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Title

Evaluation of a visual tool co-developed for training hospital staff on the prevention and control of the spread of healthcare associated infections.

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Title

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Abstract

Background: Staff training in infection prevention and control (IPC) across hospital settings has a crucial role in reducing the incidence of healthcare associated infections (HAIs). However the application of dynamic visualisation approaches in this context is under-developed, with very few in-depth evaluation studies of related processes and impacts.

Methods: A prototype training tablet app for hospital staff, using interactive visuals was developed and evaluated. To demonstrate different pathogen behaviour, dynamic visualisations of norovirus, *C. difficile*, and MRSA were developed in relation to location, survival and transmission within a virtual hospital ward model using evidence-based microbiological and staff behavioural data. A three-stage evaluation process was designed, involving a mixed sample of UK National Health Service staff (doctors, nurses and domestic staff, n = 150).

Results: Participants reported improved awareness and understanding of the pathogens responsible for HAI, the types of information relevant for different staff cohorts, those aspects of the visualisations which worked well and those which were prone to cause misunderstandings, and suggestions for further development and improvement. The tool appeared to offer staff a new perspective on pathogens, being able to 'see' them contextualised in the virtual ward, making them seem more real.

Conclusions: Results showed the benefits of a detailed co-development process and a more contextualised understanding of the potential for visual apps to be used in IPC training.

Keywords

Tablet-based app, visual training tool, infection prevention and control, evaluation

Highlights

- Staff training in infection prevention and control (IPC) across hospital settings has a crucial role in reducing the incidence of healthcare associated infections (HAIs).
- This study adds value by examining processes and impacts related to the application of dynamic visualisation approaches in this field.
- Understanding and awareness of different pathogens, location, spread and transmission were reported in response to the dynamic visualisation approaches and contextualised information.
- The development of the training materials benefitted from the involvement of the end users, and highlighted related trade-offs and tensions for designers in this field.
- The potential for further development of visual apps and in-depth studies of what works and why is highlighted.

Introduction

Antimicrobial resistance (AMR) 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 [1]; [2]. Appropriate infection prevention and control (IPC) measures across hospital settings have a crucial role in mitigating the consequences of AMR and reducing the incidence of healthcare associated infections (HAIs) [3]). Within this ambit, effective, meaningful and appropriate education and training are essential.

The hospital setting can be described as a complex service ecosystem with three categories of principal interacting actors: pathogens; the environment or setting; and, not least, people. A key challenge is to find a means of training staff which: (i) raises contextualised awareness and understanding about the invisible pathogens that cause HAIs (ii) explains how the spread of pathogens and HAIs can be prevented and controlled in the hospital environment through IPC procedures, and (iii) is effective within and across different job roles. Gauging the extent to which this challenge is being successfully met within and across different countries is difficult. Educational programmes vary widely in aims, content, form and scope, as do evaluations of their effectiveness [4]. Moreover inter-country variation in contextual and structural factors [5] also complicates comparisons.

However, drawing on our experience of reviewing a number of educational packages, and descriptions and evaluations of such programmes in relevant academic literature, it is possible to offer brief observations on the above three components. Taking the role issue first, there appears to be a spectrum of practice with some tension between meeting job-specific needs (e.g. [6]) and meeting the needs of whole service communities (e.g. [7]). The challenge of educating on IPC procedures has seen more accord, with Standardised Infection Control Precautions such as the chain of infection, hand hygiene, use of personal protective equipment, and maintenance of a clean healthcare environment forming the core content of many programmes (e.g. [8]). Arguably, achieving understanding about relevant pathogens in a way that is contextualised to practice is the component that has received least attention in education and training. Part of the issue here is the invisibility of pathogens under normal circumstances and Prieto [9] highlights the related “need to find more creative ways to visualise micro-organisms and demonstrate risk”.

The present paper engages with all three components of the challenge outlined above by presenting an evaluation of a prototype interactive tablet-based tool using visualisation techniques developed for in-service IPC training for hospital staff. The focus on visualisation is supported by a growing evidence-base that creative visual-based interventions can be a powerful medium for influencing behaviour within healthcare [10]. Within IPC there seems much scope for development using more engaging and visually dynamic approaches that harness staff expertise, new data and information technology. Indeed in a recent survey of Australia’s infection prevention and control professionals, on-line learning packages and enhanced IT emerged as the two top priorities for additional resource [11].

The study described here took a participatory co-development approach [12] involving healthcare staff, while exploiting the researchers’ expertise in visualisation techniques, to raise awareness and understanding of how the interplay between pathogens, people and settings contribute to the incidence of HAIs. This was informed by the authors' earlier work which explored the extent to which healthcare staff actively envisage pathogens in "the mind's eye" [13] and which developed related prototype computer generated visualisations that aimed to help visualise the invisible. One of the recommendations from this work was 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."* Given the proliferation in the availability and use of tablet computers in recent years, it was reasoned that these provided a promising medium for an interactive training tool.

Methods

Design

A three-stage process was designed, involving staff from two NHS Scotland boards over a 12-month period. This employed an iterative co-development method using mock-ups and prototypes of visualisations to probe and elicit feedback from NHS staff. Stages 1 and 2 were formative, interactive workshops, held in NHS Lanarkshire, and designed to elicit detailed feedback. Stage 3, held in NHS Grampian, was evaluative, to determine how well the training tool, used in a stand-alone mode, conveyed the key learning points unaided. Workshops in stages 1 and 2 were short (2 - 2.5 hours) and were designed to accommodate NHS staff working patterns and to capture as much feedback data as possible. The Stage 3 evaluation was designed to be completed in 30 - 45 minutes.

Study population

Three principal cohort groups were recruited, nurses, doctors (including medical and nursing students) and domestic (cleaning) staff as the researchers intended to develop a training tool that was usable by all NHS hospital-based staff. In Stages 1 and 2 these participants were sought by the relevant IPC department sending information out to relevant managers to disseminate. Additionally in Stage 3, information on the project and an invite to participate was sent out around the whole Board (via an e-bulletin and the staff magazine) and within the local university's School of Nursing. This resulted in staff from additional healthcare roles (e.g. radiographers and occupational therapists) electing to participate in Stage 3, as well as some healthcare-related staff and students from one of the co-author's institution. No material incentives were offered beyond light refreshments.

We sought to recruit a mixed group of around 9 participants at each of the developmental stages (1 and 2) in order to facilitate information exchange within a clinical education centre setting. For the final evaluative stage which covered a range of venues within the Board, we set an indicative target of 60 participants from different occupations. We reasoned that this would give reasonable coverage of occupational perspectives. The overall numbers and compositions actually achieved are presented below in Table 1.

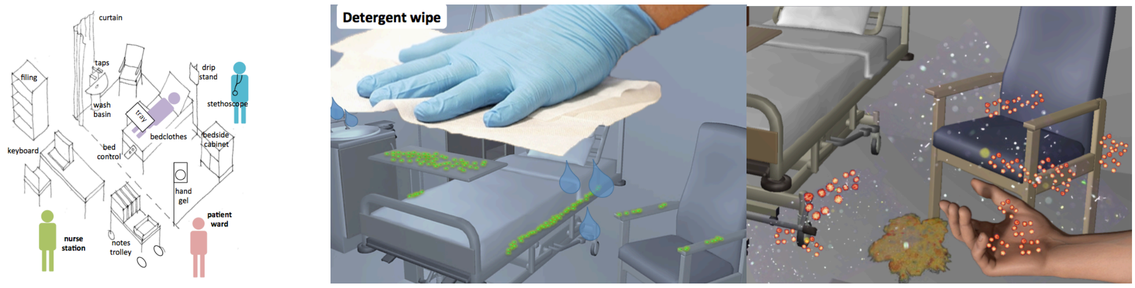
Table 1. Numbers recruited from each cohort over the three stages: A Includes 2 nursing students; B includes 3 nursing students; C includes 4 medical students; D Includes 11 nursing students; E includes 2 medical students.

Stage	**1**	**2**	**3**
domestic	n = 10	n = 3	n = 24
nurses	n = 12	n = 9	n = 51
doctors	n = 4	n = 6	n = 6
other (mixed)	n = 4	n = 0	n = 16
university nursing staff	n = 0	n = 0	n = 5
Stage Totals	N = 30	N = 18	N = 102
Overall Total	**N = 150**		

As can be seen overall recruitment significantly exceeded initial targets at all stages. We decided to capitalise on this significant interest and enthusiasm by adjusting room sizes at venues and being inclusive. Within each of the main occupational groupings there was a spread of grades and experience. One Consultant Microbiologist participated in Stages 1 and 2, while another two took part in Stage 3. At each stage several IPC nurses were involved alongside ward managers, staff nurses and nursing assistants. While the majority of cleaners were ward based, some supervisors and managers of the service also took part.

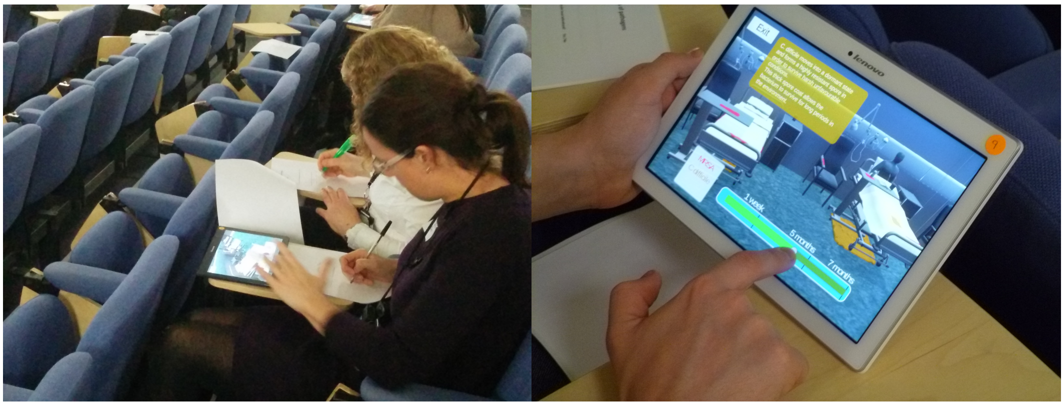
Study procedure and data collection

To investigate the potential of dynamic visualisations, three themes were chosen which would have broad relevance across job roles. These were: 1) pathogen location; 2) pathogen survival; and 3) pathogen transmission. Three key pathogens were chosen – Methicillin-resistant *Staphylococcus aureus* (MRSA), *Clostridium difficile*, and norovirus - to highlight their differences in relation to location, survival and transmission. The training information for the visualisations was selected from research data and evidence from published sources in consultation with the microbiologist advising the research team. For example Smith et al.'s paper [[14]] regarding common hand-touch points in a ward setting was used as the basis of a visual framework for Stage 1 participants to map "My role, routine and pathway" (see excerpt in Figure 1a). Similarly Bogusz et al.'s paper [[15]] on the impact of daily cleaning with single-use detergent wipes on microbial load (Aerobic Colony Count including *S. Aureus*) was used in a sequence of Stage 1 visuals on the impact of cleaning (see excerpt in Figure 1b). The Health Protection Scotland National Infection Prevention and Control Manual [[16]] was used as the main evidence base for procedures.



Figures 1a, 1b and 1c. Prototype visuals from the stage 1 workshop, ‘a day in the life of a pathogen’ sequences: (left) ward template used by staff to individually map their role, routine and pathway during their daily roles; (middle) impact of daily cleaning with single-use detergent wipes on microbial load; and (right) pathogen behaviour – Norovirus dispersal.

For stage 1, a number of visualisations were mocked-up and presented on the hospital lecture theatre screen (exemplified in figures 1a, 1b, and 1c). By stage 2, the first iterations of the interactive tablet-based prototypes, incorporating feedback from stage 1 were used (figure 2a) and, in stage 3, the tablet-based training tool, again incorporating feedback from stage 2, was used for stand-alone evaluation (figure 2b).



Figures 2a and 2b. The stage 2 workshop evaluation, with participants interacting with the visual prototypes in the tablet-based tool while completing an evaluation workbook (left). A stage 3 prototype illustrating different survival properties of different pathogens through an interactive timescale (right).

In stage 3 the tablet-based prototype tool comprised the following elements: 1) a virtual ward model, allowing a macro-micro view of the ward through ‘zoom-in / zoom-out’ to predetermined views; 2) interactive visuals for each of the three pathogens showing, in the ‘survival’ section, the effects of a cleaning intervention using a temporal feature; 3) learning points for each theme; and 4) text-based information which was layered depending on the user’s self-determined need-to-know and which included ‘risk to patient’.

Participants completed workbooks in each of the three stages responding to both specific and open questions, and in stages 1 and 2, after these were completed, open discussion across all staff roles was recorded. Stage 3 data collection focused on the workbook which invited participants to rate Likert scaled statements about the respective content on pathogen location, survival and transmission in terms of: (i) perceived relevance of information (ii) appropriateness of level of detail (iii) clarity of communication, and (iv) overall helpfulness for understanding facts and issues. The construction of these statements was informed by themes that emerged in Stages 1 and 2, and more generally by considering the relevance of wider aspects of evidence (e.g. feasibility, appropriateness, meaningfulness and effectiveness) as advocated by the Joanna Briggs Institute [[17]]).

Data Analysis

Responses to the Likert scaled evaluation statements were collated, quantified and displayed graphically using Excel software. Collation of responses from each of the main occupational groups was also undertaken for purposes of comparison.

Analyses of the written textual responses in the Stage 1, 2, and 3 workbooks, and of the audio recordings, was informed by the qualitative approach of Braun and Clarke [[18]] who advocate a process of familiarisation with data, coding, searching for themes, reviewing, defining and naming themes, and writing up. Analysis was led by two of the researchers (DL and SW) who initially read over textual responses from the workbooks, listened to the audio recordings, and read the related transcriptions. Textual content was then coded and collated in relation to initial sub-themes using frameworks piloted and cross-checked by the researchers. Through an iterative process of comparisons of patterns of convergence and divergence the sub-themes were then refined, collated and mapped to emergent "top level" themes. Table 2 provides an example of one of the themes and constituent sub-themes that emerged from Stage 1 analysis.

Table 2: Example of a theme and sub-themes

Theme	Sub-Theme
Visuals and ability to "see"	Visuals - spread/transmission
	Visuals -pathogen specific properties
	Visuals -pathogen survival properties
	Visuals -hand hygiene/cleaning
	Visuals - visualising invisible pathogens

Results

Stage 1:

Participants (n=30). Five main themes emerged from Stage 1 data: (i) information, awareness and understanding conveyed from visuals; (ii) visuals and ability to "see"; (iii) usefulness in training; (iv) future developments; and (v) non-visualisation related comments.

(i) The training information presented on the lecture theatre screen was found to be relevant and interesting. For a number of staff the visual–led information was found to be new or added details about location, transmission and survival that they were not aware of:

> *"Visuals are very effective because they make you more aware of how they spread" (*Cleaner*)*

> "*Something I don't really think much about it. Because you think the room is cleaned, it's fine, the next patient that comes in will be fine…but then this highlights how long these things can hang around for*" (Doctor)

> "*Interesting and also shocking how pathogens survive and then multiply despite cleaning*" (Nurse).

As the latter quote suggests, however, at times it was unclear if all participants were understanding the exact process that the visual sequences were attempting to convey (i.e., some seemed to infer that pathogens like MRSA could multiply themselves on inanimate objects like bedside tables). By highlighting pathogen transmission in a non-job specific way, the visuals were found to highlight the pathways of environmental transmission, which are not commonly focussed on; hand touch is often the sole focus.

(ii) Participants reported their awareness of infection risk had improved after viewing the visuals concerned with pathogenic information as these caused them to see infection risk in a new and contextualised way, i.e., that it was the visual medium that was the main factor in this being effective, and that this had an immediate impact in making them think about how they performed their job:

> *"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*)*

> *"Again frightening, question myself how good I do my cleaning in the ward, didn't realise how long MRSA could survive" (*Cleaner*)*

> *"Definitely opened my eyes" (*Nurse*)*

> *"Made me look at it in a different way" (*Nurse*)*

> *"Now when I go into a room and I look, stand at the door, I will just see all of that there, pretty much, so it has imprinted it" (*Cleaner*)*

(iii) There was much recognition of potential for use in training:

> *"Think these bug storyboards would be useful for all staff to see as it highlights the infection risk for all staff and the importance of hand washing and cleaning of the environment" (*Nurse*)*

> *"Looking at the visualised, if it is shown to new starts I think the staff would step back and think about cleaning every surface within the ward – also highlight wearing PP (*personal protection*)" (*Cleaner*)*

(iv) Likewise there were many suggestions for development of content and format:

> "*Interactive visuals where you can come up with your own route through the room and see potential for bugs to be moved from surface to surface or surface to patient*" (Doctor)

> "*Would be useful/striking to illustrate the pathogens on other sites, e.g. patients toiletries bag / juice bottle / water jug that sit on bedside cabinets and overbed tables as a reminder they persist elsewhere, although I appreciate there may not be data on this to aid with illustration*" (Doctor)

(v) Non-visualisation related comments related mostly to descriptions of roles, routines and perceived risks elicited during the workshop activities.

Stage 2:

Participants (n=18). Five main themes emerged from Stage 2 data: (i) prototype specific comments; (ii) visualisations increasing awareness and understanding; (iii) misunderstanding from visualisations; (iv) improvements; and (v) use in training.

In Stage 2 the focus was on participants engaging in specific activities on the tablets and providing detailed feedback on experiences of each of the interactive sequences of visualisations.

(i) As such much of the data pertained to specific comments on prototype features:

"The timeline visual was very useful and very clear to follow. If this was used in a ward area it would be a tool that could be used and accessed quickly" (Nurse)

(ii) Many comments related to impact in terms of increased awareness and understanding:

"This visual highlights how easily the bacteria can be spread. Even on items such as keyboards which you may not have considered as having bacteria on it. I think this is important in my role as it emphasises the importance of hand hygiene between patients and after activities you are carrying out" (Nurse)

(iii) Again, however, there was some evidence of elements of misunderstanding (e.g. one participant's feedback described MRSA as a virus). Our incorporation of a fiducial marker initiated augmented reality visual that magnified "virtual clusters" of the different pathogens for illustrative effect was generally felt to be useful and striking, but at least one respondent interpreted this in a very literal way:

> "*It was very useful to see how quick they multiplied and how many were on one tiny square*" (Nurse)

(iv) Participants reported that the information and visuals conveyed on the tablets were mostly relevant to their different job roles but some areas for enhancement were suggested, especially by medical staff:

> "*In medical school we need to know the properties of common organisms, e.g., the size, shape, whether they are gram positive or negative, what they cause, etc. If this could be put into the program it could be very useful to learn/test/revise knowledge about bacteria*" (Doctor)

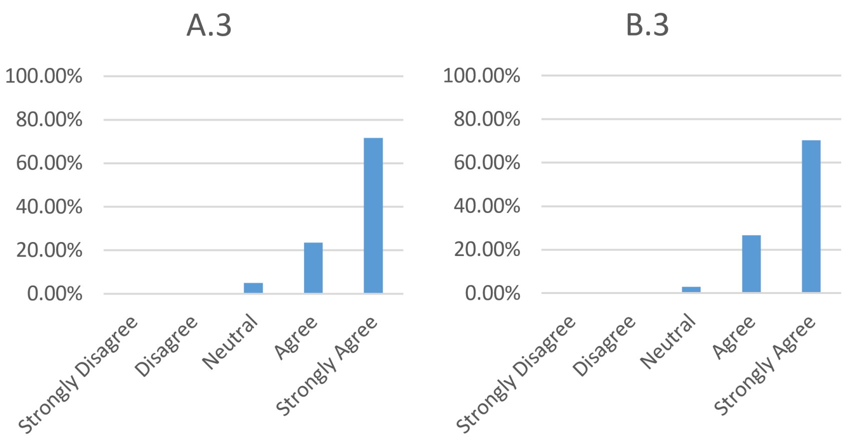
(v) The main training opportunities mentioned were as part of staff induction and also during on-going departmental training:

"As a learning tool for beginner healthcare professionals it can be widely used by many people as it is straight forward and easy to navigate" (Nurse)

A possible advantage of the tablet-based training tool was seen to be its ability to be used to conduct training on the ward rather than in a different location such as a more formal training session. One key issue was the familiarity of staff with tablet interaction; some staff were more at ease with tablet interaction whereas others required more guidance.

Stage 3:

Participants (n=102). All responses to the Likert scaled statements were tabulated and Figure 3 shows these in relation to the Pathogen Location content.



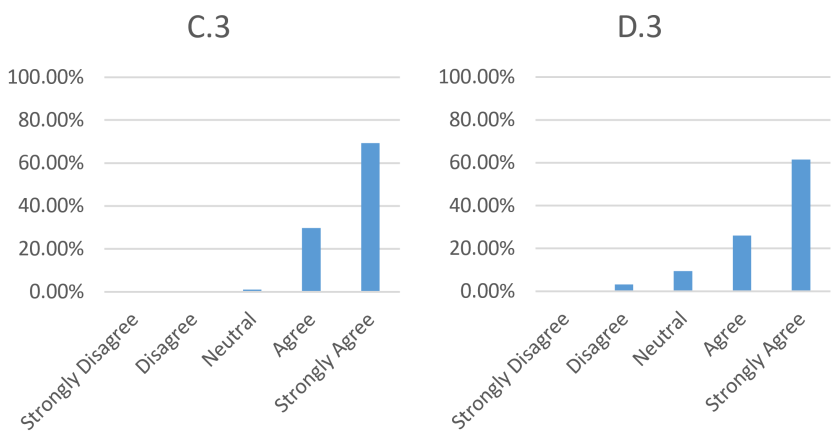
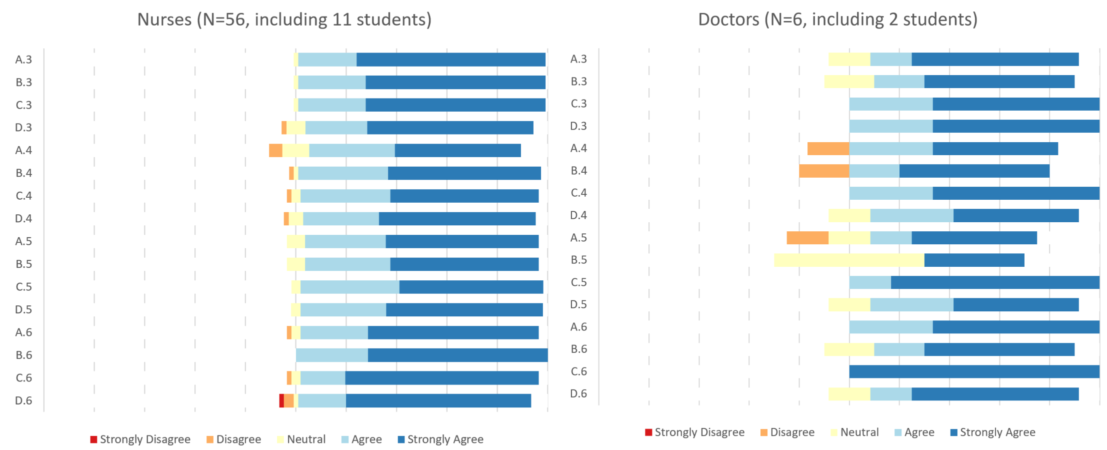


Figure 3. For Pathogen Location, responses to the statements: A3 - The training information in this section is relevant for my job role; B3 - This section provided information at an appropriate level of detail; C3 - The information in this section was communicated clearly; D3 - The use of visuals was helpful in understanding the facts and issues.

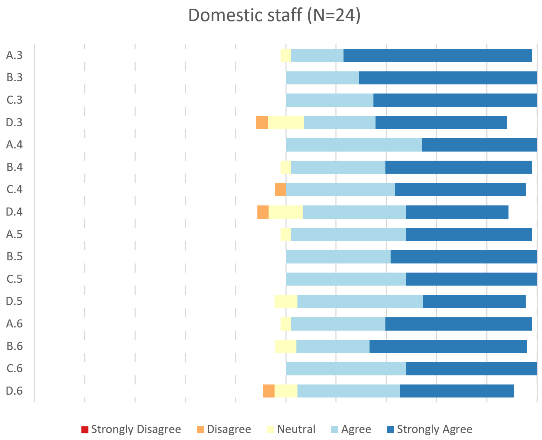
Very similar positive patterns were evident in evaluations of the Pathogen Survival and Pathogen Transmission content, with negative ratings never exceeding 5% of total responses.

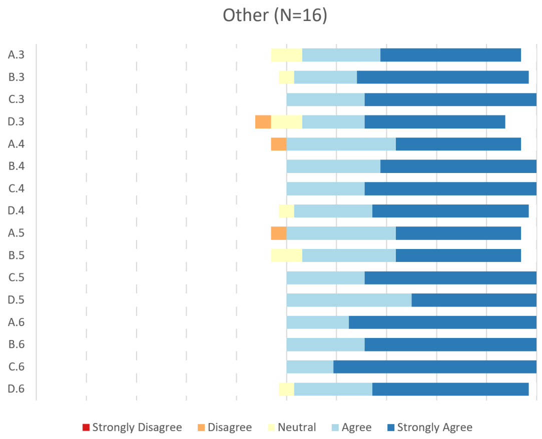
When these collective collations were analysed in terms of the main occupational sub-groups (e.g. nurses, cleaners, doctors, other), there tended to be very little variation in the nature of responses, although the small group of six doctors were very slightly more critical.

Figures 4-7 illustrate the strong tendency for participants in these different groupings to ‘agree’ (light blue) or ‘strongly agree’ (dark blue). The codes A3 – D6 in the figures represent each of the individual statements relating to activities within the Stage 3 workbook.



Figures 4 (left) nurses and 5 (right) doctors.





Figures 6 (left) domestic staff and 7 (right) other (mix of other health-related occupations).

Analysis of the qualitative data yielded four main themes, namely: (i) the value of the visualisation approach; (ii) the appropriateness of the information for education and training; (iii) suitability for different job roles; and (iv) suggested improvements.

(i) Participants particularly valued the tool for increasing awareness of pathogens and the related reasons why IPC procedures should be followed to prevent and control HAIs.

> *"Very effective at highlighting how transmission occurs. Great level of detail – exactly enough detail to get the facts across. From a nursing perspective it highlights how any job we do can transmit pathogens" (*Nurse*)*

> *"Very good tool to show domestic staff why we ask them to clean in a specific way. It would show them why we do what we do"* (Cleaner)

There were numerous comments on the value of being able to visualise and 'see' invisible pathogens and emphasising the importance of this in context e.g.

> *"The visual display of pathogens in the clinical area using the great visuals makes everything much more real and I think enhances understanding, knowledge and perhaps would aid retention" (*Nurse*)*

> *"Again bringing the pathogens alive – being able to visualise them. As before, aids learning and knowledge" (*Nurse*)*

> *"Having the information allows me to assess my actions whilst carrying out an inspection. More aware of the environment and the patient in the bed*" (Independent Auditor)

> *"Having a visual aid again highlights how these risks act in the environment. It makes more real, what we know in theory" (*Cleaner*)*

> "*Excellent visualization with true to life ward scenario. Again, useful to re-inforce consequences for patients"* (Occupational Therapist)

> *"As an estates officer, I have a duty of care when placing staff in high risk areas. This is a very good teaching tool for a visual aid regarding risk" (*Estates officer*,)*

In summary, 'seeing' how pathogens interact within the environment, their potential paths of transmission, and the related consequences and risks to patients were indicated by a number of staff to have been highly useful in their understanding of IPC and meaningful for their job roles. In particular, participants indicated meaningfulness or usefulness in being able to 'see': properties and characteristics of pathogens, survival rates, location; the ease of spread of pathogens, transmission; the effect 'bugs' can have; and how easily pathogens can be transmitted.

(ii) Participants indicated a range of potential training benefits from the tool, for: awareness raising; induction of new staff; providing a new perspective on HAIs; explaining the importance of the 'why' behind IPC and assisting with compliance to guidelines; reinforcing previous learning; and assisting different learning styles. Regarding the latter, some had clear preference:

> *"Visual demonstration meant more to me than the usual wordy terminology, making the information easier to remember" (*Radiographer*)*

> "*Feel that visuals are better as people tend to remember more what they saw, rather than read. I will remember what I have seen today*" (Nurse)

The tablet format was often seen as helpful in this regard:

> "*Being interactive ensures that attention is paid at all times, which helps the information to be absorbed*" (Senior Nurse)

(iii) Although responses were generally positive across all occupational groups, a number of the suggestions for improvements related to differentiation of users. There were suggestions for having specific information relevant to clinical or non-clinical staff groups, mediating the use of scientific language and terminology as appropriate, e.g., gram +ve and –ve, and recognising that English may not be the first language of some users.

Additionally many useful suggestions were made about how to enhance specific text and visuals in terms of accuracy and impact, and about what additional visual features could be added.

> *"I think you could add one further tab in MRSA story on outcomes e.g. longer stay, increased morbidity and mortality. Similarly one or two for C diff – including patients most at risk and potential complications" (*Doctor and clinical tutor – medical education*)*

(iv) Overall participants were able to navigate through the training tool and able to use it independently.

> "*Simple and effective, easy to navigate through each section*" (Occupational Therapist)

However, a number of participants commented on specific navigational and interface aspects which could be improved with regard to, e.g., clearer on-screen prompts, more considered linking through icons for easier navigation between and within the sections, more self-explanatory interaction controls and icons, more consistency of icon interaction, and more on-screen interactive elements.

Discussion

As has been seen, evaluations of the relevance, clarity, appropriateness and overall helpfulness of the final prototype were very positive, with negative ratings never exceeding 5% of total responses. Within this context the qualitative comments were very useful in further illuminating how the tool was beneficial. Specifically the visualisations were experienced as engaging and supportive of different learning styles while the accompanying information was mostly relevant for different staff cohorts with different levels of experience. Taken together, this was seen to offer many staff a new perspective on pathogens, as being able to 'see' them contextualised in the virtual ward made them seem more real. Moreover this served to enhance participants' awareness about pathogens by explaining why and how HAIs occur and why IPC procedures should be followed. Qualitative comments were also very useful in highlighting particular aspects that didn't work so well and suggesting improvements. As such, the design of the study and its findings provide a clear basis for further development and refinement of the tool itself and for research in this field.

The development and application of more dynamic visualisation approaches in this field is both necessary and timely. As Williams et al. [10] suggest, evidence for image-based interventions in healthcare is growing and may span both the deployment of externally generated images and the elicitation and shaping of internalised mental models. In regard to development and deployment of the former within IPC, the video-reflexive ethnography work of Iedema et al [19] offers a way forward that is rooted in actual practice. In regard to mental models in IPC and related visualisation/imagery, the literature tends to be preliminary in nature [20]. Indeed the literature at the conjunction of IPC, education/training and e-learning/visualisation is diverse, mostly formative, and does not yet constitute a corpus of well established longitudinal programmatic studies. Within this context the visualisation elements of intervention packages/bundles tend not to receive specific consideration in terms of evaluation of process and impacts.

Nevertheless a recent study shows one way forward in this area and enables comparison. Yoon et al [21] used eye tracking and think aloud protocols to evaluate student reactions to visualisations conveying trends in hospital infection transmission. These visualisations of aspects such as prevalence of infection spanned a range from static images of line graphs, through various static two-dimensional infographics, to static three-dimensional representations of a ward area. Interestingly the student participants often preferred the former as they were used to the simplicity of line graphs. This highlights key challenges for developers in this field, such as the tension between challenging established conventions and respecting established tastes, and the tension between conveying the complexity of the hospital ecosystem and the need for clear and unambiguous visual messages.

Regarding the latter tension, there is particular potential in the rapidly increasing availability of very useful, yet complex, new data on the behaviour of pathogens (e.g. survival in locations over time) and people (e.g. individual staff pathways and contacts within settings). There is opportunity to explain these dynamic processes more meaningfully through dynamic visualisation approaches such as our interactive tablet based tool. However our team's digital designers often had to make trade-offs between the inclusion of "realistic" details in the virtual ward background (e.g. details of people and "clutter") and the need to forefront the key action and information in a clear way that avoided information overload. Moreover, this had to be managed alongside our aspiration to add in aspects of the environment that are normally invisible, notably pathogens of varying types in varying locations. In this regard issues of portrayal of relative scale, mass, texture and quantity are also challenging. While clinical research datasets yield opportunities to portray numerically accurate indices of pathogenic contamination, we would argue that presenting these micro phenomena and their dynamic properties as visible within the macro context of a dynamic clinical setting for educational purposes will usually require some elements of impressionistic rendering. As the Stage 1 and 2 findings indicate, there were some times when our various portrayals may have engendered misunderstandings by some participants, but the study design helped to elicit and gain some insights into these.

Some of these challenges are echoed in a recent systematic review of visualisation and analytic tools for infectious disease epidemiology [22]. One of the key review findings is the imperative to consider users' needs and preferences. Our study has shown that the sorts of tensions discussed above can be productively managed and largely overcome through an iterative co-development process that actively encourages inputs from potential users, acts on these, and elicits further ideas and evaluation. Our approach is rooted in design thinking and in participatory development [12] advocating sharing of experiences, expertise and insights from the earliest stages possible to give a basis for meaningful co-design and co-production. Interestingly this very much accords with the aspirations of the Medical Research Council model [23] which emphasises the involvement of 'users' at all stages of intervention development and evaluation in order to deliver interventions that are fit for purpose and that thereby increase the likelihood of influencing practice.

Naturally the study has some limitations. Engagement of participants through convenience sampling targeting three main occupational groups means that it is likely that we recruited those with most inherent interest in new learning opportunities. As such the sample is not statistically representative of a whole hospital population and this limits generalisability of findings. Moreover it may be argued that the consistently positive wording of the Likert scaled statements led to positive response bias from participants. However, as Barnette [24] points out, such assumptions about response bias are questionable and contested by psychometricians, and mixing of positive and negative statements may in fact lead to unintended responses. We would argue that the nature and scope of the concurrent qualitative data also mitigates against assumptions of response bias.

Clearly, within the context of IPC education and practice, further in-depth studies are needed to unpack what works in terms of visualisations and why. The present study goes some way towards this by showing how pathogens may be usefully contextualised visually in relation to behaviours, time and places within a virtual ward environment, harnessing the dynamic potential offered by an evolving evidence base and tablet based computers. A revised version of the tool has recently been developed from this basis.

Conclusion

The dynamic three-dimensional visualisation approach of this tablet-based tool, combined with an iterative co-development approach to design, production, testing and evaluation of processes and impacts, appear to make it distinctive so far in the field as far as can be deduced from reviewing the literature. As such it provides a useful example of "proof of concept" for the development of visual-based applications in this way.

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Conflict of Interests

None.

Authorship statement

ASM conceived, planned and led the study, drafted and revised the paper; CM was co-investigator, drafted and revised the paper; DL and SW acquired and conducted the analysis of data and prepared visual materials.

Ethical considerations

NHS R&D Management approval was obtained from NHS Lanarkshire and NHS Grampian for the study (R&D ID: L15034; NRS ID Number: NRS15/GH151)