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Socio-technical Infrastructuring to assist Innovation in Healthcare Technologies

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Abstract
This paper discusses the role and value of design-led 'infrastructuring' and the development of socio-technical materials to disrupt dominant stakeholder discourses and hierarchies in the development of healthcare technologies. Case studies of two multidisciplinary projects describe the development of demonstration prototypes for: i) a visualisation tool to enhance therapist-patient interaction for physical rehabilitation following stroke and ii) a system for monitoring of nutrition and management of food provision in older hospital patients. Both cases used design-led qualitative research methods and a participative co-development approach integrated into mixed method research methodologies. This provided an enhanced level of infrastructuring amongst the varied team disciplines and stakeholders, acknowledging the importance of mobilising lay knowledge and experience. In both cases 'open innovation' processes, involving prototypes embodying the accumulated evidence and know-how from the stakeholders enabled a more personalised model for service delivery to emerge.

Keywords: Healthcare technology, co-development, infrastructuring, socio-technical materials

1 Introduction

Recent cross-council research initiatives in the UK have encouraged multi-disciplinary teams to come together to more collectively address complex issues in healthcare- and ageing-related research. This aspirational ambition presents significant theoretical and practical challenges for Design. Healthcare services quality improvement and innovation has largely been dominated by a top-down positivist, scientific paradigm, a paradigm that seldom acknowledges neither the complex realities of daily life within healthcare organisations nor the complexities of both human-to-human and human-to-nonhuman interactions within services and systems. To compound this, certain healthcare 'problems' have tended to become the preserve of particular disciplines which assume that their knowledge specialism predominates for prioritising agendas, the forms of evidence to be collected and the 'treatments' to be administered. However, innovations 'proven' through, e.g., randomised controlled trials (RCTs) must be assimilated into the routine practice of teams comprising individuals with very different disciplinary backgrounds and hierarchical status [1]. The biggest challenge facing those striving to improve the quality of healthcare remains that of implementation; ‘a challenge that is significantly shaped by less well attended issues such as culture, language and cognition, identity and citizenship’ [1, 2].

In the context of healthcare service improvement and innovation, there is the opportunity to examine and reflect upon the materials and processes used in the development of implementable improvements and innovations and to address a number of inherent and problematic issues within the healthcare design field such as dominant stakeholder discourses and hierarchies. This paper contrasts two case studies, both multi-disciplinary team cross-council funded UK research projects, and both concerned with aspects of technological development and innovation in the context of healthcare services delivery, for insights gained from the two cases. The first study was concerned with the development of visualisations for a ‘complex intervention’ in a set of pilot randomised controlled trials (RCTs) for physical rehabilitation following stroke, the second with the development of a food management and nutrition monitoring system for addressing problems of malnutrition in vulnerable older hospital patients.

2 Case studies

The two case studies have been well documented separately in previous in papers. The main references for each are provided. To provide context here each is outlined briefly below.

2.1 Case 1: Visualisations for use in physical rehabilitation following stroke

Knowledge about the musculoskeletal system and the way it operates dynamically in relation to muscle force and the effects of gravity, the specialism of Biomechanics, has the potential to assist in the communication and understanding of these issues during physical rehabilitation. Biomechanical data have previously been inaccessible to non-biomechanist experts and to lay people due to traditional modes of presentation of its data.

The researchers’ early work had created and evaluated a prototype visualisation method which was found to enable accessible communication and understanding of complex biomechanical data to non-biomechanical specialists and to lay individuals. As a result of findings from this evaluation it was felt appropriate to develop this prototype into a set of visualisation tools for a ‘complex intervention’ to enhance therapist-patient interaction during physical rehabilitation therapy following stroke in a 45-month multidisciplinary study, ‘envisage’, and for these to be evaluated in a set of pilot RCTs. The visualisation method used input data from motion sensor and motion capture technologies and re-presented this, through dynamic visualisations, using a mannequin on which various types of information could be overlaid and displayed. Figure 1 shows three examples: a tool communicating to the patient the angle of their lower limb lift and the extent to which this met the target angle set for them at that stage in their rehabilitation (left); a tool to show the reach of the upper limb - this, as in the other tools, was able to be viewed from any angle due the nature of the 3D motion capture (centre); and a tool communicating the ‘shank-to-vertical’ angle during walking with the aid of an ankle-foot-orthosis (AFO), a custom-made splint to prevent foot drop and to enable follow-through in the walking cycle (right).

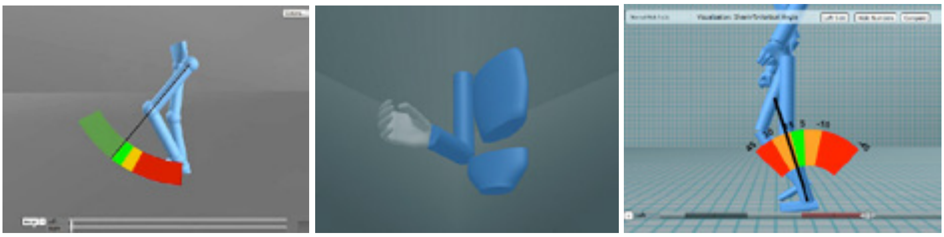

Figure 1. Examples of the visualisation tools used in the three ‘envisage’ stroke trials.

Authors [3] had identified problems with approaches to the development of interventions for use in trials, and the lack of qualitative studies to explain the analysis of quantitative data.

> *“Complex healthcare interventions involve social processes that can be difficult to explore using quantitative methods alone.” “Qualitative research can support the design of interventions and improve understanding of the mechanisms and effects of complex healthcare interventions”. “Most of the qualitative studies were carried out before or during the trials with few studies used to explain trial results.”*

The approach taken in the ‘envisage’ work, in response to [3], was to overlay onto, and to a certain extent integrate into, the traditional RCT design, a qualitative mixed methods process. [4, 5, 6] describe and illustrate the iterative process for the development of the visualisations within the RCT design and discuss the benefits of - and strategies for - involving stroke survivors and therapists through a range of forums summarised in Table 1. The discussion of the approach to - and effects of - infrastructuring the qualitative with the quantitative methods are discussed below in 4.1.

Table 1. This shows the various methods used in the different stages of the RCT. Public and patient involvement (PPI) strategy refers to strategies in [7]: A – represents collecting patient data strategies that focus on the participation of patients with the primary purpose of collecting data; B – represents a broader based PPI strategy involving data collection from a wider range of stakeholders; C – represents patient-led involvement is more complex with them being involved in the design, conduct and even analysis of the research.

Trials phase	**PPI Strategy**	**Methods**	**Visualisations development**
1. Design	n/a C B B, C	*- scoping review of literature* *- survivors’ focus group* *- professionals’ focus group* *- testing and feedback sessions of prototypes with user groups*	 *- initial selection of visualisation options* *- initial selection of visualisation options* *- iterative bespoke visualisations development for each trial*
2. Pre-trial	B A A B	*- trials leads meetings* *- trials patients’ questionnaires* *- trials patient’ interviews* *- trials health professionals’ interviews*	*- iterative bespoke visualisations development for each trial throughout pre-trial phase*
3. Trial	B	*- observation / video*	*- adjustments made as a result of trials*
4. Post-trial	A B C C	*- trials patients’ interviews* *- trials health professionals’ interviews* *- trials patients’ focus group* *- trials health professionals’ focus group*	 *- verification of findings from design and pre-trials phases plus options for future developments posed at FG3+FG4*

2.2 Case 2: Hospital food management and nutrition monitoring

Case two, the 42-month multidisciplinary study ‘mappmal’, relates to the development of a food management and nutrition monitoring system for vulnerable older hospital patients. Previously, a solution to the problem of hospital malnutrition in older patients in the UK had not been found; isolated interventions, such as ‘protected mealtimes’ and ‘red trays’ (to identify nutritionally-at-risk patients) had been ineffective perhaps due to a disregard for the complexity of interaction of all the human and non-human actors. Whereas the problem had traditionally been seen as one involving the expertise of nutritionists, dietitians, food scientists and front-line ward staff (i.e. largely concerned with identifying patients at risk and their individual nutritional requirements), there was no system in place which could accurately measure what each individual actually consumed or the exploration of the application of innovative technologies which could assist with this.

Using an inter-professional research team approach, designers worked alongside food scientists, dietitians, medical sociologists, ergonomists, computer scientists, and technologists. This team then assembled a network of expertise, the ‘food family’ (FF), i.e. those concerned with nutrition, food production, food supply and delivery, catering as well as ward staff, nurses, physicians, speech and occupational therapists, and also involved key stakeholders (KS) such as the NHS and older people representatives. These were all involved, through a series of design workshops, in the conception and iterative development of a food management and nutrition monitoring system. The materials for infrastucturing the activities of the extended research team working with the FF and KS are described in [8, 9]. Figure 2 shows stills from the animation video describing the system concept and the workings of the ‘hospitalfoodie’ demonstration prototype, showing one aspect of this prototype, the ‘wipe-away’ food-monitoring app which uses a photo of the meal linked to a smart nutritional database on the patient’s bed-side touch-screen terminal. This was initially built as an android working prototype for testing with the ‘food family’ and key stakeholders. Table 2 summarises the process and methods used throughout the ‘mappmal’ project.

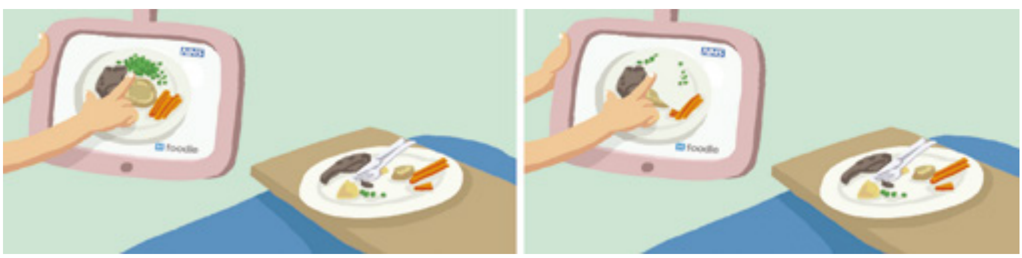

Figure 2. Illustrations © Peter Baynton Radish Pictures 2011: stills from the animation on www.hospitalfoodie.com

Table 2. This shows the key stages, and activities and methods for each stage, and which individuals were involved at each stage.

KEY STAGES

Activities and methods used	People involved
1 identifying issues with the status quo and opportunities for improvement	
ethnographic studies in 5 NHS hospitals	S, D, N
interviews (n=52) with FF and KS	S
sensory testing of existing hospital foods	FS
mapping of existing food journeys	FS, D
2 analysing, visualising and validating findings	
mapping of existing food journeys	FS, D
thematic analysis and visualising of issues	D, S
validation of findings @ WS1a	FF, KS
3 conceptualising and co-design	
identifying opportunities and stimulating new thinking @ WS1b,c	N, S, FS, D, T, E, FF, KS
ideas generation @ WS2b	FF, KS
service prototyping @ WS2c	N, S, FS, D, T, E, FF, KS
4 iterative co-design and development	
determining core elements	N, FS, D, S
building narratives and scenarios	N, FS, D, S
development of new interface application	D, T, CS
evaluating early system concepts with FF + KS @ WS3a	N, S, FS, D, T, E, FF, KS
evaluating early interface prototypes with FF+ KS @ WS3b	N, S, FS, D, T, E, FF, KS
evaluating early food supply and delivery system concept @ WS4	S, D, FF, CM
5 communication through demonstration prototype	
demonstration prototype - working simulation of key elements	N, FS, D, S
exhibition design	D
conference presentations (n=5)	N, S, FS, D
website design	D

D Designers, S Sociologist, T Technologist
FS Food Scientist, N Nutritionist, E Ergonomist
FF Food Family, KS Key Stakeholders
CM Catering Managers, CS Computer Scientist   WS = Workhop (number + activity)

3 Infrastructuring themes

Before the two cases are discussed, a number of 'infrastructuring' themes are briefly introduced to assist in the discussion of the case studies in section 4.

'Infrastructuring' is described as 'the socio-technical mechanisms for constituting and supporting a 'public' ' [10] where 'publics specifically address the ways in which participants endeavor to enact desired futures and prompt change' [11]. These socio-technical mechanisms mediate the inter-relationships not only between human-to-human but also between human-to-nonhuman (i.e. products, interfaces, systems) actors through the creation and use of a variety of activities and materials. Given that in both cases described here technological prototypes were created for use within the healthcare setting, then it was important to acknowledge how and in what ways infrastructure activities and materials assisted both these types (i.e. human-to-human and human-to-nonhuman) of inter-relationships. The careful design of these activities and materials had the potential to mediate, assist in, embody and externalise discourses, agendas and decisions into more tangible manifestations such as concepts, mock-ups, and prototypes, as a way of cumulatively embodying experience, expertise and latent knowledge. These prototype designs (not only of potential new products or services, but of potential new relationships and expectations) could be viewed not only as embodied knowledge but as provocation materials which question, e.g., 'should the future product/service be more like this, or more like that?' The various 'props' introduced can be catalytic in affecting the dynamic interactions of the human-to-human negotiations and, through prototypes, altering both human-to-human and human-to-nonhuman behaviours [12].

There is a substantial literature on Participative Design (PD) which acknowledges the importance of mobilising stakeholder knowledge and experience to co-create and co-design workable solutions, and to drive innovation. For example: [13] argues that 'the more stakeholders have a hand in a design, the more likely will it come to be'; [14] recognise the 'richness and relevance of knowledge developed by laypersons'; [15] discusses 'the importance of putting end-users and stakeholders at the heart of design'; [15] regards design as '… a distributed social accomplishment', 'not just as the work of design professionals but also of the … end-users and other stakeholders whose practices constitute design and its objects in different ways.'

Having assembled the multidisciplinary teams of researchers and the various stakeholders groups 'individuals bound by a common cause' [10] 'a dynamic organisation of individuals and groups formed by the desire to address an issue' [10] to participate in the co-design process, then there is the requirement to create the 'publics', i.e. the 'developmental space' and the 'materials' to enable this participation and to allow the 'plurality of voices, opinions and positions' [10] to emerge and be reconciled through the participative co-design and co-development process.

Although all the actors can be physically in the same space, in the human-to-human discourse and interactions, there is the potential, and indeed the need, to reduce what [16] discuss as the 'social distance' between representatives of the various professions and/or stakeholder groups with their varied cultures, languages, agendas and motivations. 'Power distance' – 'the extent to which the less powerful members of organizations and institutions ... accept and expect that power is distributed unequally' [17], exists as potentially entrenched hierarchies, e.g., between, clinician, therapist and patient. Reducing both 'social distance' and 'power distance' enables what [18] term 'greater proportional symmetry' between the human actors as a means to unblock the inherent barriers or inhibitors to innovation.

4 Effects and consequences of infrastructuring

While previous papers had described the processes and methods and the achievements of the prototypes produced in each case, this paper focusses on the effects of infrastructuring as a facilitator of open innovation, 'the process of harnessing the distributed and collective intelligence of crowds' [21].

4.1 Case 1 Stroke

The traditional approach by the 'lead' discipline (i.e. here by biomedical engineering), which had come to assume the ownership of this particular 'research problem', had been largely technocratic. With a pre-occupation with motion-capture and motion-sensing technologies and quantitative data capture, it was primarily concerned with the problems of quality of movement, speed, and angles of limbs, using pre-determined presentation formats, determining the nature of the evidence to be captured and the 'intervention' to be tested on patients (regarded as passive 'subjects') through – in this case - an RCT, administered by 'therapists'. For Case 1, the intention of the infrastructuring was to respond to the aforementioned issue identified by [3] i.e. the need for mixed methods, to disrupt the traditional approach to 'subjects', and to exploit stroke survivors' and therapists' expertise, experience, needs and desires in the design of the intervention. The infrastructuring was relatively simple in this case and comprised two main elements: i) referencing [7]'s framework for patient and public involvement (PPI), therapists and stroke survivors were given a more equal standing with the clinicians through the iterative development process - both now had a significant contributing role in the development and design of the format of the visual intervention and the successive iterations of the prototype visualisations. The principal motivation, from the biomedical engineer's perspective, for the development and use of these visualisations in trials as an intervention was for a technically enabling tool, i.e. to assist in the technicalities of clear communication and measurement of such information as walking speed, step length, gait symmetry, and angles between limbs (all quantitatively measurable, within the comfort zone of biomedical engineers). However, as the co-developed visualisations cumulatively embodied the collective needs and preferences of survivors (participating as proxy patients) and therapists, *as well as* the trials leads (biomedical engineers) they were also found to be an important socially-enabling tool. This is revealed in the qualitative during-trial data acquired from both patients and therapists. Extracts from the dialogue transcripts from during-trial using the visualisations and from post-trial interviews evidence the intensely 'social' nature of the rehabilitation therapy session [6] even although this had been conceived, by the biomedical engineers, as primarily of a technical nature. The visualisations emerging from this process were 'open innovations' in as much as the therapists, survivors and clinical leads had substantial input into their format and features. They allowed feedback tailored to the individual, and as a result were personalised.

4.2 Case 2 Nutrition

In contrast to Case 1, the approach to this research was not restrained by the RCT model and the infrastructuring was much more elaborate with many more actors involved – both human and nonhuman. An iterative design and development process was deployed using mixed methods including ethnography, mapping, personas, storyboarding, role-playing, enactment and narratives (table 2). Materials were created to support all these activities [19]. This was a large and multi-dimensional project but key to the infrastucturing here were the iterative development and use of i) a set of 'service narratives' to allow everyone to understand how the system and technologies would work in typical ward mealtime scenarios [9] revealing the intended interactions between all actors and ii) the simultaneous development and trialing of mock-ups and prototypes of technologies and interactive interfaces to test the workability of an electronic nutritional management and monitoring system linked to a nutrition composition database, allowing a personalised assessment of an individual's nutrition intake [9].

With regards to the 'service narratives', these could be seen to operate at three different socially-enabling levels at different stages of the project. Firstly, although there was not such an inherent power distance across this team as in Case 1, the narratives, produced largely as a (level one) scripted storyboard edited amongst the dietitics lead, the medical ethnographer, and the designer, reduced the social distance between the different disciplines within the research team; the differences in agenda, pre-occupation and language had to be reconciled for a workable system to be achieved. Although monitoring nutritional intake was the primary goal, how this was enabled and supported through workable technologies was fundamental. Secondly, the research team then developed this level one script into a level two script with the FF and KS, this time in a powerpoint format, for the FF and KS to evaluate and verify, to reconcile any issues arising from the concept and design. The third level comprised part of an exhibition of the working demonstration prototype itself 'hospitalfoodie' where the greater research team's (including the FF and KS) issues and findings were communicated for scrutiny by the professional communities (e.g., nutrition, geriatric, nursing etc.). With regards to the process of 'bringing into being' the nutrition monitoring and food management system itself, this followed - and evolved in parallel from - the service narrative iterations, using a set of materials and methods, from 'what if ?' exercises, to service prototyping, paper mock-ups, and working interactive prototypes [9]. Because of the extent of the active hands-on engagement across the FF, KS and research team in this case, the power distances and the social distances between these communities was significantly reduced.

5 Discussion

As [20] state: "Instead of trying to test the efficacy of an intervention under ideal, experimental conditions, pragmatic trials are designed to find out how effective a treatment actually is in routine, everyday practice" i.e. of the real world context. In Case 1, this may have been one of the designers' contributions here – to try to shift the RCT design towards more of an awareness of, and engagement with, the pragmatics and 'messiness' of the real world physical rehabilitation context and to understand, acknowledge and allow for the dynamics, narratives and behaviours in that setting. The iterations of the visualisations (enabled through the PPI development process) successively embodied the individual needs, preferences, aspirations, and languages of all the key players, i.e. stroke survivors, therapists, and biomedical engineers. This case study reflects how significantly the infrastructuring of a traditional RCT design, particularly in the design and pre-trial phases, with a PPI process and iteratively develop visual prototypes can subvert the prevailing hierarchics within a healthcare context to reduce the social and power distances between the various stakeholders. Given the limitations and formality of a pilot RCT, this could only be achieved to a limited, but still worthwhile, extent.

In Case 2, a much more open development structure not constrained by the requirements of an RCT design, the complexity of the nutrition monitoring and food management environment in the hospital was reflected at the outset by the composition of the extended development team, comprising the multi-disciplinary research team working together with the FF and KS. The key challenge here was for the design of appropriate infrastructuring and preparation of materials and the coordination to bring together this extended team, to engage and elicit their insights, expertise and experience, and to allow ideas and concepts to move forward together, and to make ideas that emerged tangible and manifest through mock-ups and prototypes. Here, there was much more the sense of [21]'s 'crowd' and of [15]'s 'distributed social accomplishment'.

Both cases recognised the importance of the extended and iterative nature of stakeholder involvement and of some degree of social innovation within the workings and dynamics between the actors involved in the creative development space. In both there was a negotiation of new ways of working with new materials, 'moving away from a technocratic view of innovation towards one that includes social innovation – innovation that arises out of social interactions … and actions that arise from the constitutions of a public' [10]. Both cases evidenced the process of the gradual crafting, refinement and emergence of an improvement or innovation through co-development and co-ownership of the technical- and and socio-technical materials required to achieve these innovations.

6 Conclusion

The limitations of achievement of both cases should be declared. The findings from the Case 1 pilot RCTs have been encouraging, showing improvement of understanding of patients' movement problems and the purpose of their rehabilitation tasks, improved communication between the patient and the therapist, and the provision of an objective tool for therapists to monitor progress and communicate it to patients. The technology is now at a stage where it would be feasible to use in a practice setting although the scale of the trial has insufficient power to be recognised clinically. Case 2 has a number of key co-dependent elements which ideally comprise the innovative system: i) interactive interfaces linked to a nutritional database and patient dietary records; ii) a 'mini-meals' trolley; and iii) new foods for older patients. Whether these can be developed further in concert remains to be seen although the new foods have been developed, and interested software developers working in the healthcare field are discussions are continuing.

In the healthcare setting, although the need for change is recognised and there has been a strong desire for a more 'collective' approach, much depends on who leads inititatives for innovation and improvement, i.e. who asks the questions, which questions are asked, and what evidence is gathered and used. Developing and implementing workable and usable and beneficial healthcare innovations and quality improvements will require the strengths of both the measurement and reductive analysis of 'science' as well as a re-assertion of the crafting and the 'art' of participatory co-creation and development processes which allow all stakeholders to work together to mutual benefit in complementary ways.

In the two cases above the recognition of social processes, and the materials to support these, within multidisciplinary team research may help reveal the value and importance of approaches which can recognise and handle the complexities of these contexts, which benefit from the expertise and insights of those who actually experience the conditions or are at the 'coal-face' of their delivery, and which can re-assert the 'art' as an essential partner with the 'science' to support technical healthcare innovations. Challenges remain in reconciling the cultures, the differences in methods, the forms of 'evaluation', and what is construed as 'evidence' or 'knowledge'. This author does not suggest the abolition of the positivist paradigm, but rather the recognition of the requirement for the casting of new actors, for the co-preparing of new scripts, and for the co-creation of new materials to disrupt dominant stakeholder discourses and hierarchies in the current positivist hegemony.

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