to individual, groups, or both.	92	8	0	(52–56,58–63)
		Feedback about the individual or team's own behavior(s)	83	17	0	(52–55,58–63)
		Specificity	67	8	25	(55,58,60,61,63)
	Comparison, goal setting and action planning	Comparison	67	0	33	(52,53,55,56,58,59,62,63)
		Goal setting	42	8	50	(52–54,58)
		Action planning	33	25	42	(55,57,58,60,61)
	Framing and incentives	Punitiveness	50	0	50	(53,55,58–60,62)
		Attack on self-identity and cognitive influences	33	0	67	(53,57,60,62)
		Intrinsic/extrinsic reinforcement and/or incentives	33	0	67	(52,55,59,60)
	Timing	Delivery timing	67	0	33	(52,54,59,60,63)
		Timeliness	92	8	0	(52–59,61,62)
		Reminders	25	0	75	(52,53,58)
APM-AF system	Technology & materials	Materials	92	8	0	(52–59,61–63)
		Key features of the technology	100	0	0	(52–63)
		Access	67	0	33	(53–55,58,59,61–63)
	Human-system interaction	Modes of feedback delivery	75	17	8	(52,53,55,58–63)
		Level of human involvement	75	25	0	(53,55–58,60–63)
		Engagement	50	0	50	(55,58,59,61–63)
	Design	Presentation strategies and cognitive load	75	8	17	(52–55,58,59,61–63)
		User-guided experience	33	25	42	(55,58,59,63)
	Validity & credibility	Data validity	75	8	17	(52–57,59,60,63)
		Trust/credibility	92	0	8	(52,53,55–63)
APM-AF as a learning strategy	Learning opportunities	Reflective learning	42	0	58	(55,58–60)
		Learning climate	58	0	42	(55,57,58,60,61,63)
	Additional strategies/procedures		100	0	0	(52–63)

+: Described elaborately, often with substantiation
~: Partially described or construct mentioned without elaboration, nor substantiation
-: Not described, nor substantiated

Table 6.5. APM-AF development & implementation constructs

Constructs	Subconstructs		Described by % of studies +	~	-	References
Stakeholders & roles	Stakeholders	Developer/research team	42	33	25	(53,55,56,58,60)
		Pilot-testers & involvement in development and implementation process	92	17	8	(52–56,58–63)
		Leadership Engagement	50	17	33	(54,57,60–62)
		Opinion Leaders	25	0	75	(57,60,61)
		Formally appointed internal implementation leaders	17	0	83	(60,61)
		Champions	25	8	67	(52,60,61)
Target behavior & added value	Target behavior, problem, and intervention	Description of underlying behavior and decision processes	67	17	17	(52,53,55–58,61,62)
		Nature of the problem	100	0	0	(52–63)
		Relevant sociocultural factors and comorbidities	100	0	0	(52–63)
		Tension for behavior change	33	8	58	(52,53,55,59)
		Targeted behavior is likely to be amenable to feedback	50	0	50	(52,53,55,59–61)
		Self-efficacy	25	0	75	(52,53,56)
		Justify need for behavior change	83	0	17	(52–55,57–61,63)
	Rationale and added value	Rationale for using AF	100	0	0	(52–63)
		Desirability, efficacy, safety, and cost effectiveness	83	0	17	(52,53,55–61,63)
		Relative advantage	83	0	17	(52,53,55–61,63)
Embedding in practice	Implementation complexity & compatibility with target behavior and work processes	Complexity of implementation process	67	8	25	(54,57–63)
		Technology supply model	67	0	33	(53,54,57,59–63)
		Compatibility	92	8	0	(52,54–63)
		Remove barriers	92	0	8	(52,54–63)
		Opportunity costs (incl. additional efforts to use technology)	25	8	67	(57,59,61)
		Available resources	50	17	33	(52,56,57,60–62)
	Inner & outer setting	Structural characteristics	8	0	92	(61)
		Networks & communications	17	0	83	(60,61)
		Culture	25	25	50	(58,60,62)
		Patient Needs & Resources	8	8	83	(54)
	Implementation	Planning	50	0	50	(54,57–59,61,63)
		Execution	42	0	58	(54,57) (59,61,63)
Formative evaluation	APM-AF system use	Intended use	8	8	83	(63)
		Actual use	25	17	58	(57,59,63)
	Development process and formative evaluations		92	8	0	(52–59,61–63)
	Harms or unintended effects		33	0	67	(54,60,62,63)
	Trialability		75	8	17	(52–56,58,59,61,63)
	Revisions and updating		50	8	42	(52–54,56,59,63)
	Replicability/digital preservation		8	8	83	(63)

+: Described elaborately, often with substantiation
~: Partially described or construct mentioned without elaboration, nor substantiation
-: Not described, nor substantiated

Discussion

This scoping review aimed to provide insights in strategies and theoretical underpinnings for audit and feedback system development and implementation from a socio-technical perspective. Of the 2125 studies found in the search, 12 studies were included describing the development and implementation of their AF systems heterogeneously in terms of study aims, AF targets and development and/or implementation strategies. Two studies explicitly aimed at illustrating how theories, models, and frameworks (TMFs) could guide choices in AF system development and implementation. A comprehensive interdisciplinary conceptual framework, based on overlapping and complementary constructs from TMFs from AF, eHealth and interventions, and implementation literature, was created to compare the studies.

Lessons learned for the development and implementation of APM-AF systems (RQ5)

In this discussion, research question 5 is answered by providing lessons learned from reflecting upon our findings for theoretical underpinnings of AF systems, (reporting on) the AF systems themselves, and their development and implementation.

Theoretical underpinnings for AF

With health(care) related problems becoming increasingly complex, interdisciplinary theoretical integration to combine different perspectives is inevitable and pivotal to be able to grasp the complexity of real-world problems (64). This study showed the added value of considering and combining AF, eHealth, and implementation literature for studying AF systems. Audit and feedback literature covered mostly AF system constructs (72%), while relevant development and implementation constructs were hardly covered (32%). Thereby, studies using only AF literature might miss important development and implementation constructs, such as stakeholder roles (e.g. leadership engagement and champions), and embedding in practice (e.g. implementation complexity and setting) that influence AF effectivity and efficiency (65,66). Therefore, we argue that TMFs for AF and for development and implementation should be balanced as exemplified in our interdisciplinary conceptual framework, and matched with studies' specific research objectives, methods, and context (e.g. setting and participants) (67).

However, selecting and combining the best fitting TMFs remains a challenge (68). Well-known examples of combined frameworks exist in implementation science (e.g. TDF (69)), but little information is provided about how constructs were combined. Overall, there is little guidance on the selection and integration of interdisciplinary TMFs (70). Evolving initiatives that create shared languages across disciplines and theories (e.g. CohenMiller & Pate (71)) and provide criteria for theory selection (e.g. Birken et al. (72)) is encouraged.

(Reporting on) AF systems

This scoping review resulted in an overview of constructs for APM-AF systems (table 6.4), enriching the AF best practices from Colquhoun et al. (18) with constructs of audit (e.g. auditees and audit input), feedback framing and incentives, and AF system constructs (e.g. technology & materials, human-system interaction, and data validity and trust/credibility). For replicability and using the framework in actual development and implementation, reporting about the audit input and what technology and materials were used is important. Furthermore, data validity/credibility was deemed as one of the five most important aspects for AF in a recent study (42).

In our view, two constructs that were underreported in the included studies require attention in future studies. First, we observed quite broad descriptions of AF system design, with a lack of attention to functional (i.e. what can the AF system do) and visual (i.e. how efficiently and effectively information is presented to users) design, and engagement with the AF system. Yet, these constructs are important for how an AF system is received and used in practice (73). The lack of design aspects and considerations of engagement might reflect the neglect of eHealth system characteristics (such as design) and engagement as active influencers for eHealth effectivity (74). Second, comparison, goal setting and action planning were hardly described in the included studies. A lack of substantiations for comparisons was also reported by a review on clinical performance comparators for AF on various clinical topics (75), while the underuse of goal setting and action planning was also found by a systematic review on behavior change interventions for APM in hospitals (28). These three constructs were derived from all included theoretical perspectives, and are common behavior change techniques (76), suggesting that they require and deserve more attention in future studies.

(Reporting on) development and implementation of AF systems

Of the 58 full-text studies assessed for eligibility, most studies (n=30) were excluded because they focused on effectiveness primarily and did not sufficiently report on development and implementation. The inclusion of 12 studies in full-text might seem little, but we believe this is exemplary of the tendency in (APM and eHealth) research to publish more about effectiveness than about the development and implementation process (3,11,12). Therefore, in future AF system studies, but also for other eHealth technologies, considering development and implementation as influencers of the effectivity and efficiency of eHealth in practice has yet to gain ground (13). During the construction of the conceptual framework, the interwovenness of development, implementation and formative evaluation became apparent through the many overlaps observed. This resonates with best practices in eHealth development and implementation, which state that implementation is integrated with development and requires an iterative and holistic approach (77). Therefore, next to reporting on evaluation, studies should report on both the constructs for AF systems and for development and implementation.

There is no single right development and implementation approach, because of the many variations in (APM-)AF objectives, stakeholders, technologies, and settings (78). Therefore, the constructed conceptual framework should be seen as a checklist which provides general guidance for potentially interesting constructs to consider; it remains to the discretion of researchers/developers which and how constructs are incorporated in their study. At a minimum, we propose to reflect upon relevant stakeholders and their roles, implementation complexity, compatibility with target behavior and work processes, including the added value of AF, and formative evaluation. Overall, supporting researchers and HCWs in selecting and integrating TMFs into their development and implementation process, and promoting the explicit reporting of the theoretical underpinning and substantiation of choices are highly encouraged (41).

The constructed conceptual framework can be used in future studies to ensure a comprehensive view of AF, for transparency and replicability of individual studies. Therefore, we recommend using the conceptual framework as a checklist and adding it (incl. substantiation of choices) as a supplementary material in future publications. Furthermore, findings from this study can be used to improve the professionalization and harmonization of AF studies, which is important considering the increasing use of audit and feedback principles in learning healthcare systems (79). The lack of attention for factors that support the development of learning healthcare systems (e.g. organisational culture and cooperation between HCWs and researchers) is recognized as an important barrier for the widespread adoption of learning healthcare systems (80). Because these aspects are included in the constructed conceptual framework, it might help future researchers and developers to explicitly consider and integrate these constructs in their AF/learning system.

Limitations and strengths

This scoping review has several limitations. Even though a comprehensive search query was used searching the most important databases for health research, we only included peer-reviewed published research, and excluded evaluation studies. As a result, it might be possible that relevant findings were omitted (e.g. from grey literature). Two systematic reviews on AF for various health targets were screened to ensure that no relevant publications were missed (1,2). Another limitation is that evaluation studies were excluded from the current review to highlight constructs relevant to the development and implementation, while evaluation is critical to know whether an intervention was successful. Therefore, it will be an important next step to evaluate AF systems in terms of processes (e.g. improved hand hygiene), clinical outcomes (e.g. reduced number of infections and decreased AMR), and technological outcomes (e.g. APM-AF system use and persuasiveness) (81). Lastly, data extraction relied on the subjective interpretation of constructs from the included publications by one researcher. However, the conceptual framework (tables 6.2 and 6.3) provided a thorough base for systematic and structured assessment, and findings were iteratively discussed and revised throughout the review process.

Conclusion

This scoping review provides novel insights in the theoretical underpinning of and reporting on the development and implementation of audit and feedback systems, while demonstrating how a comprehensive conceptual framework can be created, used and a valuable means to capture relevant constructs from heterogeneous studies with varying theoretical underpinnings. Few studies explicitly described how choices for AF systems and their development and implementation process were substantiated by theories, models and frameworks. The interdisciplinary conceptual framework that is developed in this study, is a first step towards the professionalization and harmonization of AF development and implementation. It provides guidance and a comprehensive checklist to guide researchers, HCWs and policymakers in making informed choices in the development and implementation of AF systems, with the aim to further improve the quality and safety of healthcare.

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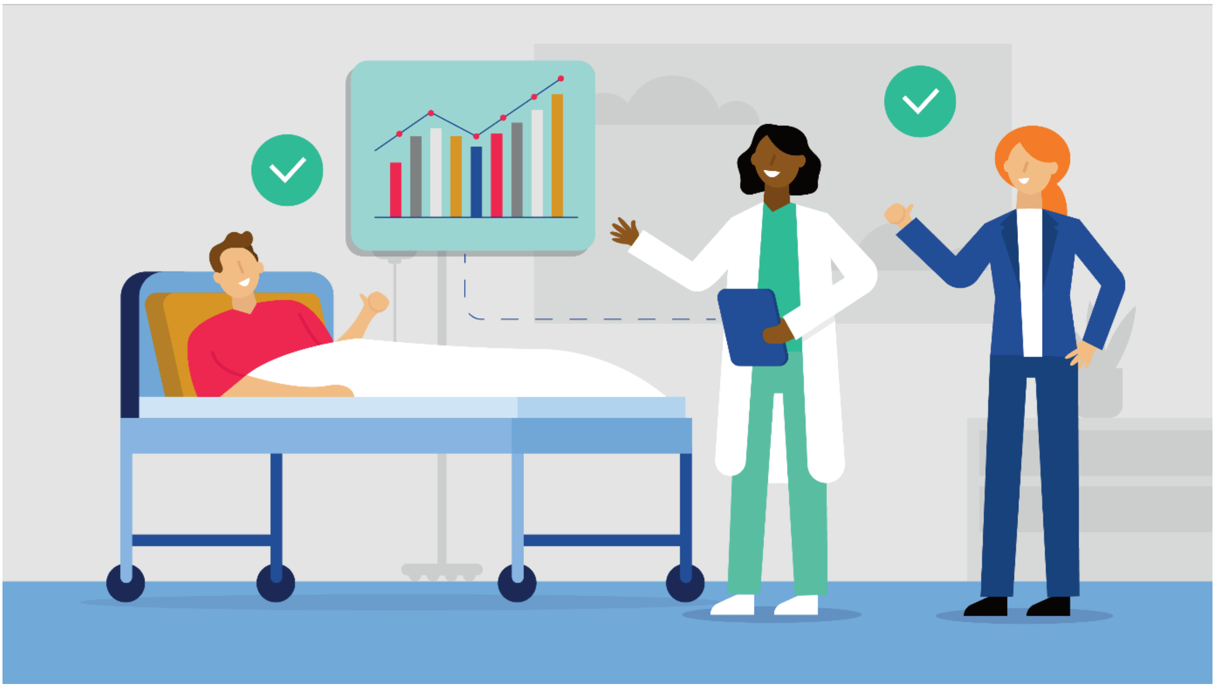
Tell me and I forget,
teach me and I remember,
involve me and I learn.
- NOT FRANKLIN
quoteinvestigator.com/2019/02/27/tell/

Chapter 7:

GENERAL DISCUSSION



In this thesis we have demonstrated how audit and feedback (AF) can support healthcare workers (HCWs) as a learning and improvement strategy to improve the quality and safety of care through antimicrobial resistance (AMR) stewardship comprising various AMR prevention measures (APM). In the general discussion, we first present the main findings of this thesis to answer the (sub-)research questions. Then, we reflect upon implications for practice and research, including future research directions. Lastly, we reflect upon the strengths and limitations of our approach, as a prelude to the general conclusion.

7.1 Main findings

Part 1: HCWs' perceptions, needs and expectations for AMR & APM

In part 1, we focused on HCWs' perceptions of AMR and APM to uncover their needs and expectations for support in APM, and if and how audit and feedback of APM (APM-AF) could be of added value.

How do HCWs perceive the AMR problem and their contribution to APM? (Chapter 2)

Findings from a cross-border survey revealed HCWs' perceptions of the AMR problem and their perceived contribution to APM. Although both German and Dutch HCWs were aware of the AMR problem, they perceived their contribution to limit AMR as insufficient, and did not feel sufficiently supported to contribute to limiting AMR. Therefore, this thesis focused on a specific APM that provides objective insights in how HCWs contribute to limiting AMR through their working routines. Audit and feedback (AF) is one of the recommended APM by health authorities, but little guidance is provided on how to apply, develop, and implement APM-AF that is of added value to HCWs, and not merely to AMR experts or for external accountability.

What are HCWs' needs and expectations for (future) APM-AF? (Chapter 3)

Via interviews with HCWs we focused on counterbalancing the current predominantly top-down, expert-driven approach for APM-AF by unravelling HCWs' needs and expectations for (future) APM-AF. HCWs required insights from audits into all facets of APM in their working routines (i.e. in antimicrobial stewardship programmes (ASP), infection control programmes (ICP) and diagnostic stewardship programmes (DSP)). HCWs preferred simple and actionable feedback that invites interdisciplinary discussions, so that substantiated actions for improvement can be implemented. HCWs indicated that APM-AF should not be seen as an isolated ad-hoc intervention, but as a recurrent, long-term, and organic learning and improvement strategy that balances the primary aims of HCWs (i.e. improving quality and safety of care for individual patients and HCWs) and AMR experts (i.e. reducing the burden of AMR).

Part 2: Developing persuasive APM-AF systems

In part 2, we focused on the persuasive design of APM-AF systems, including the use of data visualizations that fit with common AMR data visualization practices.

How can a bottom-up participatory development approach improve the persuasive design of APM-AF systems? (Chapter 4)

We demonstrated how involving HCWs in our bottom-up participatory development approach guided the persuasive design of APM-AF system prototypes and simultaneously increased engagement of end-users to foster sustainable implementation. In two consecutive focus groups, additional HCWs' needs for APM-AF as learning and improvement strategy were uncovered, including persuasive design requirements regarding the content, functionalities and design of the APM-AF system, and preconditions for implementation and sustainable use in practice (i.e. how to engage HCWs in accepting and using the APM-AF system). This study resulted in the development of various prototypes in two iterative rounds that can form the basis for future APM-AF system development, as already initiated (1).

How can data visualizations fit the visual habits of AMR professionals and scientists? (Chapter 5)

Data visualization is an integral part of data-driven APM-AF. Yet, there are no one-size-fits-all data visualization rules that can simply be copy-pasted to the field of AMR stewardship. Therefore, we created an overview of the visual dictionary (incl. common design elements for specific AMR content) for AMR research via a systematic assessment of data visualizations in scientific AMR publications based on established visualization nomenclatures and categorizations. Within the heterogeneous use of data visualizations, we found quite homogenous design choices in AMR research, and we identified common visualization problems (e.g. colour scheme mismatches). The proposed dos and don'ts (page 133) can guide data visualization creators in designing visualizations that fit the data and visual habits of the AMR stewardship target audience.

Part 3: Theoretical underpinnings for and lessons learned from our bottom-up participatory development and implementation approach

In part 3, we focused on the theoretical underpinnings for and lessons learned from our bottom-up participatory development and implementation approach.

What can we learn from current studies on the development and implementation of APM-AF regarding their theoretical underpinning and reported constructs? (Chapter 6)

To learn from other development and implementation processes and validate our findings, a scoping review provided insights in the development and implementation strategies for APM-AF systems, showing a wide variety in theoretical underpinnings and reported information. To compare the heterogeneous studies and guide (the reporting of) future APM-AF studies, a comprehensive interdisciplinary conceptual framework was created that balances theories, models, and frameworks (TMFs) from AF (e.g. Feedback Intervention Theory) and eHealth development and implementation (e.g. CeHRes Roadmap). Few of the included studies explicitly described how choices for APM-AF systems and their development and implementation process were substantiated, which reduces the transparency and replicability of individual studies, thereby limiting the possibility to learn from others. The conceptual framework (pages 171-172) can serve as a checklist that provides guidance to researchers, HCWs and policymakers for making informed choices in the development and implementation of APM-AF.

What have we learned from the bottom-up participatory development and implementation of APM-AF systems as a learning and improvement strategy? (Chapter 7)

Lastly, in section 7.2 of this chapter, we reflect upon the lessons learned from our bottom-up participatory development and implementation approach and provide recommendations for (the development and implementation of) APM-AF systems as a learning and improvement strategy. Thereby, we provide important knowledge and know-how on how the core elements of tracking, monitoring, surveillance, reporting and feedback that health authorities recommend for successful APM can be translated into a learning and improvement strategy that is of added value for both HCWs and AMR-experts.

7.2 Lessons learned and recommendations

Our bottom-up participatory development and implementation approach for APM-AF provided comprehensive insights into the interactions between the technology (i.e. APM-AF system), humans (i.e. HCWs and AMR-experts), and their context (i.e. workflow and organization), and the integration of TMFs in the development and implementation of APM-AF in hospitals. In this section, we answer the research sub-question: *What have we learned from the bottom-up participatory development and implementation of APM-AF systems as a learning and improvement strategy?* by reflecting upon the lessons learned and providing recommendations for future APM-AF (research) projects.

7.2.1 Bottom-up participatory approach to APM-AF development and implementation

Lessons learned

Several lessons learned relate to the importance and added value of focusing on HCWs' perspectives, needs and expectations in the development and implementation of APM to counterbalance the currently predominantly top-down, expert-driven approach. Furthermore, lessons were learned for the integration of APM in HCWs' care processes and the lack of integration (of antimicrobial stewardship, diagnostic stewardship and infection control) within AMR stewardship.

Focus on APM that support HCWs in assessing and improving APM

The current APM approach with AMR-experts as subjects (i.e. performing actions) and HCWs as objects (i.e. undergoing the actions) will not be durable in the long term given the expected rise of AMR and competing high-priority matters (e.g. COVID-19), and simultaneous scarcity of dedicated time, funding and personnel for APM (2–5). In chapters 1 and 2 we learned that it is important to focus on APM that support HCWs in assessing and improving APM in their working routines, rather than primarily focusing on awareness and knowledge deficits as current APM often do (6). In chapter 3 we discovered that AF on APM performance is currently scarce. If AF is performed, it is of limited added value to HCWs because of the expert-driven audit content and because of feedback that is not actionable (7). HCWs expect APM-AF to be of added value, as it will allow them to become more aware of the contribution of their own behaviour and working routines to reduce the burden of AMR, and because it can facilitate objective discussions about performance (chapters 3 and 4) (7,8).

Enrich the definitions of APM quality with the HCW' perspective

Additionally in chapters 3 and 4, we learned why the expert-driven audit content is of limited added value for HCWs and how the definitions of APM quality can be enriched with the HCW' perspective (7,8).

The limited added value of current APM-AF for HCWs is related to the gap between quality measurement for quality assurance and accountability on the one hand (current situation), and for quality improvement on the other hand (desired situation) (7). The former is focused on summative evaluations for external assurance, accountability, and verification purposes, and is thus measurement oriented. The latter is focused on formative evaluations for learning, to promote continuous improvement at the local level, and is thus change and process oriented. These differences influence the ways that quality is measured and feedback is provided: the summative approach requires high levels of measurement precision and advanced statistical techniques to ensure that measures are valid and attributable to HCWs' performance, while quality measurements for formative quality improvement do not have to be perfect, as they are informative and should be considered together with other local (qualitative) information to provide context to the measured quality of care (7,9). To create added value of APM-AF for HCWs, the quality management perspective, integrated with aspects of human-computer interaction and eHealth development, should be adopted to transform APM-AF into a learning and improvement strategy (as described in section 7.4).

To enrich the definition of APM quality with the HCW' perspective, HCWs require insights from audits of all APM (i.e. diagnostics, treatment, and infection control), in which there is a balance between improving quality and safety of care for individual patients (e.g. optimal antimicrobial use for an individual patient) and reducing the burden of AMR (e.g. avoiding the use of last-resort antimicrobials) (7). Furthermore, HCWs require actionable feedback as input for objective discussions about their working routines and behaviour, and additional help from data-, quality-, and AMR-experts to develop substantiated improvement strategies (7,8).

Iteratively optimize the fit between the APM-AF system, the HCW, and their context

Furthermore, we learned that an iterative approach is necessary for continuous formative evaluations throughout the development and implementation of APM-AF to account for the inter-adaptability of the APM-AF system, HCWs, and their context, and to iteratively elicit and sharpen HCWs' needs and expectations (6–8,10). Combining results of the various research methods (i.e. a questionnaire, interviews, focus groups, systematic assessment of data visualization and a scoping review) allowed for a comprehensive understanding of what APM-AF should entail and comprise, including specific design characteristics of APM-AF systems (e.g. functionality, usability, and persuasiveness, as described in section 7.3) and preconditions for APM-AF in practice (e.g. creating an APM-AF task force, as described in section 7.4). The use of lo-fi prototypes (chapter 4) helped HCWs to clearly envision and verbalize their needs and expectations, which can be challenging, especially for to-be-developed eHealth technologies and for complex problems that are not within the main focus of HCWs, such as AMR (8,11).

Engage HCWs with APM and the development and implementation process

The iterative bottom-up participatory approach not only optimized the fit between APM-AF, HCWs and their context, but also provided a natural process of growing engagement of HCWs and other stakeholders (e.g. AMR-experts and hospital leader) with APM-AF (8,12). By involving HCWs from the start of and throughout the whole the development process, we observed increased engagement with the subject (i.e.

AMR awareness), but also with reflecting on one's work (i.e. embracing quality management) and the development process (i.e. facilitating research activities, such as data collection) (8). Although we did not formally evaluate how this engagement influences the actual implementation and use of APM-AF in practice, engagement is a crucial precondition to nurture local champions and ownership, which are recommended for sustainable implementation (13).

Create shared ownership of APM-AF (bottom-up and top-down)

Moreover, we have learned that AMR stewardship should be an interdisciplinary affair with shared ownership between HCWs and AMR-experts, as a predominantly top-down expert-driven approach for APM is a pitfall in the current situation, as described by previous studies (14–17), and as also found for APM-AF in this thesis (7,8). As a result, HCWs' behaviours, working routines and needs for APM support are not sufficiently reflected in the development and implementation of APM(-AF), while HCWs are responsible for integrating prescribed APM in their daily working routines while caring for patients. Of course, the technical expertise of AMR-experts is of critical importance for APM, and some unpopular but necessary decisions (e.g. closing a department to prevent the spread of resistant microorganisms) require top-down interference (chapter 3) (5,7).

Integrating AMR stewardship requires more than merely adding AMR-expertise (e.g. diagnostic and therapeutic advice from clinical microbiologists and pharmacists) into HCWs' care process and working routines. It requires reshaping currently isolated APM into an integrated and supportive environment, in which AMR-experts and HCWs share ownership of APM (i.e. integrating AMR expertise and patient/department expertise by considering similar, competing and complementing values), supported by the whole organization (e.g. leadership endorsement, and support in data collection and analysis by data-experts) (6–8). For APM-AF specifically, shared ownership should be stimulated throughout the whole audit and feedback cycle, from APM-AF selection and measurement to the translation of data to feedback and implementing APM, with a clear division of responsibilities (7). eHealth technology can facilitate integrated AMR stewardship and shared ownership, because it allows for combining data from various databases (e.g. hospital and laboratory), and for the presentation and sharing of information tailored to specific target groups (e.g. doctors and nurses as identified in chapters 2 and 3) and for specific purposes (e.g. quality management, education and decision support as identified in chapter 4) within one overarching APM-AF system (6–8).

Integrate AMR stewardship programmes (ASP, ICP and DSP)

In line with the need for AMR stewardship to be integrated in HCWs' care processes, it became clear throughout the studies of this thesis that there still is a distinction between the supposedly integrated programmes of diagnostic stewardship, antimicrobial stewardship, and infection control (18). In literature, this became apparent through the two separate literature streams of antimicrobial stewardship programmes (focusing on e.g. antimicrobial treatments, while sparsely mentioning DSP as part of ASP (19)), and infection prevention and control (focusing on e.g. hospital acquired infections or hand hygiene), and separate descriptions of core components for ASP, ICP and DSP by health authorities (e.g. WHO, ECDC) (20–23). In hospital practice, separate committees and working groups exist for DSP/ASP (e.g. A-team and antibiotic committee) and ICP (e.g. infection committee), of which the former have been mandated top-down in the past decade (24), while the latter are often firmly established in hospitals (25). To achieve the overarching goals of keeping patients safe and improving the quality of care, leveraging the synergy of DSP, ASP and ICP is both imperative and practical, as such programmes use similar outcome measures, methodologies, and technologies (25,26).

Recommendations

These lessons learned resulted in various recommendations for the involvement of HCWs and other stakeholders. We recommend involving HCWs, AMR-experts and other relevant stakeholders from the beginning of and throughout the whole development and implementation process to carefully balance bottom-up and top-down considerations. This starts with composing an interdisciplinary research or development team, at least consisting of eHealth experts (e.g. health scientists and designers), HCWs (e.g. doctors and nurses), and AMR-experts (e.g. clinical microbiologists and infection control professional). Explicitly discussing values (i.e. complementing and competing interests) and roles during the development and implementation process is crucial to keep clarity and transparency in determining the stakeholder responsibilities, project targets and means. During the development process, the research team should continuously check if and how other relevant stakeholders should be included for specific purposes (e.g. support from data-experts in collecting and analysing the data) (27). Hospital leaders and managers should be involved for leadership support (e.g. dedicated time and personnel and branding APM-AF as a hospital wide quality and safety affair) and practical support (e.g. testing prototypes on the ward). Furthermore, continuous formative evaluations throughout the development and implementation of APM-AF are necessary to iteratively ensure a fit between the APM-AF system, HCWs, and their context, and to elicit and sharpen HCWs' needs and expectations. It is recommended to combine results of various research methods (e.g. questionnaire, interviews) that match with the goals of the formative evaluation (28).

7.2.2 Interdisciplinary theoretical underpinning for APM-AF development and implementation

Lessons learned

With the increasing complexity of health(care) related problems like AMR, considering and integrating different perspectives and disciplines is crucial to grasp the complexity of the problems (29). The CeHRes Roadmap, and more specifically combining the perspectives of quality improvement science (QIS) and human-computer interaction (HCI) for eHealth development and implementation taught us unique lessons regarding the interdisciplinary theoretical underpinning of APM-AF.

Integrating QIS and HCI allowed us to leverage the knowledge of complex systems to make changes (QIS), with design thinking that considers human behaviour in complex systems (HCI) needed to comprehend the wicked AMR problem and come to new disciplinary and interdisciplinary insights. From this, we learned that the current top-down expert-driven approach of APM-AF (i.e. primarily structural and procedural-oriented AF recommendations of health authorities (11,20,30–35)) should be grounded in theoretical approaches that consider technological (i.e. APM-AF systems), human (i.e. HCWs and AMR-experts) and contextual (i.e. working routines and the organisation of healthcare) aspects to unlock APM-AF's learning and improvement potentials. By integrating QIS and HCI, we learned that they especially complement each other for the exploration and definition of the AMR-problem in the hospital by considering both humans and their context (QIS and HCI), for designing the APM-AF system (HCI), for defining APM-AF as a learning and improvement strategy (QIS and HCI), and for considering implementation preconditions and barriers (QIS and HCI) (36).

From the scoping review (chapter 6), we learned that there was high heterogeneity in theoretical underpinnings of APM-AF systems, and few studies substantiated the selection and use of theories, models and frameworks (TMFs) to guide choices in the development, design and implementation of APM-AF systems (37). Poor theoretical underpinning hampers understanding of why and how development and implementation are more or less successful, making it hard to identify factors and develop better strategies that may increase the likelihood of success (29). Developing conceptual frameworks in interdisciplinary research is often a considerable challenge for development and implementation researchers, and there is little guidance on how to select and combine TMFs (38). The 5-step model by CohenMiller and Pate identifies an interdisciplinary shared language across disciplines and theories, and thus can support researchers and developers in developing a conceptual framework in interdisciplinary research (39). First, research topics and questions are identified that address a complex problem (i.e. APM-AF in the hospital). Second, relevant concepts and constructs for the topics/questions are identified (i.e. quality and safety, AMR stewardship, audit and feedback, and eHealth technologies). Third, disciplines related to the concepts and constructs are identified, considered, and chosen (e.g. QIS, HCI, integrated ASP, ICP and DSP, and eHealth development and implementation). Fourth, TMFs appropriate for addressing the research topics and questions within disciplines are identified, considered, and chosen, using the concepts and construct as guides (e.g. PDCA cycles, model of actionable feedback, and CeHRes Roadmap). Fifth, key terminologies from cross-disciplinary TMFs are clarified and defined as shared language (i.e. integrating TMFs).

Recommendations

For the theoretical underpinning of APM-AF we recommend a socio-medical-technical approach supported by the CeHRes Roadmap that joins the inter-disciplinary forces of QIS and HCI for the development and implementation of eHealth technologies (e.g. APM-AF systems) to ensure a comprehensive understanding of relevant aspects for the wicked AMR problem. More specifically for APM-AF, this means combining constructs from TMFs on AMR and APM (18,40,41), on AF (42–45) and other behaviour change techniques (46–49), on participatory eHealth development (27,50), human-centred and persuasive design (51–54), and on improvement (55) and implementation (56) science.

As our interdisciplinary approach focuses on the interactions between technologies, humans and their context, this approach might also be suitable for crossing borders between other disciplines (e.g. ASP, ICP and DSP as described in section 7.2.1) (18), and sections (e.g. AMR in the wider OneHealth context of human health, animal health, and the environment, as described in section 7.3) (57). For such future interdisciplinary projects, we recommend using the 5-step model for interdisciplinary research (39), D&I Models Webtool (58) and T-CaST (59) to explain why TMFs are selected and how they fit with research/project characteristics, and to define constructs based on existing theory or available definitions. Furthermore, for knowledge accumulation and the identification of best practices, we recommend future projects to report on how the conceptual framework is used to inform choices, and to evaluate and include lessons learned about the use of specific TMFs (also see section 7.2.5).

7.2.3 Designing APM-AF systems

Lessons learned

In chapters 3-5, various lessons learned for the design of APM-AF systems and the use of data visualizations were identified (7,8,10).

The APM-AF system was iteratively (re)designed throughout the interviews and focus groups, guided by prototypes that helped to envision and verbalize HCWs' needs and expectations. The various ways in which APM-AF would be used in practice (i.e. quality management, education, and decision support) required the design (i.e. content, functions, and persuasive elements) to be tailored to the specific aims and users. For quality management, HCWs required an overview to quickly see what does (not) go well, including trends over time and benchmarks with other regional hospitals, and improvement suggestions. Functionalities such as filtering and zooming in on subgroups/-topics were required for AMR-experts and interested HCWs to be able to dive into the data in-depth. For education, HCWs should be able to zoom in to individual cases including declarative information to reconstruct and improve the reasoning underlying decisions. For decision-support, HCWs required timely advice to optimize diagnostic and antimicrobial treatments for individual patients and warnings to proactively change empirical treatment. Thus, HCWs required various persuasive design features (e.g. primary task, dialogue and social support) to be integrated into the APM-AF system.

Furthermore, from systematically assessing data visualizations, we learned that line and bar charts are still the most commonly used data visualizations in AMR research and thus identified the need to account for the increasing amount and complexity of data in future data visualizations (i.e. informing and teaching data visualization design alternatives). Also, from observed common pitfalls (e.g. mismatches in colour choices) we formulated data visualization dos and don’ts, which can support AMR data visualization creators to match their data visualizations with their data and habits of the AMR target audience (10).

Additionally, lessons learned from studies in the scoping review in chapter 6 resulted in a conceptual framework (section 7.5) with specific attention to relevant constructs for APM-AF systems (37). We identified important constructs that are neglected in current audit and feedback frameworks (e.g. design elements of AF by Colquhoun et al. (60)), such as constructs for audit (e.g. who are the auditees and audit input), feedback (e.g. framing and incentives), and APM-AF system (e.g. human-system interaction, user-guided design, and credibility). Furthermore, we learned that although goal setting and action planning are commonly advocated behaviour change techniques for APM, these were hardly described in the included studies (61). Therefore, the last phases of the continuous APM-AF improvement cycle as illustrated in chapter 3 (planning and implementing improvements) require more attention in future APM-AF projects.

Recommendations

The conceptual framework (chapter 6) can be used to guide future APM-AF development and implementation projects and as a checklist to ensure that all relevant aspects for the design of APM-AF systems are considered and included (i.e. constructs for audit, feedback, the APM-AF system and APM-AF as a learning and improvement strategy). Specific recommendations for the design of APM-AF systems are provided in chapters 3 and 4, and for data visualizations in chapter 5. More importantly, future projects need to adapt these recommendations to their project's aims, stakeholders, and context (e.g. by following the steps provided in sections 7.2.1 and 7.2.2).

7.2.4 APM-AF as learning and improvement strategy

Lessons learned

To unlock the potential of APM-AF as a learning and improvement strategy, we learned that APM-AF should not be seen as an isolated ad-hoc intervention, but as a recurrent, long-term, and organic learning and improvement strategy. Structural data-based feedback to HCWs serves as the objective base for substantiated discussions on improvement actions and evaluations of APM so that HCWs (with the help from other relevant stakeholders, such as AMR-experts) can change their behaviours and working routines accordingly. We also learned that APM-AF alone will not be sufficient to address the wicked AMR problem in hospitals. In chapters 3 and 4, we identified important preconditions for successful APM-AF implementation, such as having consensus meetings (e.g. to identify the APM-AF objectives and consider the cost-effectiveness of improvement plans when selecting audit targets), creating an open and safe culture to discuss APM-AF, creating an APM-AF taskforce, and training on how to use the APM-AF system (7,8). Furthermore, HCWs did not want the be solely responsible for the collection, analysis, and interpretation of data because of time constraints, insufficient data management skills and AMR knowledge, which warrants the help from data-, quality-, and AMR-experts to come to substantiated improvement strategies (8).

Therefore, developing and implementing APM-AF as a learning and improvement strategy requires looking at the broader organisation of care and complementary strategies. APM that do intervene with HCWs' daily healthcare processes might still be necessary to complement APM-AF, especially in the case of last-resort antimicrobials (e.g. restrictions or preauthorization) and high-risk microorganisms or infections (e.g. prospective AF and outbreak management) (20–23). Of course, guidelines and protocols are of importance for APM-AF, as they provide guidance to

HCWs during their daily working routines, and determine the standards for ASP, ICP and DSP best practices to which audit results can be compared (11). We incorporated existing guidelines and protocols constructed by health authorities and professional societies into the questionnaire content (chapter 2), interview scheme (chapter 3), and focus groups schemes (chapter 4) to ensure that the content of the APM-AF system would not only fit with HCWs needs, but also with medical AMR stewardship best practices (31,32,35).

Recommendations

APM-AF should not be seen as a stand-alone intervention, but it should be integrated into HCWs' working routines (e.g. for quality management, education, or decision support purposes), and complemented with preconditions for APM-AF (e.g. creating an open and safe culture) and other core elements (e.g. prospective AF) as recommended by healthcare authorities (20–23). Because APM-AF as a learning and improvement strategy will influence HCWs' behaviours and working routines and possibly requires adaptations in both structures and processes of care (e.g. placing disinfectant pumps throughout the ward and streamlining the diagnostic ordering process), we recommend reflecting on the interrelations between APM-AF, HCW' behaviours and working routines and the wider context (i.e. organisation of care) with HCWs, AMR-experts and other relevant stakeholders (e.g. managers) from the start of the development process.

7.2.5 Reporting on (the development and implementation of) APM-AF

Lessons learned

In the scoping review in chapter 6, we learned that implicit assumptions about AF working mechanisms and effective APM-AF systems have driven APM-AF development and implementation, with little explicit reporting on the theoretical underpinnings (section 7.2), as well as for informed choices for APM-AF system constructs (section 7.3), and the development and implementation process (section 7.1) (37). One of the characteristics derived from PDCA cycles by Deming is documentation, which refers to reporting on each PDCA stage and cycle to increase scientific quality, learning, reflection and transferability to other settings (62). Transparency and replicability are core scientific principles to improve scientific efficiency (i.e. knowledge accumulation and sharing best practices) and enhance the credibility of published literature (63). This is especially important for eHealth development and implementation studies, as it is a given that each new project needs to adapt the APM-AF (system) to their local context (27). Therefore, demonstrating future development and research teams (incl. HCWs, AMR-experts and policy makers) how they can plan, coordinate, and execute their APM-AF project is of utmost importance for professionalizing and harmonizing APM-AF development and implementation. The development and implementation process described in this thesis, and especially the conceptual framework in chapter 6, are first steps towards the professionalization and harmonization of APM-AF development and implementation, as it provides guidance to researchers, HCWs and policymakers for making informed choices in the development and implementation of APM-AF, supported by a comprehensive checklist for APM-AF system design and the development and implementation process.

Recommendations

To guide future APM-AF projects, we recommend using the conceptual framework in chapter 6 to ensure that all relevant aspects for the design of APM-AF systems, and the development and implementation process are considered and reported on. For APM-AF systems, important constructs to consider are audit (i.e. auditees and input), feedback (i.e. feedback recipients, output, level of individualization and specificity, comparison, goal setting and action planning, framing and incentives, and timing), the APM-AF system (i.e. technology and materials, human-system interaction, design, and validity and credibility), and APM-AF as a learning and improvement strategy (i.e. learning opportunities and additional strategies/procedures). Additionally, for the development and implementation process, we recommend to at least reflect and explicitly report upon stakeholders and roles, compatibility with target behaviour and work processes (e.g. making explicit why AF fits with the problem and relevant behaviours), embedding in practice (e.g. implementation complexity and available resources and barriers that might influence the success of development and implementation), and formative evaluations (i.e. reflecting on the progress and quality of the development and implementation process to gather ongoing information on how to improve the process, outcomes of study activities and the APM-AF system). For transparency and replicability of APM-AF studies, we recommend adding the checklist as a supplementary material in future publications. This can be further supported by the documentation and publication of study protocols, materials (e.g. interview schemes and raw data), requirements and prototypes, in line with current trends of open-source (software) approaches, reusing FAIR data, and open access publishing in science in general (64,65), and for AMR stewardship in particular (66,67).

7.3 Future research directions

This thesis rendered important and comprehensive knowledge and know-how for the development and implementation of APM-AF that can be continued and evolved in various future research direction.

First, our findings for the development and implementation of APM-AF provide important input for other phases of the CeHRes Roadmap, such as the actual implementation and evaluation of APM-AF systems as a learning and improvement strategy. Evaluations should focus on implementation outcomes (e.g. acceptability, adoption, feasibility, and sustainability) (68) and on technological goals related to use and usability (based on real-world data (69)) and persuasiveness (e.g. measured with the Perceived Persuasiveness Questionnaire (70)). Additionally, for the success of APM-AF systems in practice, clinical process (e.g. adequate antibiotic prescriptions), outcome (e.g. infections and AMR) and cost (e.g. patient and/or economic) effects should be considered (see e.g. (71,72)). By using the lessons learned and recommendations from this thesis as a starting point, future research projects can develop, implement, and evaluate well-grounded, iteratively tested and holistically evaluated APM-AF systems that match the HCWs and their context.

Second, the COVID-19 pandemic has firmly brought to our attention that wicked problems require cross-border cooperation, not only between countries, but also between disciplines with valuable complementary insights (73). Cross-border interdisciplinary projects, such as the EurHealth-1Health project of which this thesis is a part, demonstrate how country and interdisciplinary borders can be crossed by comparing and consequently harmonising (inter)national guidelines, policies, and technologies (74). While AMR in the human healthcare setting still gains the most attention, more and more research and efforts are directed towards crossing borders between human, animal, and ecosystem health, also known as the OneHealth approach (75). New collaborations harnessed to tackle the COVID-19 problems (e.g. CGIAR COVID-19 Hub and Hygiene Hub (76,77)) should be pursued in future AMR and OneHealth endeavours (73). Furthermore, lessons learned and recommendations from our bottom-up participatory socio-medical-technical approach, including the development of an interdisciplinary theoretical framework, can also be employed for OneHealth and other wicked problems.

Third, considering audit and feedback as a learning and improvement strategy, and not merely for external assurance and accountability, is in line with the general trend in healthcare to optimize the (re)use of data to create learning healthcare systems (78). These are defined by the Institute of Medicine as: "science, informatics, incentives, and culture are aligned for continuous improvement and innovation, with best practices seamlessly embedded in the delivery process and new knowledge captured as an integral by-product of the delivery experience." (79). Although eHealth technologies are important enablers for the collection, analysis and communication of data, these technologies do not compose a learning healthcare system by themselves (80). Therefore, eHealth experts should cooperate with learning experts in future (APM-)AF projects to optimize APM-AF as a learning and improvement strategy. In their white paper, Zurynski et al. emphasized the considerable behavioural and organisational change (e.g. HCW' buy-in and shifting to an improvement culture) required for learning healthcare systems, while recognizing the lack of attention for factors that support the development of learning healthcare systems as an important barrier for the widespread adoption of learning healthcare systems (80). Findings from our socio-technical approach, especially the identified preconditions for APM-AF in chapters 3 and 4 (e.g. creating an open and safe culture to discuss AF and growing shared ownership) can help to professionalize the field of learning healthcare systems further.

7.4 Limitations and strengths

This thesis has several limitations and strengths. A first limitation is that the findings described in this thesis should be generalized with care. While chapter 2 focused on HCWs in various hospitals in two countries (DE & NL), chapters 3 and 4 focused on HCWs in one Dutch regional hospital. Starting with a small and homogeneous target-group allowed us to gain in-depth insights and iteratively develop prototypes, potentially at the cost of generalizability. This reflects a methodological issue apparent in all (pilot-) development processes and urges the need to test and refine eHealth interventions in diverse settings using alternative research designs (81). This thesis can be seen as an APM-AF case study for the specific hospital setting that generated recommendations based on empirical real-world data which can be translated into general guidelines for the iterative development, implementation, and continuous evaluations of APM-AF. Therefore, there also lies a strength in our approach related to this limitation. Implementing a new or existing eHealth technology into settings beyond the setting that it was developed in, requires careful considerations of the characteristics of the new setting, and local adaptations are almost always needed to ensure the optimal fit between the technology, stakeholders, and context (27). This thesis provides rich information on how relevant characteristics can be identified (chapter 2-4), and how a bottom-up participatory approach can be of added value (chapters 3 and 4). Furthermore, the developed prototypes (chapter 4) and conceptual framework (chapter 6) ensure that researchers in other settings do not have to reinvent the wheel. Thereby, this thesis has provided important knowledge, know-how, prototypes and a conceptual framework that can inform future APM-AF development and implementation projects.

A second limitation relates to the partial development and implementation process, including the selection and use of TMFs. In this thesis we did not follow all phases as described in the CeHRes roadmap, as this requires considerable time and resources (82). Our studies mainly focused on development aspects and did not actually implement APM-AF, nor focused on (summative) evaluation. Like described before in the general discussion, there is little guidance on how to select and combine the wide variety of TMFs, and this is often a considerable challenge for development and implementation researchers (83–85). Choosing a certain approach means prioritizing certain aspects over other aspects, diminishing the overall and in-depth understanding of the complex problem (85). In this thesis for example, we prioritized aspects of development (e.g. content and design) and implementation (e.g. embedding in practice) over aspects of learning theories (86,87), improvement science, the (summative) evaluation of eHealth technologies (55,88), and technical aspects of data-driven technologies (65,66,89). This was done since the former were more important for our studies' objectives (i.e. demonstrating how a bottom-up participatory approach can guide APM-AF development and implementation) and characteristics (i.e. HCWs, APM behaviours, hospital setting and APM-AF systems).

7.5 Conclusion

In this thesis we have described and discussed our bottom-up participatory approach for the development and implementation of APM-AF as a learning and improvement strategy that aims to support healthcare workers to improve the quality and safety of care through AMR stewardship. By crossing both national and interdisciplinary borders, we provided insights into the interactions between technology (e.g. APM-AF systems), humans (e.g. HCWs and AMR-experts), and their context (e.g. countries, organization, and workflow), and the integration of interdisciplinary theories, models and frameworks in the development and implementation of APM-AF in hospitals. By doing so, we provided important knowledge and know-how that crystallize the by health authorities recommended core elements of tracking, monitoring, surveillance, reporting and feedback for successful APM into preconditions for a learning and improvement strategy that is of added value for both HCWs and AMR-experts. Thereby, we theoretically and practically brought together two inevitable challenges that modern healthcare faces: the rise of antimicrobial resistance and the ongoing evolution of data-driven learning healthcare systems.

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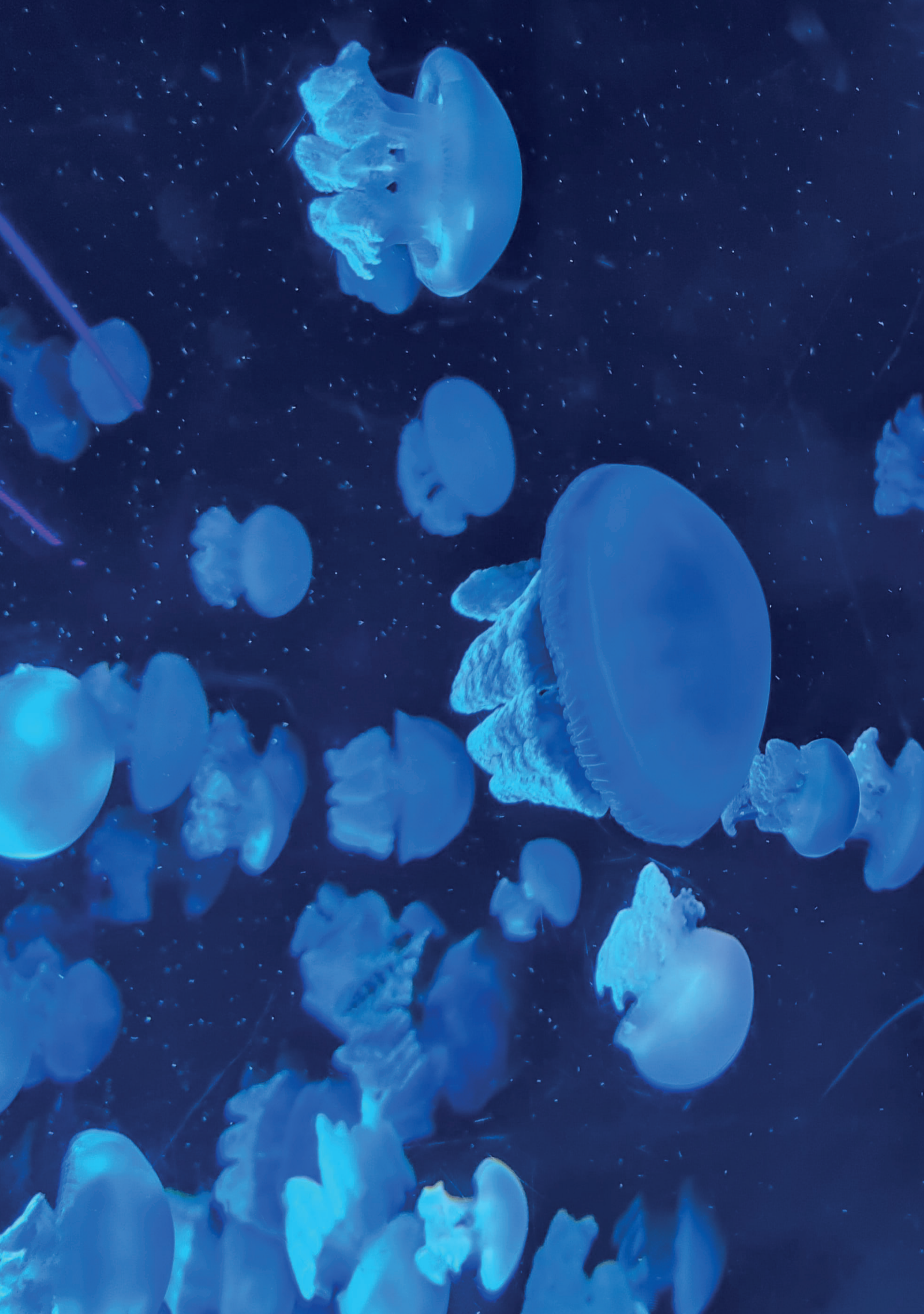
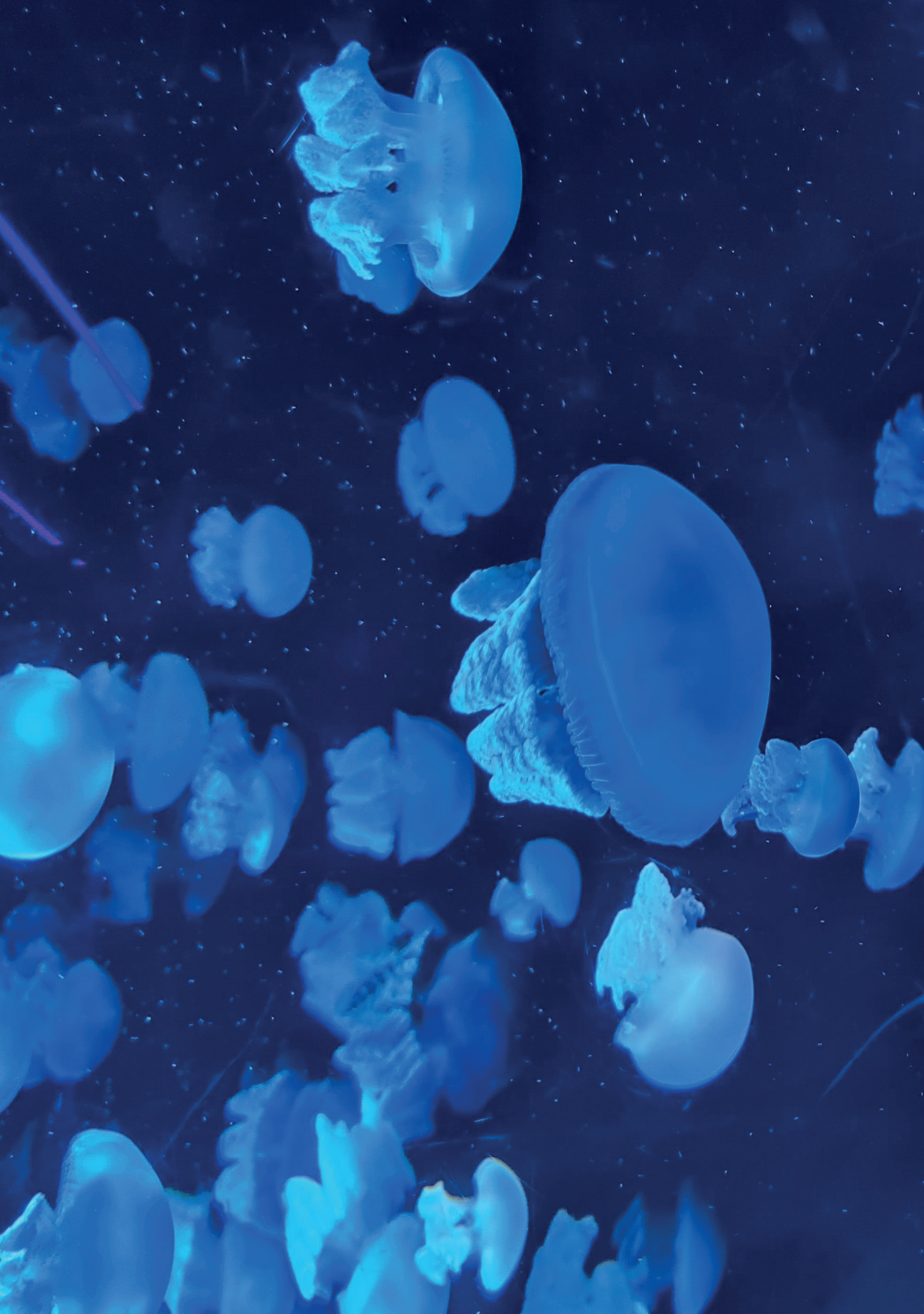


Abbreviations

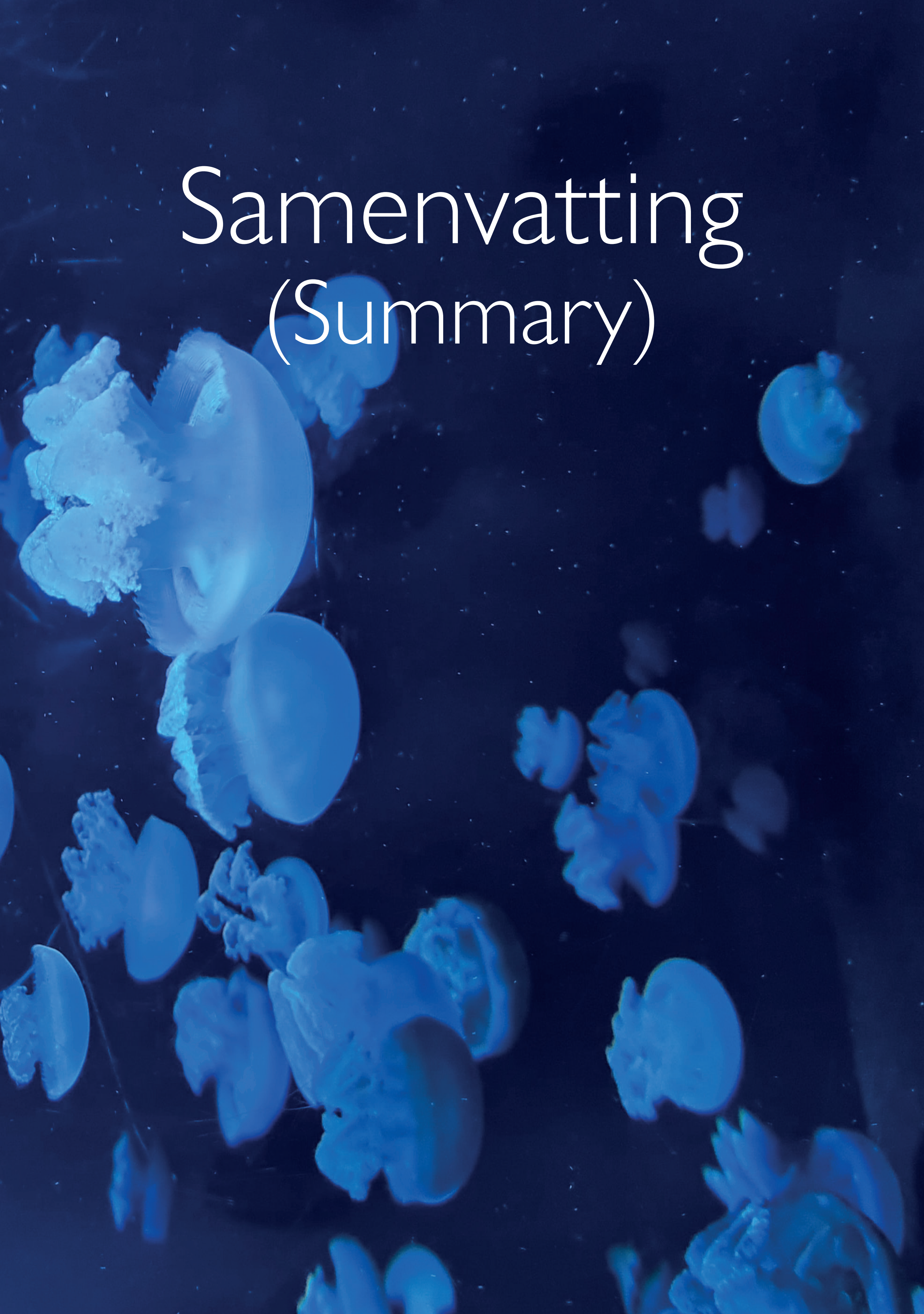
Abbreviations

AB	Antibiotic
ABX	Antibiotics
AF	Audit and feedback
AMR	Antimicrobial resistance
ANCOVA	Analysis of covariance
APM	AMR prevention measures
APM-AF	Audit and feedback for AMR prevention measures (APM)
ASP	Antimicrobial stewardship programmes
CDC	Centers for Disease Control and Prevention
CDSS	Clinical decision support system
CeHRes	Centre for eHealth Research
DE	Germany
DSP	Diagnostic stewardship programmes
EAAD `	European antibiotic awareness day
ECDC	European Centre for Disease Prevention and Control
EH1H	EurHealth-1Health
ESCMID	European Society of Clinical Microbiology and Infectious Diseases
EUCAST	European Committee of Antimicrobial Susceptibliity Testing
GP	General practitioner
HAI	Hospital-acquired infections
HCI	Human-computer interaction
HCW	Healthcare worker
HH	Hand hygiene
HRMO	Highly resistant microorganisms
ICP	Infection prevention and control programmes
IPCC	Intergovernmental Panel on Climate Change
IRIS	Infection Risk Scan
IRR	Inter-rater reliability
MDRO	Multi-drug resistant organisms
MRSA	Methicillin-resistant Staphylococcus aureus
NL	The Netherlands
PDCA	Plan do check act

POC	Point of care
PRISMA-ScR	PRISMA Extension for Scoping Reviews
PSD	Persuasive systems design
QIS	Quality improvement science
QNR	Questionnaire
RadaR	Rapid Analysis of Diagnostic and Antimicrobial Patterns
SPO	Structure, process and outcome
TMF	Theory, model and framework
UT	University of Twente
WHO	World Health Organization



Samenvatting (Summary)



Samenvatting (summary)

In dit proefschrift is onderzocht hoe *audit en feedback (AF)* systemen gezondheidsprofessionals kunnen ondersteunen om de kwaliteit en veiligheid van de zorg te verbeteren door middel van antimicrobiële resistentie stewardship.

In **hoofdstuk 1** is *antimicrobiële resistentie (AMR)* geïntroduceerd; het vermogen van micro-organismen (zoals bacteriën) om ongevoelig of resistent te worden voor de antimicrobiële middelen (zoals antibiotica) die ontwikkeld zijn om ze te doden. Zonder werkende antimicrobiële middelen kunnen veelvoorkomende infectieziekten opnieuw levensbedreigend worden en kunnen risicovolle ingrepen, zoals chemotherapie en chirurgie, niet meer worden uitgevoerd. AMR is wereldwijd een urgent probleem met in 2050 een geschat aantal wereldwijde doden van 10 miljoen per jaar.

Dit proefschrift richt zich op AMR in het ziekenhuis. Het ziekenhuis is de belangrijkste bron voor het ontstaan en verspreiden van AMR. Het gedrag van zorgprofessionals (zoals artsen en verpleegkundigen) in ziekenhuizen is van invloed op het ontstaan van AMR en het verspreiden van resistente micro-organismen, bijvoorbeeld door antimicrobiële middelen onjuist voor te schrijven en hygiënerichtlijnen niet op te volgen. *AMR stewardship* is dan ook vooral gericht op het beïnvloeden van het gedrag van zorgprofessionals en bestaat in ziekenhuizen uit drie programma's:

1. *Antimicrobiële stewardship programma (ASP)*: richten zich op het juist voorschrijven van antimicrobiële middelen.
2. *Infectie preventie en controle programma (ICP)*: richten zich op het voorkomen van de verspreiding van (resistente) micro-organismen.
3. *Diagnostische stewardship programma (DSP)*: richten zich op het gebruiken van microbiologische diagnostische testen om de juiste behandeling te bepalen.

Deze complementaire programma's bestaan uit verschillende *AMR preventie maatregelen (APM)*, zoals het aanbieden van diagnostische en therapeutische richtlijnen, scholing en het instellen van antimicrobiële stewardship teams die toezicht houden op antimicrobiële consumptie en AMR. De afgelopen jaren is, met name in Nederland, veel verbeterd door AMR stewardship. Toch zijn er nog steeds aanzienlijke kansen tot verbetering en blijft het gezien de toename van AMR ook noodzakelijk om verder te verbeteren.

In dit proefschrift worden twee veelbelovende, maar nog niet voldoende onderzochte, kansen gecombineerd die APM in ziekenhuizen kunnen verbeteren: 1) bottom-up ontwikkeling van APM en 2) eHealth technologie.

1. *Bottom-up ontwikkeling*, waarbij zorgprofessionals worden betrokken bij het ontwikkelen en implementeren van APM in hun dagelijkse werkroutines, is op dit moment nog ondergeschikt aan de top-down ontwikkeling van APM. In de huidige top-down benadering worden APM ontwikkeld en geïmplementeerd door en met AMR-experts, zoals arts-microbiologen, specialisten infectieziekten, deskundigen infectiepreventie en apothekers. Dit leidt tot APM die voornamelijk gericht zijn op het scholen van zorgprofessionals om een verondersteld tekort in kennis- en bewustzijn van AMR op te lossen, terwijl dit niet aansluit bij de behoeften van zorgprofessionals. Zorgprofessionals worden over het hoofd gezien in het ontwikkel- en implementatieproces van APM. Dit leidt op zijn beurt tot een slechte afstemming tussen APM, de behoeften en vaardigheden van zorgprofessionals en hun klinische praktijk (ook wel context genoemd), wat leidt tot suboptimale APM.
2. *eHealth technologie* wordt in toenemende mate ingezet om APM te ondersteunen. De grote hoeveelheid data die door het gebruik van eHealth technologie verzameld wordt, kunnen omgezet worden in bruikbare inzichten om zorgprofessionals te ondersteunen. Door middel van data gestuurde eHealth technologie kunnen APM afgestemd en gepersonaliseerd worden aansluitend op de behoeften van zorgprofessionals en hun context. De toegevoegde waarde van data gestuurde eHealth-technologie wordt echter alleen gerealiseerd als de eHealth technologie qua ontwerp en functionaliteiten aansluit bij de behoeften van zorgprofessionals. Daarnaast moeten de data geanalyseerd en omgezet worden in begrijpelijke en bruikbare informatie die vervolgens op een duidelijke, beknopte en actiegerichte manier gecommuniceerd wordt aan zorgprofessionals. Data visualisatie kan de transformatie van gegevens naar begrijpelijke en bruikbare informatie ondersteunen en de communicatie van deze informatie naar zorgprofessionals verbeteren.

In dit proefschrift combineren we deze twee kansen door het bottom-up participatief ontwikkelen van een APM leer- en verbeterstrategie, ondersteund door data gedreven eHealth technologie. Hiervoor hanteren we een mensgerichte socio-technische benadering met specifieke aandacht voor 1) hoe een bottom-up participatieve benadering het ontwerp van de eHealth-technologie en de betrokkenheid van zorgprofessionals bij de leer- en verbeterstrategie kan verbeteren, en 2) hoe interdisciplinaire theoretische onderbouwing weloverwogen keuzes en transparante rapportage over de ontwikkeling en implementatie van een eHealth technologie voor APM kan verbeteren.

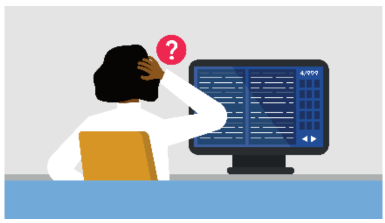
In deze samenvatting worden de onderzoeksvragen en bevindingen per hoofdstuk beschreven.

Hoe ervaren zorgprofessionals het AMR probleem en hun eigen bijdrage aan APM?

In **hoofdstuk 2** worden de resultaten van een grensoverschrijdende (Duitsland-Nederland) vragenlijst studie beschreven, waarin gevraagd is naar de percepties van zorgprofessionals met betrekking tot AMR en APM en hoe zij hun eigen bijdrage aan het oplossen van het probleem ervaren. Hoewel zowel Duitse als Nederlandse zorgprofessionals bekend waren met het AMR probleem, beschouwden zij hun bijdrage aan het beperken van AMR als onvoldoende en voelden zij zich niet voldoende ondersteund hierin.

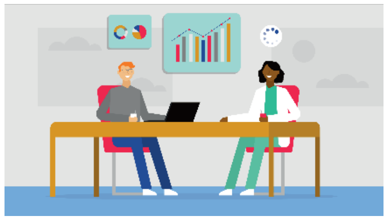
Daarom concentreerde dit proefschrift zich op *audit en feedback (AF)*, een specifieke APM die objectieve inzichten verschaft in hoe zorgprofessionals met hun eigen werkroutines (bijvoorbeeld door het voorschrijven van antibiotica) bijdragen aan het beperken van AMR. *Audit en feedback van APM (APM-AF)* is één van de aanbevolen APM door gezondheidsautoriteiten. Er wordt daarbij echter weinig invulling gegeven aan hoe APM-AF toegepast, ontwikkeld en geïmplementeerd kan worden zodat het ook daadwerkelijk van toegevoegde waarde is voor zorgprofessionals en niet alleen voor AMR-experts of voor externe verantwoording aan bijvoorbeeld de inspectie.

Wat zijn de behoeften en verwachtingen van zorgprofessionals voor (toekomstige) APM-AF?

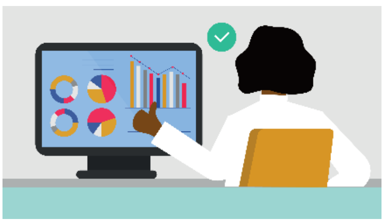


In **hoofdstuk 3** richtten we ons via interviews met zorgprofessionals op het balanceren van de huidige voornamelijk top-down, expert-gedreven aanpak voor APM-AF met bottom-up behoeften en verwachtingen van zorgprofessionals voor (toekomstige) APM-AF. Zorgprofessionals eisten inzichten uit audits in alle facetten van APM in hun werkroutines (ASP, ICP en DSP). Zij prefereerden eenvoudige en actiegerichte feedback die uitnodigt tot interdisciplinaire discussies, zodat onderbouwde verbeteracties kunnen worden gerealiseerd. Zorgprofessionals gaven aan dat APM-AF niet moet worden gezien als een geïsoleerde ad-hoc interventie, maar als een terugkerende, langdurige en organische leer- en verbeteringsstrategie die de primaire doelen van zorgprofessionals (d.w.z. het verbeteren van de kwaliteit en veiligheid van zorg voor individuele patiënten) en AMR experts (d.w.z. het verminderen van de last van AMR) in evenwicht brengt.

Hoe kan een bottom-up participatieve ontwikkelaanpak het persuasieve ontwerp van APM-AF-systemen verbeteren?



In **hoofdstuk 4** hebben we laten zien hoe het betrekken van zorgprofessionals bij de bottom-up participatieve ontwikkelaanpak leidde tot een persuasief ontwerp van APM-AF systeem prototypes. Tegelijkertijd verhoogde deze aanpak de betrokkenheid van eindgebruikers, wat duurzame implementatie bevordert. In twee opeenvolgende focusgroepen werden aanvullende behoeften van zorgprofessionals voor APM-AF als leer- en verbeterstrategie blootgelegd. Dit betrof onder andere persuasieve ontwerpeisen voor de inhoud, functionaliteiten en vormgeving van het APM-AF-systeem, en randvoorwaarden voor implementatie en duurzaam gebruik in de praktijk (d.w.z. hoe zorgprofessionals betrokken kunnen worden bij het accepteren en gebruiken van het APM-AF-systeem in de praktijk). Dit onderzoek resulteerde in de ontwikkeling van verschillende prototypes in twee iteratieve rondes die de basis kunnen vormen voor toekomstige APM-AF systeem ontwikkeling, zoals reeds gestart (1).



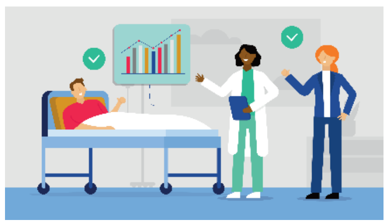
Hoe passen datavisualisaties bij de visuele gewoonten van AMR-professionals en wetenschappers?

Data visualisatie kan helpen bij het transformeren van data (uit bijvoorbeeld audits) naar begrijpelijke en bruikbare informatie. Data visualisatie is dan ook een integraal onderdeel van APM-AF. Toch zijn er geen one-size-fits-all regels voor data visualisatie uit andere velden die eenvoudig kunnen worden toegepast op AMR-stewardship. Daarom hebben we in **hoofdstuk 5** een 'visueel woordenboek' voor AMR-onderzoek geconstrueerd, inclusief veelvoorkomende ontwerp elementen voor specifieke AMR-inhoud. Dit is gedaan via een systematische beoordeling van data visualisaties in wetenschappelijke AMR publicaties op basis van bestaande visualisatie nomenclatuur en categorieën. Binnen het heterogene gebruik van data visualisaties in AMR-onderzoek identificeerden we homogene ontwerpkeuzes en veelvoorkomende visualisatie problemen (bijv. mismatches in kleur gebruik). De opgestelde do's en don'ts (pagina 133) kunnen ontwikkelaars helpen bij het ontwerpen van visualisaties die passen bij de data en bij wat de AMR stewardship doelgroep gewend is om te zien.

Wat kunnen we leren van bestaande studies over de ontwikkeling en implementatie van APM-AF met betrekking tot hun theoretische onderbouwing en gerapporteerde constructen?

Om te leren van andere studies en onze bevindingen te valideren, heeft de scoping review in **hoofdstuk 6** inzicht gegeven in bestaande ontwikkel- en implementatie-strategieën voor APM-AF-systemen. Er werd een grote verscheidenheid aan theoretische onderbouwingen en gerapporteerde informatie aangetoond. Om de heterogene onderzoeken te kunnen vergelijken en (de rapportage van) toekomstige APM-AF-onderzoeken te ondersteunen, werd een interdisciplinair conceptueel raamwerk gecreëerd dat theorieën, modellen en raamwerken voor AF (bijv. Feedback Intervention Theory) en de ontwikkeling en implementatie van eHealth (bijv. CeHRes Roadmap) integreert. Slechts weinig van de geïncludeerde studies beschrijven expliciet hoe keuzes voor APM-AF-systemen en hun ontwikkel- en implementatieproces werden onderbouwd. Dit vermindert de transparantie en reproduceerbaarheid van individuele studies en beperkt daarmee de mogelijkheid om van anderen te leren. Het in dit proefschrift ontwikkelde conceptuele kader (pagina's 171-172) kan dienen als een checklist die onderzoekers, zorgprofessionals en beleidsmakers helpt bij het maken van weloverwogen keuzes bij de ontwikkeling en implementatie van APM-AF.

Wat hebben we geleerd van de bottom-up participatieve ontwikkeling en implementatie van APM-AF-systemen als leer- en verbeterstrategie?



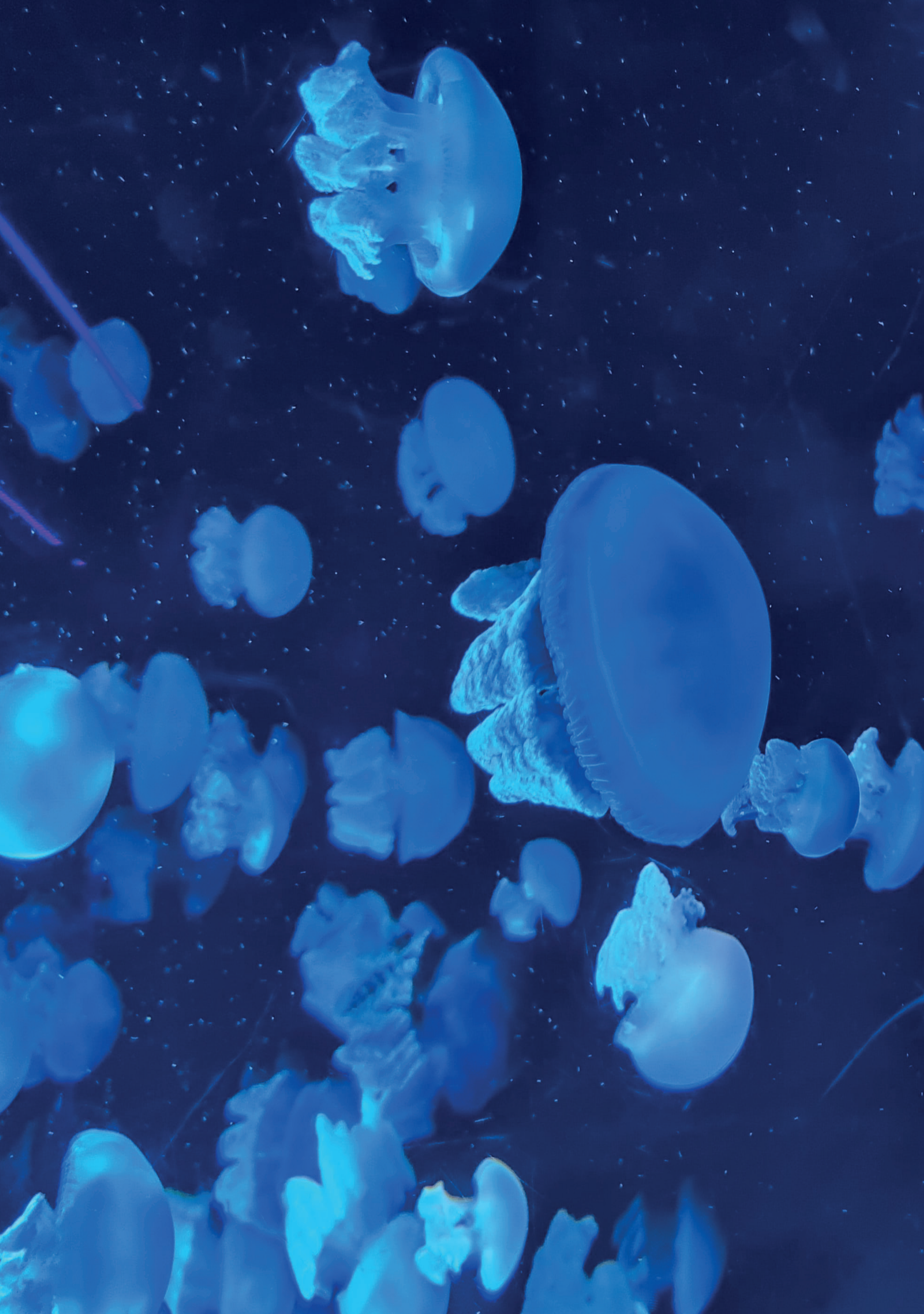
In **hoofdstuk 7** reflecteren we op de geleerde lessen uit onze bottom-up participatieve ontwikkel- en implementatieaanpak om aanbevelingen te doen voor (de ontwikkeling en implementatie van) APM-AF-systemen als leer- en verbeterstrategie. De belangrijkste aanbevelingen zijn:

1) Betrek zorgprofessionals, AMR experts en andere relevante belanghebbenden (bijv. ziekenhuis bestuurders) vanaf het begin van en gedurende het gehele ontwikkel- en implementatieproces om bottom-up en top-down overwegingen zorgvuldig af te wegen.
2) APM-AF moet gezien worden als een voortdurende leer- en verbeterstrategie die geïntegreerd is met de werkroutines van zorgprofessionals, rekening houdende met de randvoorwaarden zoals beschreven in hoofdstukken 3 en 4 en in aanvulling op andere APM (bijv. beslissingsondersteuning).

3) Voor de theoretische onderbouwing van APM-AF bevelen we een sociaal-medisch-technische benadering aan om een breed begrip van relevante aspecten voor het 'wicked' AMR probleem te verkrijgen. Specifieker voor APM-AF betekent dit het integreren van theorieën, modellen en raamwerken voor AMR en APM, voor AF en andere gedragsveranderingstechnieken, voor participatieve eHealth ontwikkeling, mensgericht en persuasief ontwerpen, en uit de verbeter en implementatie wetenschappen.
4) Het conceptuele kader (in hoofdstuk 6) kan worden gebruikt om toekomstige APM-AF ontwikkel- en implementatieprojecten te begeleiden om ervoor te zorgen dat alle relevante aspecten voor het ontwerp van APM-AF-systemen worden overwogen en gerapporteerd (d.w.z. constructen voor audit, feedback, het APM-AF-systeem en APM-AF als leer- en verbeterstrategie). Specifieke aanbevelingen voor het ontwerp van APM-AF-systemen worden gegeven in hoofdstukken 3 en 4, en voor datavisualisaties in hoofdstuk 5. Belangrijk is dat toekomstige projecten deze aanbevelingen aanpassen aan de doelstellingen, belanghebbenden en context van hun eigen project.

Conclusie

Door zowel nationale als interdisciplinaire grenzen te overschrijden, heeft onze bottom-up participatieve ontwikkel- en implementatieaanpak vernieuwende inzichten opgeleverd over de interacties tussen de technologie (het APM-AF systeem), mensen (zorgprofessionals en AMR experts) en hun context (landen, organisaties en werkroutines) die aanknopingspunten bieden voor de ontwikkeling en implementatie van APM-AF in ziekenhuizen. Daarnaast hebben we de toegevoegde waarde van interdisciplinair onderzoek voor AMR en APM aangetoond en gedemonstreerd hoe interdisciplinair onderzoek vormgegeven kan worden door de integratie van interdisciplinaire theorieën, modellen en raamwerken. Hiermee hebben we belangrijke kennis vergaard waarmee de door gezondheidsautoriteiten aanbevolen APM, zoals tracking, monitoring, surveillance, rapportage en feedback, getransformeerd kunnen worden in een leer- en verbeterstrategie die van toegevoegde waarde is voor zowel zorgprofessionals als AMR experts. Daarnaast kan deze aanpak vertaald worden naar andere 'wicked problems' om de kwaliteit en veiligheid van de gezondheidszorg te verbeteren.



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Kip H, **Keizer J**, Kelders SM. Development methods for eHealth technologies: an initial overview. Oral presentation at Supporting Health by Technology X conference. 10-11 June 2021, Enschede, The Netherlands. (online)

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Köhle N, **Keizer J**, Kip H, Sieverink F, Beerlage-De Jong N, Kelders, S.M. & van Gemert-Pijnen JEWC. Blended eHealth education. Presentation at Supporting Health by Technology conference. 16-17 May 2019, Groningen, The Netherlands.

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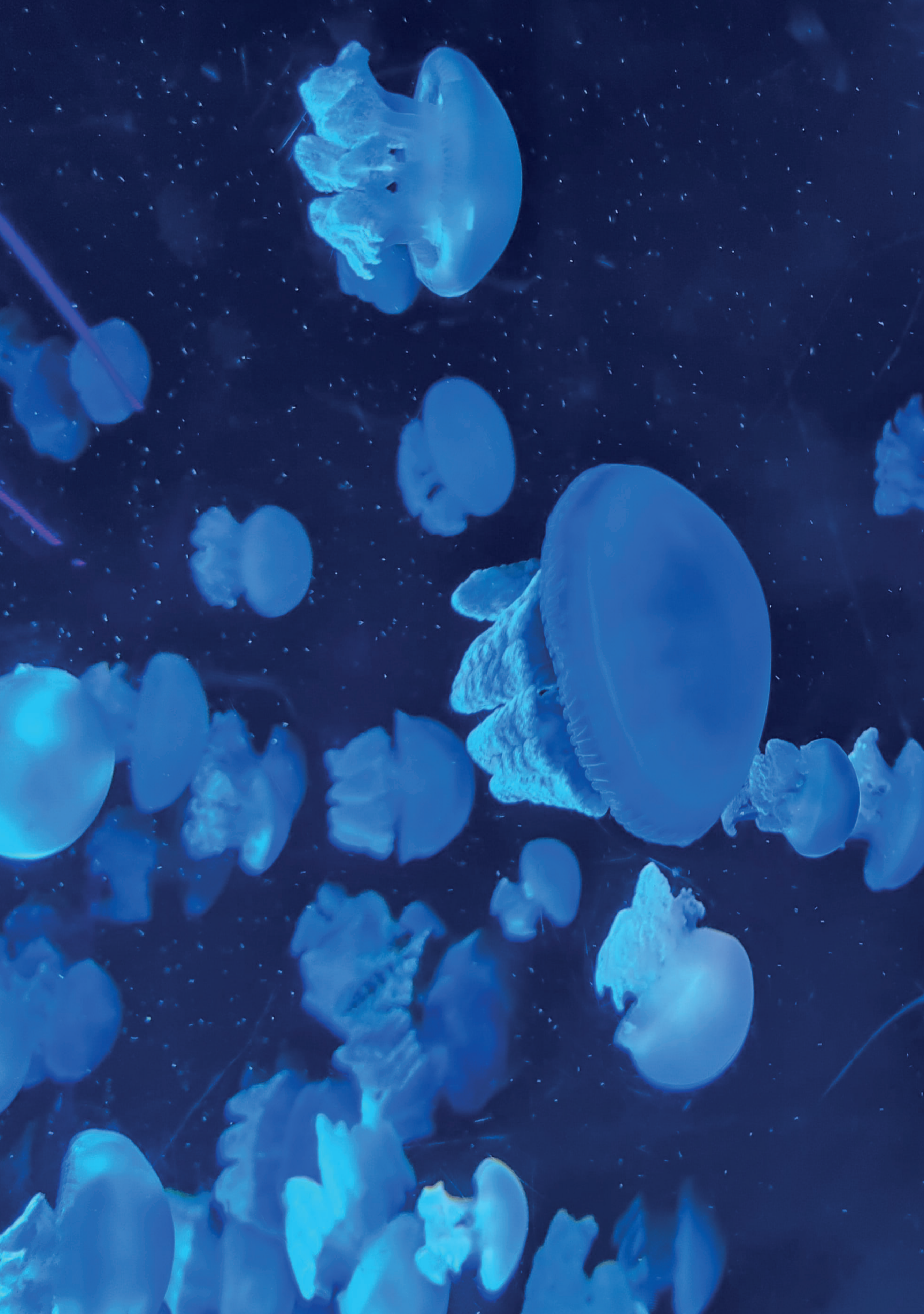
Keizer J, Al Naiemi N, Te Riet-Warning R, Braakman-Jansen LMA, van Gemert-Pijnen JEWC. EurHealth-1Health: supporting healthcare workers to limit antibiotic resistance in hospitals. Poster presentation at Supporting Health By Technology conference. 1 June 2018. Enschede, The Netherlands.



Dankwoord (Acknowledgements)

Dankwoord (Acknowledgements)

Tijdens mijn laatste jaar Health Sciences kwam ik als student-assistent van de eHealth MOOC in aanraking met de wereld van eHealth onderzoek. Samen met zorgprofessionals in de praktijk een (technologische) bijdrage leveren aan het oplossen van échte problemen; dat sprak mij erg aan. Ik was dan ook erg enthousiast toen ik de kans kreeg om me tijdens een PhD traject te verdiepen in eHealth technologie in de strijd tegen "super bugs". Dit resulteerde in dit proefschrift waarmee hopelijk een steentje bijgedragen wordt aan het beperken van AMR en het verbeteren van de gezondheidszorg. Dit betekende ook dat ik de kans kreeg om met veel verschillende mensen samen te werken. Zonder hun hulp had dit proefschrift er niet gelegen, dus een uitgebreid woord van dank is zeker op z'n plaats.

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Soedah, al.