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Disentangling complexity: a visualisation-led tool for healthcare associated infection training

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Abstract: Training in infection prevention and control (IPC) measures is crucial to minimise the incidence of healthcare-associated infections (HAIs), a growing cause of patient illness and death in hospital. This paper describes a participative approach to developing a prototype tablet-based digital training tool using dynamic visualisation-led techniques to raise awareness and understanding of IPC and HAIs for hospital-based staff. An evidence-based and iterative visualisation prototyping process was used to engage staff and invite contributions from across a number of roles within the NHS, a typically hierarchical sector. Findings suggest the visualisation-led approach was helpful in articulating the behaviours of pathogens and staff and their interactions within the complex setting and service ecology of the NHS and in making IPC training materials clearer and more engaging.

Keywords: infection prevention and control; service ecology; dynamic visualisation; prototyping; participative approach

1. Introduction

Appropriate staff training in infection prevention and control (IPC) across hospital settings to reduce the incidence of healthcare associated infections (HAIs) is a particularly urgent issue given the rise in antimicrobial resistance (AMR). The latter is recognised as one of the most important global issues for human and animal health due to the increasing numbers of resistant infections leading to many existing antimicrobials becoming less effective (ESRC, 2014; WHO, 2015). AMR is the subject of much current attention, e.g., from the UK cross-council AMR initiative (Medical Research Council, 2015) and via the EC AMR Road Map (European Commission, 2015). However, awareness of the need to address this issue is accompanied by a lack of significant innovation in antimicrobials and although the

development of new antimicrobials is an urgent priority, this requires substantial commercial investment and a relatively long-term strategy. While acknowledging the need for new antimicrobials, the work described here takes a complementary approach to tackling HAI through IPC, one which can be progressed and implemented in the shorter term, and is concerned with the participative cross-cohort approach taken for the development of a training tool using visualisation techniques for in-service IPC training for hospital staff.

2. The hospital setting as a complex service ecosystem

For the purpose of this paper, the hospital setting can be described as a complex service ecosystem (Morelli & Tollestrup, 2007). At one level it has three principal categories of interacting actors: 1) people; 2) pathogens; and 3) the environment or setting. The first category involves the full spectrum of workers involved in delivering the healthcare service including clinical consultants, junior doctors, nursing and domestic cleaning staff, as well as visitors and - not least - the patient. Pathogens form the second category and take many forms - virus, bacterium, fungus, prion and parasite: norovirus, *C. difficile* (*Clostridium difficile*), and MRSA (methicillin-resistant *Staphylococcus aureus)* may be the names of pathogens associated with HAIs which are most familiar to the reader. The third category, the setting, comprises both 'hard' elements such as furniture, equipment and surfaces supporting the bioburden (i.e. the number of bacteria living on a surface) and 'soft' environmental elements such as temperature, humidity and air currents providing the conditions for the proliferation and distribution of pathogens.

2.1 Hierarchical but co-dependent

The behaviours of people moving into and through the hospital setting as they perform their individual but overlapping roles form another aspect of this ecosystem. Individuals from across the different cohort groups (healthcare staff, cleaners, visitors and patients) form a complex web of action and interaction for potential transmission of HAIs. Within the hierarchical hospital organisation there are clearly differentiated roles from, e.g., the clinical consultant to the domestic cleaner. Domestic staff have their vital role, cleaning certain areas of the ward environment, e.g., floors and toilets, without necessarily having a clear understanding of the specific natures of different pathogens. Nursing staff may be regarded as carrying the most conspicuous burden of IPC through cleaning routines associated with the patient and on various surfaces within the ward environment particularly in and around the patient bedside. Junior doctors are required to handle patient notes as well as examine the patient. Visitors are another rogue element to consider while the patients themselves are also unwitting sources - as well as reluctant recipients of - infection. The behaviours of all these groups in terms of contact with people and surfaces have been studied through covert audits (e.g. Smith et al., 2012), often revealing poor hand hygiene compliance. To complicate matters further, there are also the complex behaviours of the various pathogens, each with its own preferred habitats and reservoirs in the setting, its various states of existence,

degrees of persistence despite cleaning regimens with biocides, and preferred routes of transmission of infection. There is significant co-dependency in this setting. Individuals within all cohorts are required to observe IPC protocols: just one transgressor creates serious ramifications for others, most seriously for the patient.

2.2 Current IPC training

Current practice in staff training for IPC varies across Scotland's National Health Service (NHS) boards. The Standard Infection Control Precautions (SICPs) manual is used for mandatory staff induction. E-learning courses such as Promoting Hand Hygiene in Healthcare are available. Online resources are available through NHS Education for Scotland (NES), such as a Standard Infection Control Precautions (SICPs) e-learning course, mandatory at staff induction. Staff are also directed to online courses supplied by NES, such as the Scottish Cleanliness Champions educational training programme which has been influential in advocating an 'all-workforce' approach to educating for good IPC practice (West et al., 2006; Macduff et al., 2009). The content of these programmes is essentially text-based information supplemented by visual diagrams and photos, occasionally inviting some basic interaction. The issue here for the individual receiving training is how one is guided or elects to navigate through the considerable content. Different health boards will also develop and prepare their own IPC training resources locally in a variety of formats for face-to-face training, e.g., using tablets, slides, and handouts showing correct practice. One of the UK's largest suppliers of hospital cleaning products, e.g., wipes and disinfectants containing biocides, provides digital tablet-based training packages to approximately 200 hospitals UK-wide. These include training videos demonstrating evidence-based procedures of how to clean, e.g., hospital ward surfaces using their cleaning products and also provide incentives to evaluate one's learning through interactive questionnaires and games. However, there is little available which helps 'visualise the invisible' and which can influence 'the mind's eye' (Macduff et al., 2013) with regard to pathogens and staff behaviours respectively in the above types of training resource, both online and tablet-based.

2.3 Recognising different learning needs

There are limitations to what can be achieved from learning by rote: workers on the job have to recall correct procedures without perhaps having an adequate awareness or understanding of the nature of the pathogens likely to be present or the consequences if certain protocols are not observed. A significant training challenge within IPC is one of addressing phenomena which are fundamentally invisible, i.e., the occurrence of different kinds of pathogens, each with their preferred locations, relative abundance and degrees of persistence as well as their complex routes of transmission. Consider, then, the differing training needs of the different worker cohort groups. Cleaning staff may not be so comfortable with the more text-based norms of 'educational' materials such as those found in the online e-learning modules described above; indeed some individuals may have problems with literacy. Nursing staff have, as do junior doctors, a relentless schedule of

individual tasks to conduct for each of their patients requiring any new routines to be normalised, along with countless others, in everyday practices and procedures. Visitors are part of the 'world outside' bringing with them unschooled behaviours and unpredictable reservoirs of pathogens. Each of these groups, it could be argued, requires to 'see' and understand the issue in their own particular way. So, does this imply bespoke training for each of the cohort groups, or could a more generic approach be accessible and useful to all?

3. Disentangling complexity?

The authors have previously described findings from a programme of research exploring the use of prototype visual methods with hospital-based healthcare workers and patient-focused public representatives to help 'see' invisible pathogens in the hospital setting as a means of addressing the HAI issue (Macduff et al., 2013). A key outcome of this research was the recommendation that further development of the concept prototypes for staff training would be beneficial if the visualisations could be augmented with specific training information and scenarios centred around the prevention of HAIs.

The current programme of work, originally outlined in Loudon et al. (2015), is driven by the hypothetical question *'Could more HAIs be prevented if hospital staff could 'see' microscopic pathogens?'* However, the particular question explored in this paper refers to Schoffelen et al.'s 'complex entanglement' (2015: 180). Can we make this 'complex entanglement', i.e., of the co-dependency of all staff, of pathogen behaviours, and their interactions with the setting, i.e., with the hospital ecosystem described above, 'more articulate, obvious, engaging or clear' while being 'transparent and readable' (ibid) through these visualisations for these NHS staff in their interdependent roles?

4. Evidence-based, iterative visualisation prototyping method

We deployed an evidence-based design (EBD) approach utilising data on staff behaviour, e.g., 'who touches what?' (Smith et al., 2012), and data obtained from studies by microbiologists on the location, abundance and persistence of different pathogens as a result of, e.g., transmission by various means (human and environmental) or as a consequence of cleaning regimens intended to eliminate or mitigate pathogen growth as the starting point for creating the dynamic visualisations. Visualisation prototypes were designed to convey key 'learning points' determined in consultation with the team's NHS advisors.

Using an iterative workshop-based approach, over three key stages, prototype visualisations developed by the team were presented in two NHS regions and used to interrogate understanding and awareness of four different hospital staff cohort groups: doctors, nurses, cleaners (domestics) and other (mixed) roles. Stages 1 and 2 were formative, interactive workshops, designed to elicit detailed feedback for the subsequent iteration of the visualisations. Stage 3 was evaluative: how well did the training tool convey the key learning points?

One of the key challenges of working with NHS staff is reconciling their limited availability with a participatory design approach. The cross-cohort workshops in stages 1 and 2 had to be designed to conduct activities and capture responses within a short 2.5-hour window with staff who were at either end of their shift or on call. To orchestrate the required target numbers proved challenging, but was achieved through the assistance of one of team, an in-house NHS microbiologist. Given the number of participants required for stage 3, designed to be a stand-alone evaluation of the training tool, bookable 1-hour slots for a 45-minute evaluation, convenient to staff's individual time commitments, proved successful.

Workbooks were designed for each stage for participating NHS staff inviting their critical comment on how well they thought these had been conveyed through each of the visualisations, suggestions for improvements, and for their relevance and appropriateness to individual roles.

4.1 Stage 1

Data as described in section 3 above were collated with assistance from the team's microbiologist as the basis for developing mock-up visualisations for the stage 1 workshop. Participants (total N=30: domestic (n=10); nursing (n=12); doctors (n=4); and other (mixed) roles (n=4) were asked to individually record their normal routines through a simplified ward diagram (figure 1, left) in their workbook and to record their job role to help identify any cohort issues during desk analysis. These diagrammatic routines were subsequently projected in the workshop to illustrate the complex web of interaction which had been noted through a visualisation made of Smith et al.'s (2012) covert study of staff touch points (figure 1, right).

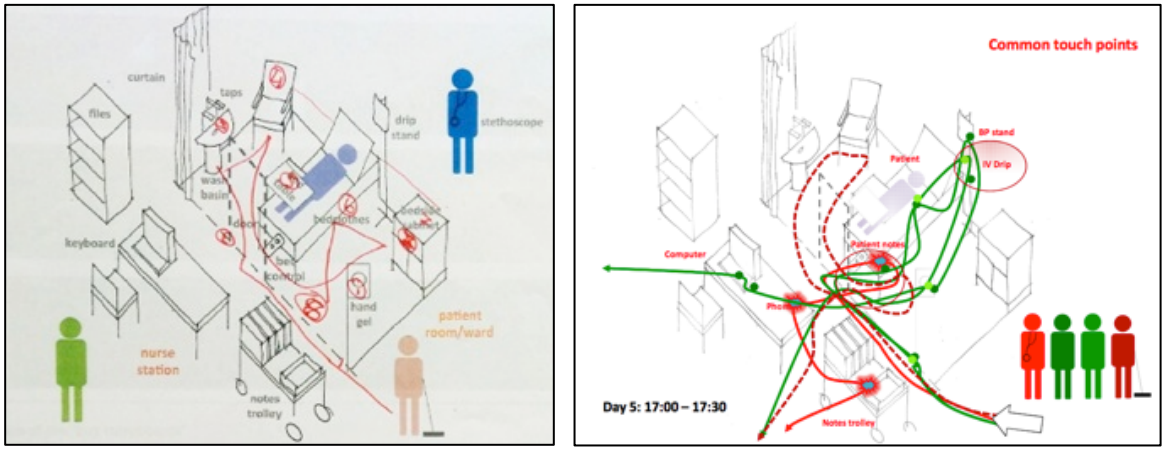

Figure 1 From the stage 1 workshop, 'my role, my routine, my path', comparisons of: (left) example of a hospital worker's (cleaner's) perception of their route through the ward and which elements they thought they usually touched, one of 30 collected during the workshop; and (right) a still from a dynamic visualisation of covert data from Smith et al.'s (2012) study of 'Where do hands go?' revealing the complex web of sequential touch-points from the half-hour ward routines of a junior doctor, auxiliary nurse, senior nurse and cleaner.

Participants were then asked to record their responses on the worksheets to each of three projected visualisation sequences: i) my role, my routine, my path (figure 1); ii) a day in the life of a pathogen (figure 2); and iii) location and survival of pathogens in the healthcare environment. These visualisation themes were selected to be complementary and to help gradually reveal the different aspects of the 'complex entanglement' of actors and elements.

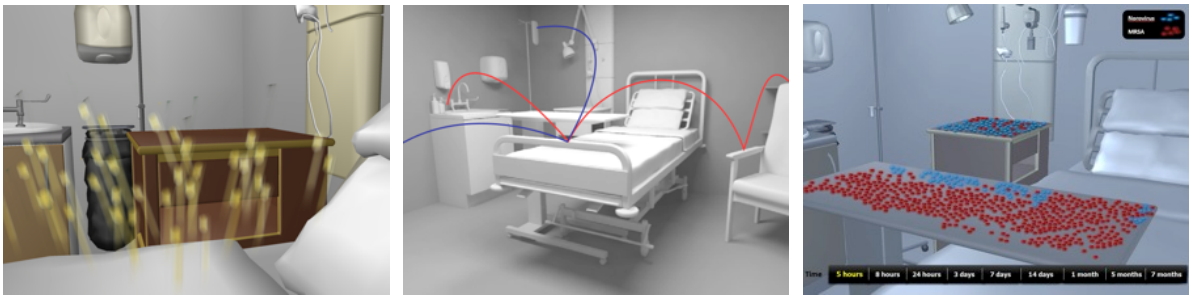

Figure 2 From the stage 1 workshop, 'a day in the life of a pathogen' sequences: (left) pathogen behaviour - MRSA dispersal; (centre) pathogen transmission - potential complexity of routes; (right) pathogen survival - norovirus and MRSA.

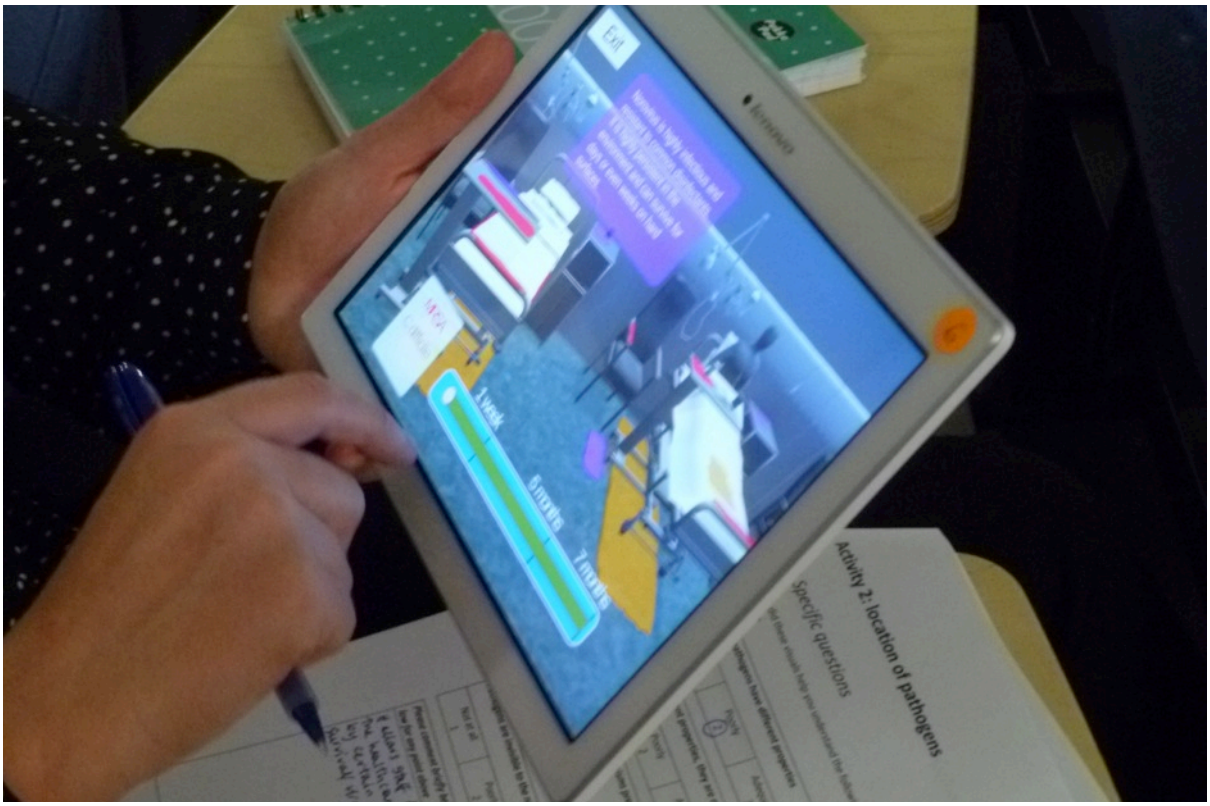

Figure 3 The stage 2 workshop evaluation, with a participant interacting with one of the visual prototypes in the tablet-based tool while working through the workbook questions, in this case relating to the location of the three different types of pathogens, norovirus, C. difficile and MRSA in the virtual hospital ward model.

4.2 Stage 2

In developing the Stage 2 visualisations the detailed feedback from the stage 1 workshop was used to further develop the visualisations with specific training information. Here, significant technical development was also required: feedback had suggested that understanding would be enhanced if the visualisations were contextualised in a ward setting where the angle of view could be changed as well as the ability to 'zoom in' to the invisible.

This required the development of a virtual ward model as a part of the tool in which the visualisation sequences would be contextualised and, as the intention was that the prototype tool was to be tablet-based, interactive tablet-based visualisations were developed requiring considerable software development and interaction design work.

This workshop was conducted at the same NHS hospital as stage 1 but with different participants (N=18) including nurses (n=9), doctors (n=6) and cleaning supervisors (n=3). Rather than responding to projected mock-up visualisations as in stage 1, participants were provided with tablets loaded with the visualisations and interacted with these (figure 3). Participants' responses were recorded individually through workbooks in the same manner as in stage 1. Here, four training theme visualisation sequences, 1) location of pathogens, 2) survival properties of pathogens, 3) cleaning/surface recontamination, and 4) transmission and spread were available to explore together with a more experimental augmented reality (AR) tool, enabling visualisations of 'bugs' to be viewed on the tops of existing surfaces through use of the tablet's camera.

Figure 4 Stage 3 evaluation using the Pathogen Viewer in the training tool which uses the tablet camera, paper markers and augmented reality (AR) to simulate the presence of different pathogens on surfaces. The tablet shows MRSA (left) and C. difficile (right).

4.3 Stage 3

For stage 3, again the detailed feedback in the workbooks from stage 2 guided the development of the final (within the time available for this work) iteration of the visualisation prototypes. Tablets were loaded with the updated prototype training tool which provided four dynamic and interactive visualisations for evaluation, 1) pathogen location, 2) pathogen survival, 3) pathogen transmission, and 4) pathogen viewer (AR) (figure 4). This was tested by 93 staff from a variety of different roles over 3 different hospital sites in an NHS board different to the one used in the first two stages plus 9 nursing lecturers and nursing students in one university site. The tablet tool was designed to be used in a stand-alone manner with a one-page information sheet as part of the workbook which was again self-completed by staff, as they worked through each of the visualisations using both free responses and Likert-scale evaluation.

5. Findings

With reference again to Schoffelen et al.'s (2015) 'complex entanglement', and the question posed in 3 above, what progress did we make, through our visualisations, in untangling the inherent complexity of the hospital ecosystem, of the co-dependency of staff, of pathogen behaviours, and of their (i.e., both staff's and pathogens') interactions with the setting and to make this 'more articulate, obvious, engaging or clear' while being 'transparent and readable'?

5.1 Verbal and workbook feedback

In stages 1 and 2, the audio-recorded discussions between the team and participants following the visualisation sequences had been presented and workbooks completed proved valuable in revealing the level of engagement across and between the different cohorts. As stage 3 did not involve a workshop able to bring together everyone at the same time, only individually booked sessions, there was no opportunity for group discussion.

Each workbook was designed specifically for its particular stage. Written feedback in the 150 workbooks completed across the 3 stages proved highly valuable and the great majority of staff appeared very keen to provide this. We exceeded our target numbers of participants for each stage indicating that HAIs was a subject of interest across the cohorts. This volume of feedback helped the team understand how successfully the visualisations had worked for each individual in their particular role. Thematic analysis, in three passes, of audio and written responses identified top-level and sub-themes for each stage. The team were able to identify potential issues in the way that information or sequences had been presented. This feedback was used to develop the next iteration of the visualisations in the training tool.

5.2 Stage 1

Desk analysis of the workbook responses revealed that participants from the different cohort groups generally responded positively to the potential use of visualisations of

pathogens and behaviours in training, with relevance to a wide range of job roles and experience levels. Visualisation appeared to be an effective medium to engage staff with the information, and to help raise awareness and understanding of specific issues related to pathogens and infection control. The visualisation approach appeared to enhance the communication of key information from normally difficult-to-access research data, showing the potential of the visual approach to assist in learning new information or reinforcing current knowledge.

As an example, with regards to the visualisations developed to convey the 'transmission' properties of pathogens, these elicited comments revealing raised awareness and understanding, for example:

> "Shock and surprise at the amount of contamination from what initially seems a minor spillage [norovirus]" (nurse); "How easy a virus can be spread" (cleaner)

In a further example, responses from across all cohorts revealed that the visualisations had helped convey 'pathogen specific properties':

> "It shows you just how airborne the virus is [norovirus]. Even though you wash your hands it will get in your clothes / in your hair" (cleaner); "Something I don't really think much about it. Because you think the room is cleaned, its fine, the next patient that comes in will be fine…but then this highlights how long these things can hang around for" (doctor)

There were some examples of misunderstandings in the stage 1 visualisations (here, relating to the effectiveness of cleaning, a common misunderstanding due to the way this had been conveyed):

> "Shows that despite staff thinking they have cleaned up that spores still are present." (nurse) "Shocked! No matter how many times it's cleaned and it's still there." (cleaner); "Even once the room was cleaned there is still pathogens in the room, on furniture and in the air. I was shocked at how long the pathogens live in a room even once the room has been cleaned" (cleaner)

5.3 Stage 2

The format for feedback in stage 2 was similar to stage 1. Both audio-recorded and written data were obtained. Analysis revealed the following: the visual training tool would be generally applicable to the job roles represented at the workshop although there was an indication that some content in the different prototypes would need to be tailored to different roles and levels of experience (our stage 3 feedback indicated that this would not need to be the case); there was potential for use in both informal and formal aspects of training in making education interesting and engaging and help raise awareness and understanding; the stand-alone visualisations proved largely effective in providing an understanding of the intended learning points without further explanation.

However, as in stage 1, feedback indicated some inaccuracies, misunderstandings on our part and the need for further improvements. For example, in relation to one of the stage 2

visualisations intended to convey the following 'learning points' relating to the location of pathogens - 1) different pathogens have different properties; 2) due to these different properties, they are mainly found in specific locations; 3) there are a mix of micro-organisms present in the ward environment – not all of which cause risk to patients; and 4) pathogens are invisible to the naked eye – two of the doctors provided the following written comments:

> "Not 'properties' -> it is reservoir, potential transmission and survival that come over well" …" 'properties' means structure, virulence, disease mode, treatment, eradication. There is a bit of this with the coccal shape of the MRSA and the rod shape of *C. difficile*." (doctor); "I feel it showed pathogens can be in different locations but I don't feel it highlighted this was due to different properties." (doctor)

In a stage 2 visualisation concerned with the survival properties of pathogens before and after cleaning, one nurse wrote:

> "Did not know that the germs can last as long." "That the germs last much longer than you would anticipate and are not resistant to disinfectant, so would need deep clean. But the visual does not say about cleaning" (nurse)

Again comments revealed examples of misunderstandings:

> "Hospitals are dirty even when they look clean" (doctor); "This shows very noticeably how pathogens are invisible to the naked eye but they grow very quickly even though they're not seen" (cleaner).

One issue arising in team discussion about the nature of the visualisations during their development was if these should be tailored for each of the separate cohorts. As in workshop 1, the comments in workshop 2 indicated that the visual training tool on the whole would be generally applicable to all job roles present in the workshop. However, in workshop 2 there were some comments which indicated that some of the content in the prototypes was more suitable for different job roles (and different experience levels) and they may require different levels of information to be presented. There were some participants who found the information presented to be quite basic, yet others found the information useful. In the final discussion, it was suggested that information could be tailored to specific groups using layered information. In the discussion session, one of the nurses commented that having this on tablet would mean it could be used when convenient, e.g. during breaks.

Through feedback of this nature, the team were able to understand what worked and identify potential errors, e.g., in terminology or lack of clarity and corrected through this iterative process.

5.4 Stage 3

Given the numbers to involved at this stage (N=102), the workbook was designed differently to those for stages 1 and 2 with two free response questions (In terms of your job role, what was most / least meaningful for you, and why?), four Likert-scale questions (the training

information in this section is relevant for my job role; this section provided information at an appropriate level of detail; the information in this section was communicated clearly; and the use of visuals was helpful in understanding the facts and issues) with a final free response question for any other comments.

From the stage 3 visualisations, in answer to the question *"In terms of your job role, what was most meaningful for you, and why?"* the visualisations were able to prompt responses from across the cohorts:

> "Being able to visually see where pathogens lie in the environment as this increases awareness of how easily it is to spread pathogens. Highlights places pathogens lie where people might not have realised before" (senior nurse); "Norovirus is more important for workers. A large range of surfaces not cleaned" (Domestic).

Additional comments from stage 3, revealed the power of the visualisation approach:

> "This will be useful to help staff visualise the reason for hand hygiene at WHO moment 5" (infection control nurse); "Good visual effects for all to take notice" (domestic assistant manager); "The visuals were ideal in retaining the information" (independent auditor).

As in the two previous stages, all cohorts were able to contribute to suggestions for improvement to the visualisations and training information in the tool as well as revealing some misunderstanding suggesting the need for an iterative development and evaluation process.

Stage 3 represents the end of this particular stage of development, which has proven proven to be informative and engaging for staff. The feedback from this stage will inform further iterations in the next stage of this research.

6. Discussion

The visualisation prototypes discussed here represent a synthesis - from an evidence base provided by microbiologists (e.g., data on pathogens and staff's behaviours) and from the individual and collective feedback from all healthcare worker cohorts contextualised in a ward setting with the objective of imparting key learning points. Using the iterative prototyping and workshop-based process, each of the different cohorts contributing had input to the design of the visualisation tools while, in stages 1 and 2, simultaneously witnessing others' public responses to the same materials.

Taking an EBD and participative (within the limitations of NHS staff availability) design approach to the iterative development, adjustment and refinement of the visualisation prototypes has enabled these to become broadly readable and to communicate key information from normally difficult-to-access research data across the different cohorts, and demonstrated its potential to assist in raising awareness, learning new information or reinforcing current knowledge.

Findings from the responses from the mixed cohort groups (doctors, nurses, cleaners and others) suggest that the visualisations were an effective means with which to collectively engage these different groups of healthcare workers, helping raise awareness and understanding of specific issues relating to IPC and HAIs. Here, again, Schoffelen et al.'s (2015: 181-182) work is useful, 'encouraging people to engage with a visualisation' (…) 'encouraging making sense of the dynamic backstory of an issue' (…) and 'enabling reflective interpretation'.

The process of developing these visual training tools reflects a collective design construction process, which avoids the reification of the prevailing medicalised hierarchical and authoritative structure within the healthcare system, enabling a more democratic form of discourse: here a cleaner's input and views in shaping these tools is as vital as a clinical consultant's.

7. Conclusion

Within the time and resources available, the team was able to make progress developing visualisations for training in four areas: 1) pathogen location, 2) pathogen survival, 3) pathogen transmission, and 4) pathogen viewer. With this iterative and participative approach we suggest there is the opportunity for the further development of successful IPC and HAI training materials in a cross-cohort manner appropriate for the complex and dynamic service ecology model. This approach may have value in untangling complexity in other areas.

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