Creative Visualisation Opportunities Workshops: A Case Study in Population Health

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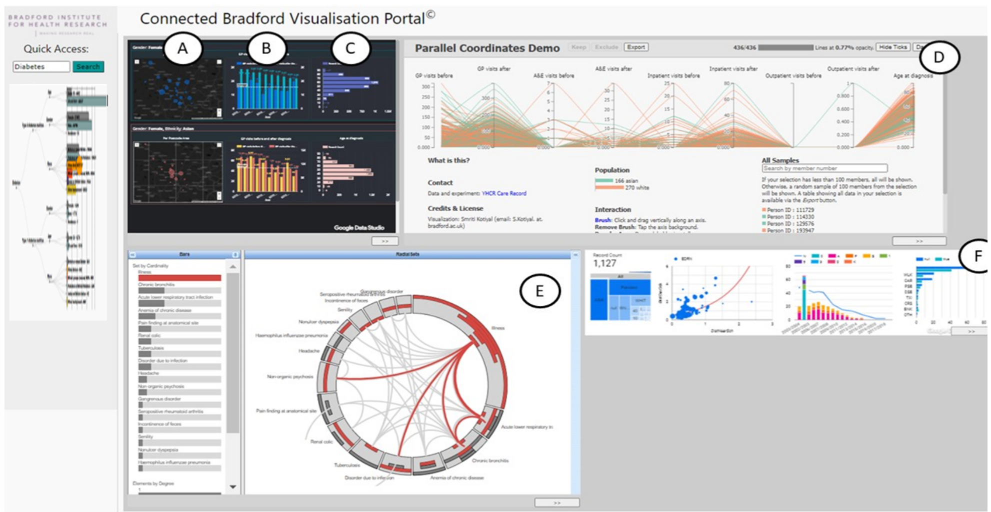

Fig. 1. "Wizard of Oz" prototype (used in Workshop 2) showing: (A) incidence for White British ethnicity (top row) and Asian ethnicity (bottom row) for cohort comparison (T3), (B) number of GP visits before and after diagnosis broken down by locality, and (C) age distribution at time of diagnosis. (D) Selection of a postcode area creates a parallel coordinates plot showing population pathways (T4) across services. (E) Selecting a sub-cohort of interest creates a Radial Sets [3] visualisation displaying overlap of reasons for A&E visits. (F) Education data for patients who suffer from headaches including special education needs and eligibility for free school meals.

Abstract— Population Health Management (PHM) relies on the analysis of data from several sources to account for the complex interaction of factors that contribute to the health and well-being of a population, while considering biases and inequalities across sub-populations. Visualisation is emerging as an essential tool for insight generation from data shared and linked across services including healthcare, education, housing, policing, etc. However, visualisation design is challenged by poor data connectivity and quality, high dimensionality and complexity of real-world routinely collected data, in addition to the heterogeneity of users' backgrounds and tasks. The Creative Visualisation Opportunities (CVO) framework provides a structured approach for working with diverse communities of visualisation stakeholders and defines a set of participatory activities for the effective elicitation of requirements and visualisation design alternatives. We conducted three workshops, applying variations of the CVO framework, with over one hundred participants from the PHM domain, including clinicians, researchers, government and private sector representatives, and local communities. In this paper, we present the results of preliminary analysis of these activities and report on the perceived impact of visualisation in this domain from a stakeholders' perspective. We report real-world successes and limitations of applying the framework in different formats (through online and in-person workshops), and reflect on lessons learned for task analysis and visualisation design in the PHM domain.

Index Terms—Visualisation, Decision-making, Co-design

1 Introduction

The Creative Visualisation-Opportunities (CVO) workshops framework is a participatory design method that allows visualisation researchers to systematically *"pursue domain problem characterisation"* and explore opportunities for collaboration and co-design of visualisation solutions that can tackle real-world problems [18]. Successful application of the framework has been reported in the literature, in which it proved beneficial in various contexts, including education, politics, digital humanities and international security. Visualisation experts have reported benefits of using the framework as it allowed them to focus workshop activities and subsequent analyses on characterising domain problems and gathering requirements from stakeholders, while exploring opportunities for visualisation research [19].

Population Health Management (PHM) is an understudied application domain for visualisation [28], despite the high levels of stakeholders' interest and expectations of visualisation tools, and a common belief that visual analytics is key to support whole-system approaches to

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maintaining the health and well-being of a population, while accounting for biases that impact the most vulnerable groups.

We studied the applicability of CVO workshops as a tool to characterise the problem domain of PHM. Our choice of the framework is driven by the following challenges inherent in the PHM domain:

1. **Fragmented and inaccessible data models**: The sheer volumes of data generated by health organisations are kept in silos. While data and systems integration offer great opportunities to support digital innovations that improve the health and well being of a population [22], integration relies on storage and communication standards that are not always upheld by proprietary medical software [27]. Additionally, data governance issues lead to a discontinuity of the information presented in visualisation solutions within and across analytic contexts. While significant progress is being made in connecting up data from different sectors including health, social care, education and policing (e.g., [37]), stakeholders' ability to describe the opportunities afforded by these initiatives and reason about potential benefits of visualisation is currently hindered by their lack of experience with these newly emerging data models. This introduces a risk to visualisation design studies, as traditional task elicitation (e.g., through interviews and contextual enquiry) are prone to falling in the silos of fragmented data and services, while missing the opportunity of capturing system-level decision making tasks that can benefit from connected datasets and integrated care pathways.

2. **Shifting analytics and decision-making landscapes**: There is a great level of uncertainty about the art of the possible in terms of decision-making tasks that can be supported by visualising data linkage across sectors. Stakeholders are still unsure about this new way of working and the implications that an integrated view of data will have on their decision workflows. This is especially true for participants who are closer to data analytics roles. In an early conversation with a Head of Business Intelligence for a District-wide Clinical Commissioning Group, it was highlighted that: *"There is a new commitment to system-wide working in population health management... Priority programme areas have been set at a system level as a commitment to work as one [system]. They are around frailty, CVD, diabetes, children and young people's mental health, reducing inequalities, and... access to healthcare. So they're set as a system, and how we support that is new because they've been reframed very recently... So I don't have the answers to a lot of it, I'm afraid, yet!... the key is that people cannot define what the question is 99% of the time, that they want the data to be able to provide them with the answer for"*. This motivates more participatory approaches that create spaces for stakeholders to brainstorm ideas and exchange solutions.

3. **Stakeholder diversity and digital divides**: Health data visualisation solutions offer great capacity to increase the effectiveness of communication across stakeholder groups (e.g., clinicians, commissioners, patients and carers), enhance shared decision making, improve quality of care processes, and create spaces for virtual care. This is motivated by the proven ability of visualisation to break down communication barriers that are imposed by unfamiliar health terminology [16]. However, such capacity is often challenged by lower than optimal levels of stakeholder engagement, which are primarily due to technological barriers [33], information overload [39] and varying levels of digital literacy [15]. These barriers call for participatory design opportunities that can engage and inspire participants to think about how visualisation technologies can help them achieve their goals.

4. **Context-sensitive terminology**: The diversity of stakeholders and decision-making contexts in PHM is reflected in the different ways in which visualisation needs are expressed. One notable example is the term *"vulnerability"* which is often described as an important insight to identify the specific needs of population sub-groups and susceptibility to health inequalities. Our early discussions with stakeholders showed that the way a clinician defines vulnerable groups in their services, for example, can be different from the way a commissioner refers to and defines such groups, each referring to a different set of characteristic risk factors. These context-specific definitions are key to understanding visualisation priorities set by diverse stakeholders.

These challenges highlight the need for a structured approach to engage with PHM stakeholders and capture abstract visualisation tasks while accounting for the context-sensitive variations, and constantly evolving requirements in this challenging domain. This paper presents the results of applying three different variations of the CVO workshops framework with over one hundred participants, including clinicians, researchers, public and private sector representatives, and local communities. The variations reflect our efforts to adapt to real-world constraints including the amount of time participants were willing to dedicate and a lack of ability to host large in-person events, due to the COVID-19 pandemic. This meant that we had to vary parameters of the framework and adapt the activities accordingly. We reflect on this experience and describe strengths and limitations of each one of these variants in Section 3, and offer lessons learned and implications on task characterisation for PHM in Section 4. Finally, Section 5 concludes our work and offers pointers for future work in this domain.

2 Background and Related Work

The CDC defines population health as *"an interdisciplinary, customizable approach that allows health departments to connect practice to policy for change to happen locally"* [1]. This approach leverages partnership working across different sectors, including public health, industry, academia, health and social care, local governments, and communities to achieve positive health outcomes.

Communicating health data through visualisation is described as a "wicked problem" [30], given several challenges that it presents to the design community. The design of effective visual analytics relies on rigorous task analysis in which designers seek to understand the tasks that users perform, and the real-world contexts in which these tasks take place. The nested model for visualization design and validation defines abstract tasks as domain- and interface-agnostic operations performed by users [24]. This well-defined concept helps visualization researchers to *"reason about similarities and differences between tasks"*, as noted by Munzner [25]. In order to design and evaluate visualization tools that serve a wide range of user goals, typical in population health management settings, a higher level of *abstraction* and a lower level of domain-specificity enable visualisation researchers to explore the design space of visualisation in a systematic way, while contributing to the evidence base that underlies recommendations and guidelines for mapping data to specific visual encoding techniques. The ability to assess the usability and effectiveness of those techniques, when applied within certain real-world contexts, relies on a clear structured definition of what users seek to achieve in the real-world. To uphold this structure, several task typologies and taxonomies have been introduced in the visualisation literature (e.g. [4–6, 8, 9, 21, 23, 24, 38]). These taxonomies have informed stages of the design study methodology [35], and have proven especially useful in the early stages of task elicitation and analysis [13, 17], and the generative phase of design [2].

Building on our previous work, we first approached the PHM problem space with a taxonomy-driven approach to task elicitation, in which we previously used the *exploratory analysis*, *confirmatory analysis*, and *presentation* goals from Schulz et al. [34] to guide user story generation [13], and followed up with two additional workshops [14] that were guided by Brehmer and Munzner's typology [5] of *why* tasks are important, *how* tasks are currently performed, and *what* information needs to be available in order to perform a task as well as information that arises once a task has been performed. However, we soon realised that this deductive approach to task elicitation can rather limit the extremely broad thematic variation of user tasks in this domain. Early conversations with PHM stakeholders, in which we sought to elicit -for example- *why* a task was being performed, did not always yield meaningful answers. Furthermore, participants' ability to articulate the information that needs to be available for a task to be performed or the subsequent decisions or actions that can be taken as an outcome of performing the task was hindered by the challenges described in Section 1. We found a need to explore alternative methods from the visualisation literature to structure the conversation with our stakeholders, while opening up avenues for inductive analysis to capture the full breadth of themes, contexts and tasks that constitute this challenging problem space.

The need for understanding stakeholders' experiences holistically has led us to explore participatory design approaches, which focus on what people can *make* from *"toolkits"* we provide for them to use in expressing their *"thoughts, feelings and dreams"* [31]. This experiential view of co-design shifts the power to users in a way that empowers them to lead from the *"moment of idea generation"* [32], and through later stages of the participatory design process. Our focus on users' experiences and participatory methods is further motivated by the successes of experience-based co-design in healthcare settings (e.g., [12]) and reported benefits in generating design ideas for visualisation that supports public health policy [20]. For a comprehensive review of healthcare data visualisation solutions that have benefited from participatory design methods, the reader is referred to [7].

In visual analytics, the Creative Visualisation Opportunities (CVO) framework [18, 19] is a participatory design method that offers a well-defined structure to elicit tasks and visualisation design alternatives in a series of accessible and engaging co-design activities. The CVO framework defines a series of four core workshop activities: *wishful thinking*, *barrier removal*, *visualisation analogies* and *storyboarding*. Knoll et al. extended the recommendations for the CVO framework and described scenarios where some of the activities (e.g., barrier removal) could be omitted to accommodate for time constraints [19]. We experimented with some of these variations while further adapting our activities to accommodate limitations in both space and time allocated. To our knowledge, this is the first study that reports on adaptations to the framework that aimed to support online workshops, a format which enabled us to engage with a large number of stakeholders and introduced new opportunities and challenges to the framework.

3 CVO Workshops

Participants were invited to three workshops, that were delivered in varying formats, to elicit their vision for visualisation tools that can support their decisions, based on data-generated insights. The scope of each workshop was driven by participant recruitment opportunities that were available to us and the amount of time they were happy to dedicate to exploring visualisation opportunities with us. Following the recommendations by Kerzner et al. [18], we ran a first round of qualitative analysis within days of each workshop. We allowed themes to emerge from the data about the analytic tasks and contexts within which visualisation is perceived to be useful. We documented those themes after the first workshop in a report that was sent to participants, and we tested the relevance of these themes and the potential emergence of new ones as we analysed the results of later workshops.

3.1 Workshop 1: Child Health and Well-being

Our first workshop was organised as a co-located event with the ActEarly City Collaboratory's online workshop. The workshop was attended by approximately 90 members of the ActEarly Consortium [1], including leading researchers and experts in PHM informatics, simulation modeling, and social and housing policy, in addition to public sector representatives, charities and non-governmental organisations. The Consortium aims to improve the life chances of children by focusing on improving the environments that influence their health. As the workshop's goal was to *"Identify shared goals and create a high-level description of data tools that can support the ActEarly Consortium"*, the event offered an opportunity to uphold the `TACTICS` of effective CVO workshops summarised by Kerzner et al. [18], which include highlighting the relevance of the `topic` in the workshop theme, leveraging a sense of stakeholder `agency` and `collegiality`, increasing their `trust` and `interest` in the activities, while addressing `challenges` and barriers to their engagement in workshop methods. The `topic` of the workshop was driven by the three themes prioritised by the Consortium on healthy places, healthy learning and healthy livelihoods to ensure a high level of `agency`, `interest` and `trust`.

3.1.1 Process and Structure

One consequence of our CVO workshop being driven by the main ActEarly Workshop's agenda was that severe limitations were posed on the amount of time allocated for creative visualisation activities, and we were only given an hour slot in the half-day event. Another set of limitations was introduced due to the organising committee's decision to cancel all in-person activities, as they were deemed unsafe at the time, and instead hold the workshop online. To make up for this, we shared a workshop booklet prior to the event, that explained to participants at a high level what we meant by *wishful thinking*, *visualisation analogies*, etc. The booklet explained that our session, titled "Healthy Solutions", aimed to identify what the community would find useful with regard to accessing and visualising data like Connected Bradford [37], a whole-system data accelerator that has been set up in the City of Bradford, UK to link health, education, social care, environmental and other local government data to support PHM. The dataset, spanning a period of over forty years linking data for about 800,000 individuals via pseudonymised NHS number and other data variables, presents countless opportunities for data visualiastion in PHM. We wanted to capture some of these opportunities in light of the three themes of ActEarly.

An agenda and plan were circulated ahead of the meeting, outlining four stages of the activity: *divergent wishful thinking*, *convergent wishful thinking*, *task contextualisation* and *wrapping up*; providing a brief description of these stages and an overview of the Connected Bradford dataset [37], to allow participants to think about the possibilities afforded by the wealth of data available. Participants were warned against the time limitations of the activity and given a "homework" to engage in wishful thinking before the event.

The online session started with a ten-minute presentation that aimed to set the stage and establish the principles of creativity, collegiality and trust. The audience were then asked to join one of eight breakout sessions and comprise eight focus groups. Each group was supplied with a link to a Google Jam Board and had a facilitator and a rapporteur who took notes and encouraged participants to write ideas on the Jam Board. Facilitators and rapporteurs were supplied with additional material that provided possible ways to lead the activity and prime the discussion. The Jam contained a series of slides that walked participants through the sequence of activities outlined in the divergent and convergent parts of the wishful thinking stage of the CVO framework, and provided a space for participants to express on sticky notes what they would like to be able to *know*, *do*, and *see* (Figure 2). Subsequent slides then walked participants through two additional steps for the *task contextualisation* stage of the activity: *(i) telling stories with data*, where they were asked to select sticky notes from previous slides and try to create a narrative around how ideas are related, and how solving one task can unlock possibilities for another; and *(ii) putting it all in context*, where participants were encouraged to think about decisions and real-world interventions that could benefit from the availability of the intelligence described in their wishful thinking. These steps aimed to try and build a narrative around the ideas they have contributed on previous slides, prioritising ones that they felt should act as starting points, and building a narrative around what's next, while pointing out expected barriers.

We hypothesised that this hybrid of *Barrier Removal* and *Storyboarding* stages of the framework would be most appropriate, as asking participants to develop full sketches and storyboards was deemed to be too intimidating given the time limitation and the online nature of the event. Therefore, the *task contextualisation* activity was meant to elicit preliminary knowledge about potential task sequences, perceived barriers to translating the knowledge gained from visualisation to decisions in the real world, and potential visualisations that can support different components of the decision-making process.

[1] https://actearly.uk/

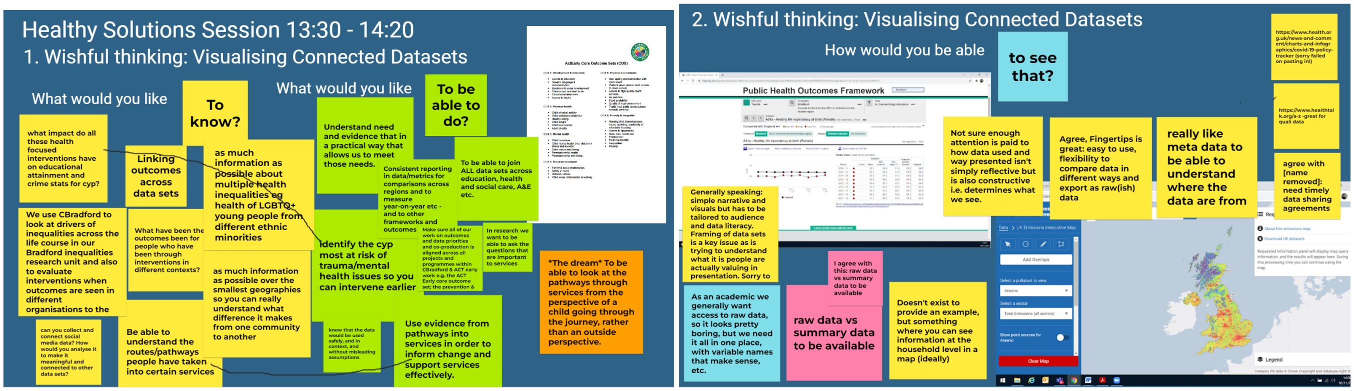

Fig. 2. Example slides from Workshop 1 Jamboards. Participants engaged in expressing needs for visualisations to allow them to *know* information of interest and *do* something about it (left). They then contributed visualisation examples (including links and screenshots) that they were familiar with to inspire ways to *see* the information they need (right).

3.1.2 Workshop Outcomes

The workshop successfully provided a space for the generative phase of task analysis, and both divergent and convergent wishful thinking activities led to the identification and prioritisation of a number of high-level user tasks.

In addition to identifying tasks, preliminary thematic analysis enabled us to identify six PHM **Decision Contexts** in which some or all of these tasks might be of relevance: **[DC1]** clinical decision making, **[DC2]** resource commissioning, **[DC3]** performance monitoring and quality improvement, **[DC4]** policymaking (addressing health inequalities), **[DC5]** service planning and delivery, and **[DC6]** PHM research. Figure 3 provides a summary of prioritised tasks mentioned in these decision contexts. These contexts overlap and interact, so they are not disjoint. For example, while clinical decision making deals primarily with individual cases and sets the focus on medical data about these individuals, decisions in this context can be influenced by guidelines for quality improvement, policies that tackle inequalities, regulations for service planning and delivery, or constraints due to decisions made in the commissioning context. In order to capture these interactions, further task analysis is required to understand the flow of information and visualisation artefacts within and across these contexts. We elaborate more on this point in Section 4.

Many of the barriers expressed by participants were in line with those identified by Preim and Lawonn for visual analytics in public health [28], namely, data heterogeneity, dimensionality, and lack of reliability. Additionally, some new insights were generated in the session as participants elaborated on anticipated inconsistencies and integration challenges and highlighted an urgent need for a common approach to data presentation that enables users from different backgrounds to communicate and make sense of data, while learning new ways of integrated care planning and delivery. Comments such as *"Caveat – it can be tricky to do it in practice because all the different agencies will work in very different ways and may not make full sense of uploaded data"*, and warnings of "*assumptions around demographics and claiming wider benefits when take up/impact may vary"* emphasise the need for visualisation design that can present unified data views while informing users about these inconsistencies to support decision-making within and across organisations and sectors.

3.1.3 Strengths and Limitations

This variant of the CVO framework has put the method to the test under severe constraints in both space and time. One consequence of not having a shared physical space for brainstorming ideas was that some of our workshop participants felt overwhelmed by the *task contextualisation* part of the activity, and some felt that they could not contribute ideas to these slides. This was reflected in smaller numbers of sticky notes than on the previous slides. It was not possible to record all the conversations in the breakout rooms but facilitators gave a brief overview of the discussion to the wider community once everyone was back in the main session. The challenges around putting tasks in context were reflected in feedback from different groups. Time was a major limiting factor and participants felt rushed to think through decision processes that are generally very complex and constantly evolving. These findings are in line with findings by Dimara et al. [10, 11] as they highlighted the disconnect in how sensemaking and intelligence generation tasks for visualisation can feed forward to decisions made on the ground. Despite these limitations, the workshop provided a wealth of information from a generative design perspective, as it allowed us to interact with a wide audience and collect dozens of quotes in which they expressed their data understanding needs.

3.2 Workshop 2: Visualising Connected Data

Our second workshop was organised as a standalone half-day in-person event that took place at a research facility that constitutes a partnership between two regional universities and the Bradford Teaching Hospitals NHS Foundation Trust. Participants were recruited from the three partner organisations based on their research profile and interest in PHM. Fifteen participants attended the workshop, including two clinical consultants, one general practitioner, two senior research fellows, three research interns, a Director of Research, a university professor, three participants with programme director or manager roles, a senior statistician, and a Public Health Intelligence Analyst.

To decide on the theme for the workshop,we considered focusing on one of the decision contexts that were captured in the first workshop (e.g., service planning for child mental health), but after considering several possibilities, we agreed that this narrow focus might jeopardise the sense of `agency` and `interest` of our participants. We, therefore, promoted the workshop as a *"Creative Visualisation Workshop for Connected Bradford"*, and used the decision contexts from the first workshop to inform some of the activities.

3.2.1 Process and Structure

In contrast to the first workshop, we were not too limited in time in this workshop, so the information circulated before the workshop only had an agenda and a brief statement of purpose. We started the day with introductions, a presentation and ice breaker, then we moved on to the *wishful thinking* activity. We facilitated two activities for wishful thinking. In the first activity, titled *"I use data for..."*, we told participants that we understand some of them wear several hats and can be involved in different contexts of data-driven decision-making. We placed six labels on the table for the six decision contexts identified in Workshop 1 and asked participants to write their initials on sticky notes and place them next to as many labels as were relevant to them or their stakeholders (acknowledging that some of our participants were from data analytics roles). We also asked them to add more labels if they thought of other PHM contexts in which data needs to be analysed and visualised. In the second activity, titled *"I would like to know..."*, we

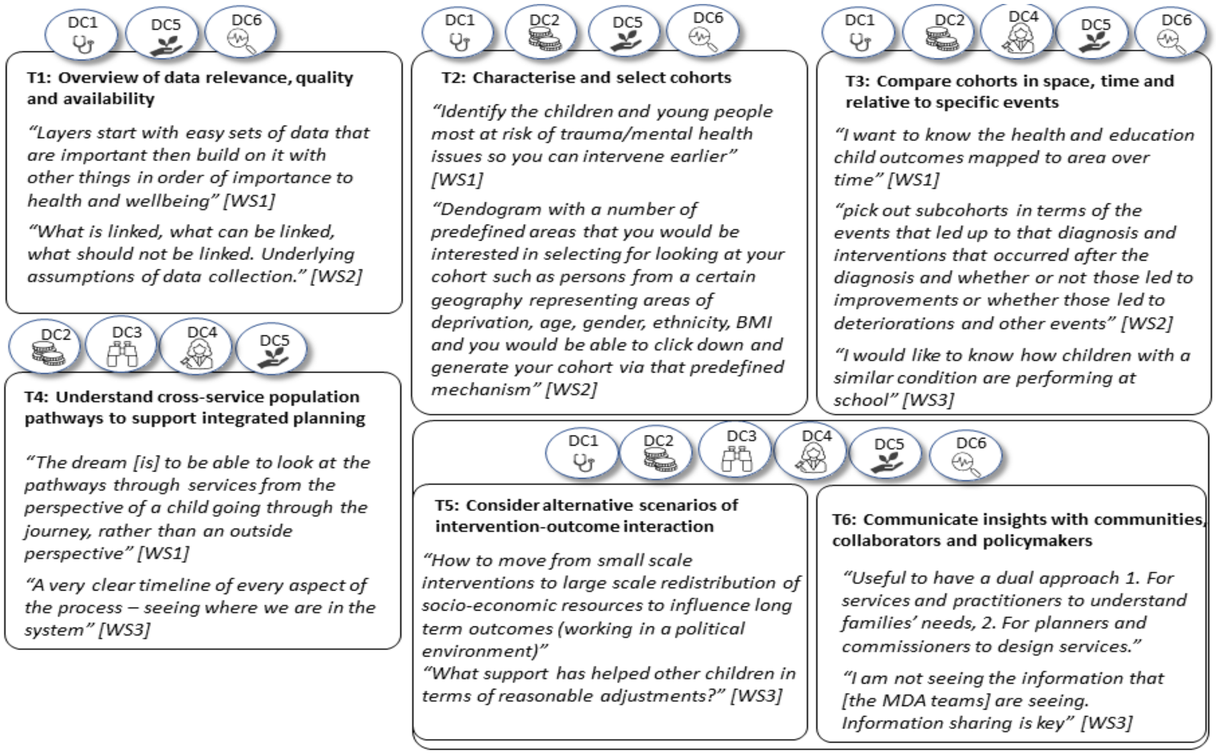

Fig. 3. Summary of generated user tasks mentioned in different decision contexts at the three workshops. Mappings between tasks and contexts are based on our preliminary analysis and will be refined in future analyses.

asked participants to write down questions that they wanted answered from connected datasets on blank sheets of paper. To alleviate the pressure on our participants, we provided the reassurance of making available a pool of tasks to choose from. We asked participants to select relevant tasks for their contexts, once they have expressed their own tasks or have run out of ideas.

The second part of the session was dedicated to exploring *visualisation analogies*. We started with a presentation showing visualisation examples in which we mapped tasks to visual data representations. We then played a video (Supplementary Material A) that demonstrated an early prototype which we developed (Figure 1) to show how a potential investigation may flow from a cohort comparison dashboard (T3) to a cross-service population pathways view (T4) and including tasks such as cohort characterisation using RadialSets [3] (T2) and selecting a sub-cohort to overlay educational and lifestyle data. Following this demonstration, participants were supplied with a VisKit (Supplementary Material B) that included different visualisation techniques which were deemed relevant for the tasks in Figure 3, in addition to large blank sheets of paper for sketching. Participants engaged in the activity by selecting specific tasks relevant in their domain, selecting visualisations from the VisKit, annotating and discussing potential strengths / weaknesses of the selected visualisations in addressing the task(s). Participants were encouraged to annotate and expand visualisations from the kit and to sketch their own visualisations (Figure 4).

Following a coffee break, the final session saw participants engaging in a storyboarding activity, in which we played example videos from the work by Knoll et al. [19] to inspire ideas and provide an example of the expected outcomes of the session. Participants were divided in two groups and each group discussed possible scenarios for the video then delegated one group member to narrate the sequence of interactions, using paper visualisation artefacts (Supplementary Material C).

3.2.2 Workshop Outcomes

Participants expressed specific information needs that were deemed relevant to their practice. For example, one of the consultants stated *"Things I would like to see for newly diagnosed people in [deprived area name removed] put on a tablet or medication – what is their outcome in a year's time? What has been achieved from diagnosis, as it is currently unknown because the codes and interpretations [are] variable and the quality of recording varies from one service to another"*. This task combines cohort selection (T2) for newly diagnosed diabetics, comparison (T3) in space (across services) and time (since diagnosis). It also includes a consideration of alternative scenarios for intervention-outcome interactions (T5). This type of composite task was consistently captured in this workshop, as opposed to more high-level and less composite tasks that were captured in Workshop 1. This can be attributed to the small number of participants, the shared physical space which allowed more detailed discussions and consensus for ideas, and/or the media used for expressing new tasks (by writing on paper rather than typing anonymous sticky notes on Jam boards).

While one of the two groups discussed ideas for high-level cross-service decision-making contexts ([DC2-6]), the second group (which had two clinical consultants) focused on cohort analysis to support clinical decision making ([DC1]). Both groups discussed different levels of granularity for decisions made for a population or cohort versus individual patients. Abstract tasks in Figure 3 were reflected in the videos and no additional tasks were identified, although different ways to mix and compose these tasks were captured from the activities.

3.2.3 Strengths and Limitations

A key value of conducting an in-person CVO workshop was the ability to bring the abstract tasks in Figure 3 to a level of detail that was not possible to obtain in Workshop 1. While there were no additional high-level tasks added after analysing the results of this workshop, we were able to identify sub-tasks through the storyboards and to map those sub-tasks to potential design alternatives. One example is T2: Characterise and select cohorts. Participants detailed the challenges in this cohort selection. Taking Diabetes as an example, they explained that routine data is *"fundamentally process-driven and that means that the code of Diabetes in the patient record is not 100% reliable for diagnosis"* so generating cohorts cannot be fully automated and requires visualisation solutions that can account for these uncertainties.

They further elaborated the need to *"generate intersections and unions"* of cohorts, while using *"predefined mechanisms"* for cohort selection including *"patients from certain geographies, representing areas of deprivation, age, gender, BMI, etc."*, and requested to be able to *"submit a ticket"* if criteria for cohort selection was not supported in those mechanisms. Based on this narrative, one can break down T2 as follows:

- T2.1 Identify codes and events that minimise uncertainty for cohort selection
- T2.2 Characterise reliability of selection criteria across services and cohorts
- T2.3 Perform set operations (e.g., intersection and union) to selected cohorts
- T2.4 Modify and add new criteria for selection

Similar hierarchical breakdown was made possible for tasks T1 and T3-T6 through the artefacts collected in this workshop, which was a key strength of the outcomes. Additionally, participants selected visualisations that were closest to their mental model of population pathways flowing across different events and services. Sankey diagrams were a popular choice and participants created several sketches and annotations that made use of this technique to explain sequences relevant to specific incidental events, for example, before and after a diagnosis (Figure 4 right) or interventional events (labeled *"modifiable variables"* in Figure 4 middle). These artefacts are a key strengths of holding in-person workshops, since they provide a visual depiction of stakeholders' expectations of what they need to *see* in order to make sense of connected datasets, as opposed to textual descriptions of these ideas that were captured on sticky notes in workshops 1 and 3.

While it is recommended that CVO workshops should be held as full day events, we found great benefit in this half-day workshop, as it captured the level of detail needed for hierarchical task analysis and for identifying visualisation alternatives that can address some of these tasks. A limitation was that the smaller number of participants and the fact that participants in this group had a high level of familiarity with Connected Bradford data was that a relatively large part of the conversation was dedicated to barrier removal (despite it not being explicitly labelled in the agenda), as participants discussed in detail data reliability and consistency issues, such as the diagnostic code variations discussed earlier.

3.3 Workshop 3: Child Mental Health

While the first two workshops allowed us to work with experts and health professionals as stakeholders of visualisation in PHM, this workshop focused on communities as key stakeholders. We invited a group of parents to share their perspectives on information that could help them make better informed decisions for neurodiverse children and overcome challenges in these children's care journey. This online workshop was conducted in collaboration with colleagues from the local authority who were keen to develop a tool for the early profiling and identification of children with neurodiversity in order to intervene early, while keeping track of children's journey across care pathways.

Similar to Workshop 1, we did not include a full storyboarding activity in this workshop, and instead focused on *wishful thinking*, *barrier removal*, and included a slide on *visualisation analogies*, and another on "Telling stories with data", which constitutes only one step of *task contextualisation*. Participants were encouraged to think about the information they need relative to different stages of their journey: *(i)* before deciding that a neurodiversity profile is needed, *(ii)* once profiling has taken place, and *(iii)* while on waiting list for services.

3.3.1 Workshop Outcomes

Participants expressed a number of tasks that they would like to be able to perform using an information sharing and visualisation tool. In the pre-assessment stage, participants expressed interest in qualitative information to support their decisions. For examples, *"advice on financial impact"* and knowing *"who the right person is to talk to"*.

Once a child assessment has taken place, participants expressed an interest in cohort comparison (T3) relative to the diagnostic event (see Figure 3) and comparison over time relative to multiple milestones *"like to like - something about my journey with my child and others with similar experiences (e.g., divorce, separation, family dynamics, etc.)"*. They also wanted to see scenarios of intervention-outcome interaction (T5). Parents were also interested in the cross-services population pathways (T4) as they wanted to see *"A clear illustration of the whole system"*, while a vast majority of their tasks were on the communication front (T6), wondering who the key contacts are at different stages of the journey and ways to communicate with those contacts.

3.3.2 Strengths and Limitations

Engaging with the community was a key strength of this workshop as it added a fresh perspective on expectations of visualisation to solve population health problems. One notable observation is that the language used to describe visualisation was quite different from the previous workshops, as participants repeatedly referred to *"illustrations"* rather than charts or specific visualisations, which poses the question of whether illustrative techniques have the potential to better engage with this lay audience. Another notable strength was that participants wrapped data-driven insights with more qualitative information (e.g., recommendations for books, tips, peer support, etc.) which contribute to real-world decision making. This was an interesting contrast between the communities' perspective captured in this workshop and the PHM experts' views captured in Workshop 1, since parents and communities generally have a good understanding of what *insights* they need to learn in order to *decide* on actions that can benefit their children, while experts had a good idea of *insights* that could be generated from data, but with a less clearly expressed pathway for these *insights* to influence population-level *decisions* and actions on the ground.

Importantly, this workshop offered a new opportunity for identifying task sequences, despite not having a bespoke storyboarding activity. Throughout the discussion, participants shared a story line, based on their own lived experiences, and this made it possible for us to understand the order in which visualised data can support some of these experiences. It was clear to us, for example, that an overview of relevant data (T1) can act as an entry point to support participants' journey in the pre-assessment phase, in which they expressed the need for *"high level information for each of the conditions"*, displayed over time *"from pregnancy and birth"* and *"as the child is developing"*. This overview needs to offer pointers on "what to look for", including symptoms and *"a list of issues: sensory, etc. which ones are most relevant to one's child"* in addition to impact of life events such as *"family trauma"*.

Characterising and selecting similar cohorts (T2) and performing comparisons (T3) came next in the story line contributed by participants, as once an assessment has been made, they expressed a need to learn about *"others with similar experiences"*, and compare *"like to like"*. This experiential view of data was clearly expressed in this workshop and we elaborate more on this point in Section 4. Next, an understanding of *"different pathways"* (T4) including *"what referrals have been made and when"* and identifying intervention scenarios (T5) such as *"a list of possible accommodations"* was perceived as helpful.

4 What we have learned

We found the CVO framework to be an effective way of eliciting requirements for visualisation in the field of population health management. Given the vast diversity of decisions made by individuals and organisations in this domain, there is an excellent opportunity for the visualisation community to build new theories and novel solutions that support these decisions. The CVO method proved useful in that it allowed us to cover a broad domain space in a short amount of time. We reflect here on the key learning points after applying the three variants of the method described in Section 3.

4.1 Contextual view of tasks

The data collected from our CVO workshops provided a fisheye view of the landscape of decision making contexts in PHM, while providing a level of detail that enabled us to understand some of the structural similarities of abstract tasks across these contexts (Figure 3). These structural similarities present several opportunities for integrated ways

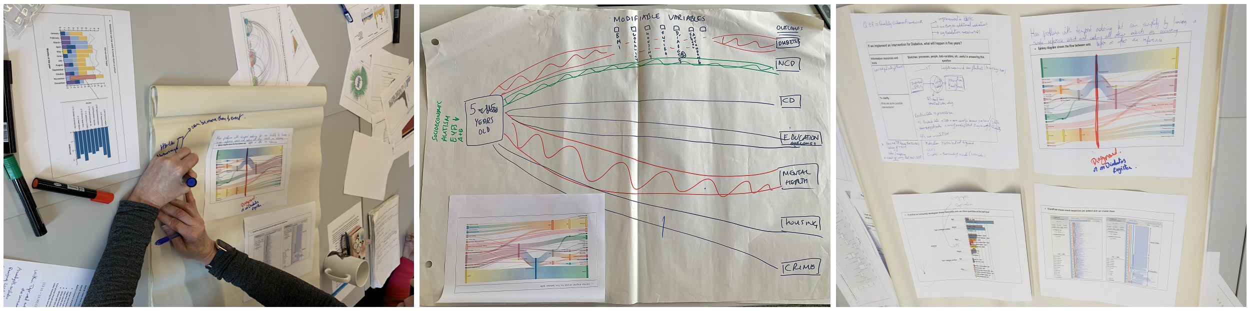

Fig. 4. Visualisation analogies session in Workshop 2 allowed participants to use visualisations from the VisKit, while annotating and sketching information that could be visualised using a given technique.

to visualise data from across services and organisations, a demand that has been highlighted by experts in Workshops 1 and 2, who expressed a need for a *"system-level dashboard"* as well as by communities who, in Workshop 3, requested *"a single version of truth"*.

Despite this need for a unified view of cross-service connected data, it is critical for visualisation researchers and data analysts to approach PHM decision contexts individually as they perform further task elicitation and analysis, and to thrive to design and develop context-aware dashboards that account for the soft boundaries between contexts, within which terminology can mean something that is specific to the context and would have a different definition as it gets translated to another context. This idea of bounded contexts is well established in Domain-Driven Design, e.g., for microservice architectures [29].

To explain why this contextual view is important, we consider the abstract task of selecting and characterising cohorts (T2), through the lens of a domain-specific instance, which is to *"identify and characterise* ***vulnerable*** *cohorts"*, a task that has been repeatedly requested by participants from clinicians caring for individual patients in primary and secondary care settings, to integrated care (cross-service) decision makers looking at service planning strategies that address health inequalities. While the task phrasing did not change across these contexts, follow up conversations revealed that the term *"vulnerability"* is defined differently in each context.

Clinical decision makers define *vulnerable* groups as patients with risk factors of adverse outcomes in the context of a specific disease (e.g., Diabetes). Therefore, the tasks of selecting and characterising *vulnerable* groups (T2) and comparing them to other cohorts (T3) in clinical settings will require data variables that depend on a specific disease in question, which will vary across specialties.

Conversely, our clinical commissioning participants highlighted the need for tools to support whole-system approaches to address the needs of *"vulnerable communities"* as an open-ended task. We followed up with questions to identify exactly what is meant by vulnerability and we found different definitions, with varying degrees of certainty about what this means in different PHM contexts. One participant noted *"different definitions are arising"*. They further elaborated that criteria for vulnerability include age, genetic, ethnic and socioeconomic, and environmental vulnerabilities. Comparative visualisation tasks were mentioned as a way to define vulnerability in this context, with one participant explaining '*'[if] you are at a higher risk of harm from a harmful agent than the people in the same category who don't have the same characteristics, then you are vulnerable"*.

4.1.1 Context-sensitive task characterisation

To consider the impact that this context-sensitivity of tasks has on the task characterisation stage of the design study methodology [35] and subsequently on designing visualisation solutions, we map the task of identifying vulnerable groups to a well-established task taxonomy in the visualisation literature. The Andrienko & Andrienko taxonomy provides a model in which data is structured into two parts [4]:

1. *Referrers*: define the context in which data is collected. Three types of referrers are defined in the taxonomy: *time*, *space* and *population*. A *reference* is a value combination defined by these contexts. For example, a person existing in a certain time and place is a *reference* defined by the three types of *referrers*.
2. Characteristics: are data attributes or measurements taken within the context defined by referential components. For example, a diagnostic code assigned to a person in a certain time and place (e.g., a locality or a practice).

A *relation* in this model is a mapping between references, between characteristics or across sets of references and characteristics. Such relations can include *order*, *distance* and *continuity*. A functional view of visualisation tasks is advocated in the model with lookup and comparison tasks proceeding in two mapping directions between referrers and characteristics: a direct mapping describes identifying characteristics for known referrers, and an inverse mapping proceeds in the opposite direction. Using this functional view, one can describe the task of identifying vulnerable populations as an *inverse lookup* task, where members of the reference set (population) need to be identified based on a set of characteristics that define their vulnerability. This task type is represented in the taxonomy by the equation:

$$?x_1 : f(x_1, \mathbf{R'}_2, ..., \mathbf{R'}_m) \in \mathbf{C'} \quad (1)$$

Where x_1 represents the unknown references (people), $\mathbf{R'}_2...\mathbf{R'}_m$ represent subsets of the value domains for other referential components that provide further context for vulnerability (e.g., location ranges, and time periods of interest) and $\mathbf{C'}$ is a subset of possible characteristics that identify vulnerability. In decision contexts where $\mathbf{C'}$ is known (e.g., in clinical contexts where risk factors for a certain disease are known), the set of variables that constitute $\mathbf{C'}$ will vary across diseases. However, the general structure of the task remains the same. In decision contexts, where $\mathbf{C'}$ is not known and vulnerability is defined based on finding clusters or cohorts that have an increased risk of harm, when compared to other cohorts, this becomes a *relation seeking* task, according to the Andrienko taxonomy which is modelled as:

$$?y_1, y_2, x : f(\mathbf{r}_1, x) = y_1; f(\mathbf{r}_2, x) = y_2; y_1, y_2 \in \mathbf{C'}; y_1 \lambda y_2 \quad (2)$$

which reads as: find the references x (which can be members of the population or localities), and the value of characteristics y_1 and y_2 (which define risk factors for vulnerability), given the known reference sets $\mathbf{r}_1$ and $\mathbf{r}_2$, provided that the values of y_1 and y_2 exhibit a relation λ (e.g., increased or decreased risk). Here, equation 2 uses a simplifying assumption that the characteristics, on which a comparison of vulnerability is based, are known to be of type y_1 and y_2. In practice, the characteristics defining vulnerability are not known to the users and so they would be seeking to identify $\mathbf{C'}$, which defines a subset of all possible characteristics that can identify vulnerability. A visualisation researcher undertaking task analysis may use different qualitative data collection tools to narrow down the size of the set $\mathbf{C'}$, by honing in on those characteristics that capture both objective and subjective measures of vulnerability.

Since the structure of the tasks in equations 1 and 2 are fundamentally different, we conclude that different decision contexts in PHM will impose different sets of requirements on the visualisation and interaction functionality supported in prospective visual analytics and decision support tools in this domain.

4.2 Experiential view of data

Domain experts who participated in our workshops expressed a need for visualisation tools to provide them with an experiential understanding of the journey undertaken by members of the population. This was clearly articulated on one of the wishful thinking Jam Boards for Workshop 1 (see bottom right of Figure 2 left): *"The dream [is] to be able to look at the pathways through services from the perspective of a child going through the journey, rather than an outside perspective"*.

Given this, our analysis of Workshop 3 results sought to capture information about the experiences of children, as described by their parents and communities. As we analysed the results of this workshop, we observed the use of experiential language, including expressions of social, emotional, and affective reactions such as *"hate"*, *"concern"* and *"accuse"*. Unsurprisingly, these words came up in Workshop 3, but not in previous workshops. An observation that leads us to believe that there is a clear need and expectation of visualisation technologies to provide a communication medium between communities on one end and PHM experts and policymakers on another end. This medium should wrap data-generated insights with qualitative information that captures communities' lived experiences and provide decision-makers with a sense of presence in those experiences. Simultaneously, these tools should provide communities with a sense of being supported. This need was articulated in wishful thinking activities in Workshop 3, where a participant expressed the need for a tool to deliver the message that *"we've got you! We're holding you while you go through this process... having the reassurance from multidisciplinary teams and [accessing] information from professionals at the right time"*. How visualisation can support these experiences is one of the big challenges posed by the PHM application domain.

4.3 Decision provenance

Visualisation researchers acknowledge a gap in our understanding of how decision making tasks are supported by visualisation, and how they relate to other high-level tasks, e.g., sensemaking [10]. The ability to build an evidence base that establishes a forward mapping insight generation to actual decisions requires an understanding of the role that visualisation can play in the different stages of decision making, described by Herbert Simon as: `INTELLIGENCE` generation, `DESIGN` solution alternatives, and `CHOICE` of optimal solution(s) [26]. We found that the CVO methodology created spaces for participants to first think about the `INTELLIGENCE` stage of their decision making through wishful thinking. As we progressed through to convergent task contextualisation stages, we found that many participants struggled to articulate how they would use this `INTELLIGENCE` to design solution alternatives. In many cases, the alternatives at a population level were expressed in an exploratory rather than confirmatory way. In other words, participants did not have a predefined set of alternatives that they liked to assess. They felt that the generation of these alternatives is an evolving and iterative process. We attribute the lack of certainty around possible alternatives to two reasons which we detail below.

4.3.1 Responsive Decision Landscape

In addition to decision processes in PHM being constantly evolving, significant changes in these processes and the degree to which they rely on data-generated intelligence have been reported by our participants, in response to major events such as the COVID-19 pandemic. This was especially true for the resource commissioning context, as participants explained that while investments needed to be justified by proving that investing in one area could lead to savings in another area of investment, as the pandemic hit, this proactive data-driven approach had to be interrupted. In a follow up interview, we sought to better understand this change, and our participant said that the message from commissioners was *"You'll get whatever funding you need, just keep a log of it and get on with it!"*. This temporary shift from predictive to reflective analytic needs prioritised the `CHOICE` stage, and emphasised the additional `REVIEW` stage for decision making, which was suggested by Dimara and Stasko [10], while almost entirely skipping the `INTELLIGENCE` and `DESIGN` stages. This type of responsive decision making is not uncommon in PHM as an application domain and should be reflected in visualisation requirements to ensure that the supported decision workflows have sufficient agility in emergency response situations.

4.3.2 Mismatch in decision task specification

Similar to findings by Dimara et al. [11], we have found that the visualisation needs for decision makers and their perspectives on the quality of available visualisation tools differ from those of data analysts. Decision makers generally expressed their frustration about some of the existing systems. One participant described one such system saying *"[it] does not take into account the demographics or employment or housing or anything else"*. While some data analysts spoke highly of the system stating that it *"...takes the raw data and visualises it in a brilliant way for staff who aren't keen to read the data; they like looking at a chart"*. However, limited examples were given on how the system supported real decisions. In order to reconcile these views, visualisation tools should strive to display as much information as possible about the provenance of decisions [36], while exposing the pipeline of information being processed and shared at every stage of the process.

5 Conclusion and Future Work

Until recently, data governance was the biggest challenge that hindered efforts to develop whole-system approaches to PHM. While it may be argued that this is still the case in many parts of the world, an increasing number of cities in the UK are overcoming this challenge and creating large repositories of linked anonymised data, similar to Connected Bradford [37]. Despite this, we are not aware of any system-wide dashboards or visualisation systems that support any of the stages of decision making (including insight and intelligence generation) from data across more than two services (e.g., beyond primary and secondary care). There is a great opportunity for visualisation research to play a key role in this new way of working in the field of PHM and to bridge communication gaps between the different stakeholders and the wealth of data linkages available.

The Creative Visualisation Opportunities framework is an established method for early stage design requirements elicitation but is relatively new to visual analytics design. Through applying the framework to a case study in PHM, we have found that it presents several opportunities to address diverse real world challenges that are poorly addressed by current, more narrowly focused, deductive approaches to task elicitation and design requirements analysis. The framework creates a shared space for brainstorming ideas by representatives of different stakeholder groups while enabling them to imagine *"new and innovative ways to work with their data"* [19].

We have found that online workshops were effective in reaching out to larger audiences and allowing them to think freely and express their needs in the wishful thinking stages of the framework. However, the online format was not as well suited for the later stages (e.g., convergent thinking and storyboarding). We have also found that pipelining workshops in a way that allows the analysis of one workshop's results to feed into the next workshop to be an effective way for idea generation and consolidation.

While the workshops have offered us with a broad overview of the decision contexts in PHM and analytic tasks that can cater to these contexts, further research is needed to refine the mapping between tasks and decision contexts and to better understand where commonalities and differences exist for each task when considered within different contexts. We intend to expand on these connections in subsequent analysis iterations and future workshops.

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