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Complex entanglements: design-led research for infection prevention and control training tools

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Abstract

Anti-microbial resistance (AMR) is an established and growing challenge in developed and developing countries around the world. Effective infection prevention and control (IPC) is an essential aspect of tackling AMR and healthcare associated infections (HAIs). The uptake of appropriate IPC protocols is heavily influenced by the awareness and perception of risk and consequent behaviour of humans interacting with and within physical care and treatment environments. Here, the development of effective communications and teaching tools is essential in ensuring individuals' perceptions, awareness, understanding and behaviours are in line with scientific recommendations for reducing infections and their transmission.

This positioning paper problematizes and highlights challenges facing Design for work in the area of IPC. It outlines a programme of design-led inter-disciplinary research to develop interactive digital educational training tools to address IPC issues using dynamic visualisation techniques, participative co-design, and iterative prototyping approaches while utilising data from scientific disciplines. It is concerned with the challenges presented in modelling the complex entanglements of messy situations and in translating and (re)presenting complex data in 'accessible' formats to a variety of stakeholders. It also acknowledges the value of work in other fields such as agent-based modelling, software programming and computational science. The discussion is illustrated by examples and findings from the development of prototype pedagogic interventions for two distinct environments, the first within the hospital ward and the second within the small animal veterinary practice.

Keywords: design-led research, visualisation, participative co-design, iterative prototyping, infection prevention and control, anti-microbial resistance, healthcare ecosystems

1 Introduction

The work described here is situated within the context of growing global concern due to the increasing incidence of antimicrobial resistance (AMR), now recognised as one of the most challenging issues for human and animal health. The causes of AMR are multifarious including over-prescription of antibiotics (ABX), inappropriate use of ABX and as a consequence of poor infection prevention and control (IPC) and increased incidence of healthcare associated infections (HAIs). Growing numbers of resistant infections are leading to many existing ABX becoming less effective (ESRC, 2014; WHO, 2015). O'Neill (2016) predicts that the toll on human life due to AMR will exceed 10 million annually by 2050. As a consequence it is the subject of increasing attention from, e.g., the UK's cross-council AMR initiative (Medical Research Council, 2015) and via the EC AMR Road Map (European Commission, 2015).

As the emergence of new ABX will continue to prove an expensive and protracted - if not elusive - process, the programme of work described here takes a complementary approach to tackling HAIs through improved IPC, one which can be progressed and implemented in the shorter term, pursued through the Design-led development of educational tools using visualisation techniques for the in-service IPC training for staff in human and animal hospitals.

2 A challenge for design?

While it is recognised that in addressing the global challenge of AMR, those scientific disciplines more usually associated with research into, e.g., pathogens, infectious diseases, the microbiome, antibiotics, bio-markers and diagnostics, have become, to a greater or lesser degree, engaged with this challenge, it is also acknowledged that *"in the UK, the field suffers from limited capacity"* (Pearce, 2017). It is also acknowledged that there is, in the field of Design (along with the social sciences and culture), a *"lack of full engagement of existing capacity with the challenge …*" (ibid). One question then, is how can Design, as a field, become more fully engaged with this challenge and to better understand what its potential contribution(s) could, and should, be?

While good evidence in scientific data (microbial and behavioural) exists to inform best practise in IPC, these data are largely published in traditional academic journal formats. These papers are often the result of reductive studies, the presentations of data are often de-contextualised, and the studies seldom incorporate multiple factors. Thus, they have a limited impact on how practitioners understand the relationship between their behaviours and the practise of IPC and the mechanisms for - and risks of - HAIs and AMR developing in healthcare environments in the context of their daily practice.

In healthcare settings there are a multiplicity of actors. There are numerous roles and hierarchical status of healthcare staff: the consultant practitioner, nursing staff, patient (and – in the veterinary hospital arena - animals), and ancillary services staff. These individuals' routes-of-travel through the sequence of spaces, the points of contact with, e.g., furnishings, surfaces, equipment and patient records ('hard' elements of the setting), air temperature, humidity and currents ('soft' elements of the setting), together with the diverse nature of pathogens, and treatment and cleaning interventions create complex, messy and dynamic care and treatment 'ecosystems'. Microbes with their different locations, routes of transmission, densities and persistences, are invisible to the naked eye and so without resorting to populist clichés in their representation, how does one convey the diverse nature, location, transmission, density and endurance of these invisible pathogens, and an understanding of when and where risks arise?

3 Modelling complex, dynamic and messy situations

What can Design contribute to the above? This depends, to an extent, on how designers see themselves, and to what extent - and at what level - they wish to become involved in the AMR challenge. Some traditional disciplines within Design may wish to take the graphic information design route. There have already been attempts at visually representing the whole AMR 'system'. For example, the Department of Health's (DoH, 2014) systems map: " … provides a visual representation of the various influences on the development of AMR and the interaction between them … to understanding the pathways that spread infection and resistance. A top level map shows the high level pathways that infections may take between animals, the environment and humans …". Sub-maps also provide pertinent details for animals and environment, hospital, general practitioner care and the community, and pharmaceuticals, diagnostics and vaccinations. The DoH's map for 'Drivers that increase the burden of infection' (DoH, 2016) is similarly informative but again limited. The DoH's key purpose "in building systems maps is to gain insight in the underlying structure of a messy, complex situation" (DoH, 2014) but it admits that this is a generic approach which would benefit from further development. Here, the ability to represent and reflect the complexity and dynamic nature of IPC environments in which HAIs and AMR are generated is severely limited.

The above immediately poses the challenge of how to model and represent this 'complex entanglement' (Schoffelen et al., 2015, p180) of multifarious agents, causes and consequences, in an accessible and meaningfully contextualised manner. While from a theoretical perspective, Actor Network Theory (ANT) may be helpful in illuminating the actors and their roles and relationships in these kinds of contexts (Mullaney, 2016; Morelli & Tollestrup, 2007) a significant challenge is in communicating the dynamic complexity of the roles of the various actors and agents implicated in the development of HAIs and AMR in an accessible, contextualised and meaningful way to the diverse range of stakeholders involved their daily practice. It requires only one transgressor in this ecosystem chain for infection to spread. Surely this is a daunting challenge to model and represent?

4 A prototype IPC training tool

In an attempt to address the issue of HAIs, an exploratory study, visionOn, led by the author, was concerned with the design and development of a prototype interactive IPC training tool for hospital staff. Its objective was to improve awareness and understanding of IPC issues in the hospital ward setting. This was developed over three stages through a 12-month co-design process, involving two Scottish national health service (NHSS) boards, the input of 150 NHSS nurses, doctors, cleaning and other ancilliary staff and students, together with a commercial partner with tablet-based educational and training content on the market to assist in the correct use of their hospital cleaning products.

As a consequence of the study, the project team produced a proof-of-concept tool for the in-ward training of hospital staff in the IPC of HAIs. This tablet-based tool explored the use of dynamic visualisation methods to 'make visible' pathogens and their location, survival and transmission in the ward-based context. The interactive tool (figure 1) comprised: a virtual ward model with a zoom-in (micro) zoom-out (macro) facility; interactive ward-based visuals with spatial (routes of transmission) and temporal (persistence of pathogens over time) dimensions which were pathogen specific (MRSA, norovirus or *C. difficile*); learning points showing, e.g., (with respect to cleaning regimens), that different pathogens have different survival times within the ward environment depending on whether adequate cleaning had taken place or not; and further layered information available if required, such as risk to patient (specific to each pathogen type). The development team comprised the author - a designer specialising in co-design in healthcare, a nursing academic with IPC expertise, and a microbiologist. A software engineer with extensive experience of co-development and iterative prototyping methods and a medical visualiser were also key members of this small team who developed the tool on an Android platform. Source code comprised Java software for the Graphical User Interface to communicate via Java Native Interface to native code written in C++. To keep costs low, the open source 3d graphics library OGRE and the Bullet Physics SDK library were used to provide dynamic simulation for the movement of pathogens, e.g., along the surface of objects or through the air. Taking some cues from serious games approaches, an interactive dynamic infographics approach to imparting details from the behavioural and microbial data derived from previously published data. At each stage of development the prototypes were evaluated by a range of hospital staff in different roles (e.g., doctor, nurse and cleaner) through a workbook with a mix of open and Likert-scale questions.

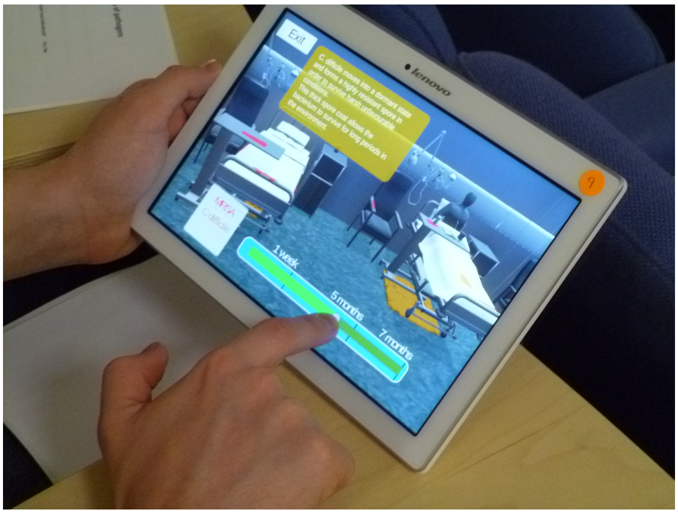

Figure 1. A healthcare participant interacting with a second stage prototype of the tablet-based tool while evaluating this through a set of workbook questions, in this case relating to the persistence of MRSA in the hospital ward over time.

On evaluation, the prototype tool was found to increase participants' awareness about pathogens, helped to explain 'why' IPC procedures should be followed, and helped to reinforce understanding of how HAIs occur. The tablet-based visualisations were also found to be engaging and supportive of different learning styles, to contain information relevant for the different staff cohorts with a mix of experience levels. Staff reported that this offered a new perspective on pathogens, enabling them to 'see' these contextualised in the virtual ward, to make these 'seem more real'. A fuller description of the process of the tool's development can be found in Macdonald et al. (2016) and the findings are detailed in Macdonald et al. (2017).

However positive were the findings outlined above from the evaluation of this prototype, on reflection there was a tendency to create a virtual ward model driven, from the software engineer's and medical visualiser's perspective, fueled by feedback from stakeholders, with ambitions of an ever-increasing level of 'realistic' detail such as bed-side and general ward clutter. This created a tension: did this 'visual faithfulness' approach serve our purposes well, or did this provide a somewhat distracting background, presenting a challenge for clearly locating and 'making visible' the more pertinent issues, e.g., the location of pathogens, their population densities, the causes of infection and their routes of transmission? In a digital world saturated with 'virtual realism', is this the best course of development to follow?

5 Value from mathematical modelling and computing-led simulation?

If, however, our attention is momentarily averted from the visually and virtually realistic 'solution', and if one considers the potential contribution of mathematical modelling, Suthar et al. (2014) provide a model, set in the context of a veterinary teaching hospital, which "… simulates contamination of transmission points, healthcare workers, and patients as well as the effects of decontamination of transmission points, disinfection of healthcare workers, and ABX treatments of canine patients ... [and which] was parameterized using data obtained from hospital records, information obtained by interviews with hospital staff, and the published literature."

What is immediately interesting and valuable in this work is the attempt to model the complexity of the situation, using data from a number of sources. It differentiated the types of treatment pathway trajectory through a succession of healthcare spaces, and the effects of various regimes and interventions, e.g., in the decontamination of transmission points, and in the rates of colonization by various pathogens on, e.g., surfaces and in animal patients and in staff. The modelling code, using a version of MATLAB, enabled hundreds of simulations to be run, starting with an empty, sterile hospital and populating this with microbial data on colonisation of surfaces, staff and animals over the course of a simulated year. The audience for this kind of academic paper is obviously very specialist, but what if the benefits of this kind of mathematical modelling could be made more accessible and have wider benefit in the challenge of tackling HAIs and AMR?

Simulation, as the imitation of a real world process, system or actor(s), is useful for the purpose of understanding of – and experimenting with – the world we are intending to look at. However, the format of the presentation of the data in the Suthar et al. journal paper is problematic to the non-specialist: the data are abstract and decontextualised: although they might show, e.g., the distribution of strain types and colonisation or infection status in the patient population, understanding and 'seeing' the connection between these and human interactions and behaviours for the practitioner still remains problematic. How, then, does one make these data 'come alive' in a meaningful manner?

An 'events simulator' such as MicroSaint® Sharp, is essentially a dynamic data-fed flow chart with the option of presenting the data in a simulated environment. Taking an emergency hospital admissions ward as an example, the consequences of different numbers of individuals arriving with a variety of treatment needs, being triaged, and being processed through the treatment rooms can be observed. Such a simulator helps present complex data visually in a contextualized manner, and so may be able to reach and engage a larger and varied number of 'stakeholders' in the identification and discussion of issues. Additionally, much work, centred around Agent Based Modeling (ABM), is being developed in the field of computational science. ABM is "a class of computational models for simulating the actions and interactions of autonomous agents (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole. It combines elements of game theory, complex systems, emergence, computational sociology, multi-agent systems, and evolutionary programming" (Wikipedia, 2018) as, for example, in Malik et al. (2015). Would ABM-type approaches indicate a potentially fruitful track for Design to pursue in this AMR context?

6 A prototype microbial reality simulator

With the above in mind, a new study, AMRSim (A Microbial Reality Simulator), is concerned with the development of a pedagogic intervention designed to influence the perception of risk, amongst veterinary staff, in the small animal veterinary practice environment. This is a more recent and, as yet, incomplete study, but one in which the issues from the first study, visionOn, have been reflected upon and which have thrown into sharp relief some challenges for the AMRSim team. It is proposed that the AMRSim model will have four layers of actor data: spatial, people, animal, and microbial (figure 2). As microbes may be transferred to surfaces, other humans and animals and back again as each of these actors interact within the indoor environment, the risk of contamination is being proposed as the combination of the number of contacts and their duration. The flow of humans and animals through their environment, the actions and interactions between humans, animals and their environment will be modelled from captured video data and through interviews and questionnaires**.** The prevalence, density and location of microbes within the veterinary practice will be based on extensive published data collected from similar veterinary facilities. Within this model, and for the purpose of constructing the AMRSim tool and defining the nature of - and selecting - the data, the team is considering the use of underlying mathematical 'rules', such as a '*medium/substance*' rule for pathogen spread (e.g., fluid/liquid, aerosol effect) and a '*contact*' rule (e.g., for structures and surfaces) that dictates, e.g., 10% of transfer for every second of contact.

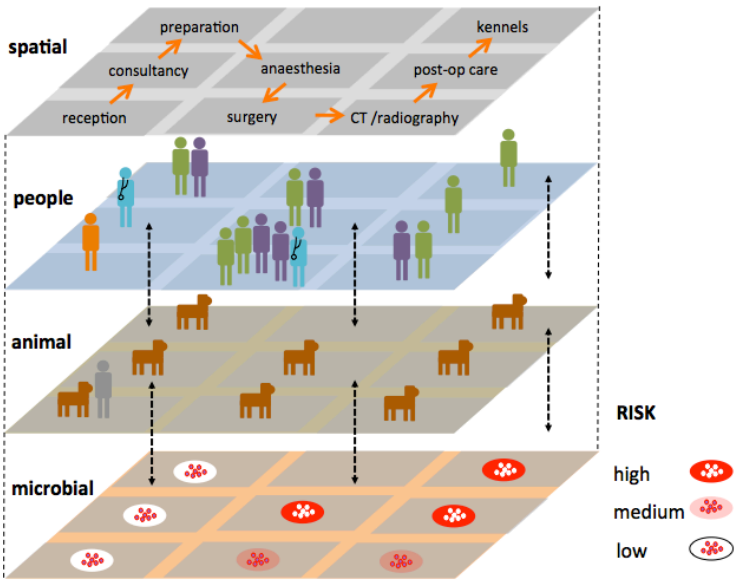

Figure 2. The AMRSim conceptual model showing the different layers of data within the tool. As staff and animals move through the different spaces of the small animal veterinary hospital for different procedures the risk of infection is proposed through a set of rules.

The AMRSim team comprise the following specialisms: co-design specialising in healthcare; 3D programming, simulation and visualisation; veterinary bacteriology; veterinary pathology and infectious diseases; veterinary surgery; veterinary nursing; environmental psychology; and healthcare spatial design. The digital training tool user interface and all interactive simulations will be produced using Unity 5. All models and animations will be generated in Autodesk 3DSMax and exported as FBX files in Unity. The tool will be developed iteratively through a series of multidisciplinary and stakeholder co-design workshops. The ambition, through one of the project workpackages, is to be able to demonstrate a change in perception of risk after the use of the training tool. A further study beyond the resources of this current project, would evaluate the effect of this form of training on the actual incidence of infection and resistance-development.

7 Discussion

Indisputably, inter-disciplinary work is vital to make in-roads into the AMR challenge. This is already evident in the discussions, questions and proposals which have emerged when the different specialisms in the AMRSim team, such as 3D programming, environmental psychology, veterinary surgery and bacteriology, work together. In the visionOn project, the approach taken did not allow the separate layers of data to be stripped out and presented separately or in combination. Although the findings from the use of the visionOn training tool indicated that it had increased awareness and understanding across the different hospital staff cohorts, the prototype model was fairly representational (3D virtual ward) but was very limited in what it could show (predetermined locations, routes of transmission, and persistence of *C.difficile,* norovirus and MRSA with and without the effects if cleaning). It was pre-programmed with these interactive scenarios and did not allow for the opportunity to more speculatively model, e.g., when IPC was working well or poorly with the consequent real-time impact on microbial load: something we may wish to address in AMRSim.

If we were able to model infection risk and transmission scenarios in a way which enabled us to change the variables (within each of the space, animal, human, and microbe data) and if we were able to see different kinds of data presented simultaneously, could this help us understand sufficiently well to change our perception of risk - and ultimately affect behaviour? Referring back to the ABM discussion above, our desire is to simulate the actions and interactions of autonomous agents with a view to assessing their effects on the system as a whole. Elements of those tools outlined in section 5 above may be useful to consider. As a way into the development of the AMRSim tool, we shall also focus on situations and places where there is a high risk of both acquiring and developing infections, identified from the data and from interviews, rather than following the whole patient journey.

Addressing different healthcare issues (ageing and stroke), a technique used in prior work may be appropriate here. In the development of a digital mannequin to clearly communicate functional demand (i.e. how hard the muscles work on either side of a joint to support that joint), the mannequin was presented in dynamic 3D as the data had been captured in 3D. Its 'stick-like' appearance was found most suitable as a platform for further visual graphical data. A 'traffic light' system superimposed on the hip and knee joints showed 'green' (low functional demand) through 'orange' to 'red' (high functional demand when there was a high probability of failure of the muscles to support that joint). At the same time the changing numerical value of the 'moment' (the product of a force and the distance from a set reference point) on the joint was simultaneously displayed alongside (figure 3). While 'functional demand' and 'moment' data in this case may traditionally have been the preserve of the biomechanist and physicist and have little meaning to lay or non-specialist individuals, nonetheless it was found to easily convey, in an accessible manner, the changing 'stresses' on joints to lay or non-specialist individuals such as older people and therapists (Macdonald et al, 2009; Macdonald, 2018).

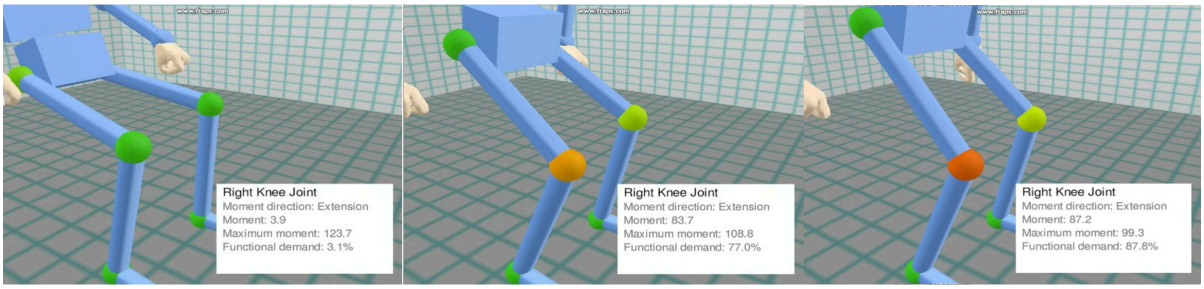

Figure 3. The digital 3D mannequin conveying complex dynamic data: stills from a video showing the changing 'functional demand' (FD) of a single individual during movement and how the changing FD was represented using a 'traffic light' system (green = low functional demand and red = high functional demand). It was also shown simultaneously, numerically (as a percentage), alongside the moment force (numerical value) and direction.

What is of value here is the ability to convey different kinds of data, all concerned with the dynamic movement of that individual, in different ways meaningfully to different stakeholders - simultaneously. Although the mannequin tool can be invested with the data specifically relating to a single individual, the mannequin is not 'realistic' but provides sufficient dynamic and contextualised information for the specialist, non-specialist and lay alike to clearly understand the issues arising. A development of this approach was later used in post-stroke rehabilitation trials and was found to improve communication between patient and therapist, to improve understanding of the need for particular rehabilitation exercises and the progress made with these (Ballinger et al, 2017).

8 Conclusions

Ten other new AHRC-funded projects have recently been supported by the same initiative (AMR in the Real World: The Indoor and Built Environment), and which include: the influence of ventilation design on the prevalence of anti-microbial bacteria in homes (architecture-led); designing ambient communications to improve hygiene in primary school toilets (communication-design-led); niches for organic territories in bio-augmented design (architecture-led); re-envisaging infection practice ecologies in nursing through arts and humanities approaches (nursing and design-led); information design and architecture in persuasive pharmacy space: combating anti-microbial resistance (communication-design-led); excising infection in the surgical environment (architecture-led). So, here is the beginnings of a small group of designers and architects working alongside disciplines in the more traditional fields associated with AMR, HAIs and IPC. However, the critical mass of this group needs to grow and greater opportunities for Design to be involved in collaborative international efforts needs to be developed.

Returning to Pearce's (2017) statement that there is, in the field of Design a "lack of full engagement of existing capacity with the [AMR] challenge …", this author hopes the work described above will begin to make some inroads into this area and begin to provide examplars where the contributions of Design-led approaches can be clearly understood and communicated. The specific individual contributions of Design expertise may not necessarily be unique in themselves, but in combination and working with other (perhaps more reductive) disciplines, they appear to have a certain potency.

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