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LDx: An electronic storyboard that supports the users' requirements process in developing a user interface for the clinician-researchers team

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DECLARATION

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Date: 30th April 2022

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ABBREVIATIONS

UI	User Interface
UX	User Experience
TAM	Thematic-Analysis Method
CTAM	Concurrent Thematic-Analysis Method
CDR	Clinical Data Repository
SW	The Semantic Web
LD	Linked Data
LOD	Linked Open Data
UCD	User-Centred Design
HCI	Human-Computer Interaction
CKDdb	The Chronic Kidney Disease database
RGED	The Renal Gene Expression Database
PKDB	The Polycystic Kidney Disease Mutation Database
ADPKD	Autosomal dominant polycystic kidney disease
LinkedCT	The Linked Clinical Trials
RDF	Resource Description Framework
RL	Reinforcement Learning
CTS	Collaboration Technologies and Systems
PACS	Picture Archiving and Communication System

ABSTRACT

This thesis presents the development of an electronic storyboard named LDx, which stands for Linked Data Experience, to facilitate the users' requirements gathering in developing a future user interface to support data exploration, data quality and data integration tasks in the healthcare domain.

In the healthcare domain members of a clinician-researchers team find it difficult to directly interact with data repositories and Linked Data datasets to undertake common tasks that they typically need to do to explore their research hypotheses. I proposed the development of a tool, an electronic storyboard, that integrates the common tasks involved through one user interface to support data exploration, data quality assessment and data integration tasks.

To initiate the necessary user-centred design process, I designed the LDx electronic storyboard to facilitate the user requirements gathering process. The LDx electronic storyboard consists of a graphical user interface that includes data exploration, data quality and data integration sections.

The LDx electronic storyboard was evaluated in terms of its efficiency and user satisfaction via one usability test - a Think-Aloud Test. The participants of the first experimental study were members of a clinician-researchers team (including principal investigators and research managers). A second experimental study was conducted to support and verify users' requirements for developing a future user interface via a triangulation technique (including interviews and direct observations). The participants of the second experimental study were members of a clinician-researchers team (including principal investigators, researchers and statisticians).

This research has yielded one major contribution, **the design, development and evaluation of the LDx electronic storyboard**, to support the users' requirement gathering, and two minor contributions.

The first minor contribution is the **state-of-the-art review of user interfaces/tools in the healthcare domain to identify problems that the electronic storyboard intends to address**. The second minor contribution is **the inclusion of direct observations in the Triangulation approach to support and verify the users' requirements process.**

The contributions described in this thesis could be transferred to any other domain in order to enhance user engagement and ease data exploration, quality, and integration tasks.

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1. INTRODUCTION

Clinical data repositories (CDRs) are databases that enable arbitrary querying and analysis of clinical data and analyses for reporting and research [1]. As a result, CDRs exhibit various issues when used as a source of research data. For example, the inability to conduct efficient data exploration and data integration of the clinical data repository is related to poor user interface design [2]. Similarly, the use of CDR data poses unique challenges for the clinical researcher [3].

The context in which data are collected is frequently variable and may not be appropriate for answering clinical questions - let alone research questions [4]. To illustrate, there may be implicit assumptions about how the data was manipulated prior to being entered into the CDR. For instance, clinical concepts may have been merged to aid in the standardisation of reporting across multiple sites.

Given that technology has the potential to improve medical processes and workflow [5], a user-friendly interface can aid in the exploration and integration of clinical data repositories without requiring computer expertise [6, 7]. Data exploration does not have to end with the identification of data [8] but can also result in the generation of clinical case reports by facilitating the sharing of clinical experiences [9], data integration tasks [10] and extracting information for statistical analysis purposes [11]. However, user interfaces that do not take the clinician-researchers team needs/workflow into account can cause user frustration, resulting in a negative user experience [10, 12] because of workflow disruption [13]. These pitfalls can be translated as one of the most common reasons clinical applications fail to effectively improve health outcomes, research, and care quality as the application and clinical research workflow are incompatible – including the sequence of tasks performed to complete clinical care in what order and by whom.

Clinical research repositories have been developed to aid clinician-researchers in several fields such as nephrology [14]. Incompatibilities frequently occur because of the wait-and-see approach used to implement many nephrological interventions in which an intervention is introduced into a clinical setting, and the clinical research workflow adjusts or does not adjust. Frequently, a lack of integration with clinical research workflow and needs forces clinical staff to develop workarounds or adaptations that jeopardise the interventions' core components. To demonstrate this, the clinician-researchers team uses as many information resources as possible to provide the best care to the patient.

Perhaps the most familiar aspect of health research is the usability and development of clinical data repositories as an increasing portion of health research is now information-based [15-18]. Additionally, the use of CDR presents unique challenges for the clinical research team [3]. The context in which data are collected is frequently variable and may be unsuitable for answering both clinical questions and research questions.

1.1. Motivation: the need for careful User Interface development for Clinical Data Repositories

Clinical research centres[1] now receive funding[2] for research [19] in various clinician-research domains. However, insufficient studies focus on researching and developing user-friendly interfaces that adhere to the clinician-researchers team workflow for conducting data exploration, data integration, and data quality from clinical data repositories by comprehending the sequence of tasks being performed, including their nature and order.

Additionally, some research has focused on implementing semantic web technologies to integrate datasets and thereby facilitating new research and knowledge discovery. However, a user-friendly interface for data exploration, data integration, and data quality is required to communicate and utilise the linked data efficiently.

Prompt identification of users' requirements and needs can help minimise the clinician-researchers team's workflow disruption. This is achieved by offering a visually pleasant way of exploring and integrating datasets and assessing their trustworthiness of data. Then, it can lead to improving productivity and expectations. For example, the clinician-researchers team is constantly faced with the challenge of analysing and integrating diverse data sources related to patients. These can include personal clinical data, patient-generated data, third-party curated data and third-party services data. Additionally, the quality of the integrated data needs to be verified by including only trustworthy sources on an ongoing basis.

Equally important, previous research [10] has shown that the user interfaces for the clinician-researchers team would be developed effectively if a customised implementation plan is created prior to the final user interface development. The

[1] https://www.rcsi.com/dublin/research-and-innovation/research/resources-and-facilities/clinical-research-centre
[2] http://www.beaumont.ie/media/Annualreport2019WEB190820201.pdf

customised implementation plan must include an exhaustive qualitative data collection to support the users' requirements process. The exhaustive collection of data can be accomplished by including the triangulation methodology that includes at least two methods of collecting qualitative data – for example interviews and direct observations. The customised plan must suit the availability of resources and participants. Triangulation is a method used to increase the credibility and validity of research findings [20]. The advantage of triangulation is that it can compensate for method weaknesses when more robust methods are unavailable or impractical to apply. Previous research has included Interviews and direct observations in the triangulation methodology to support user requirements in the development of software development [21, 22]. The inclusion of the triangulation methodology in software development helps to target users' tasks to improve compatibility. A successful user interface that genuinely considers users' requirements and needs could help with adopting new technologies such as the Semantic Web and Linked Data by allowing ease of navigation by non-expert users such as the members of a clinician-researchers team.

To sum up, Linked Data is an approach increasingly being considered in healthcare and which has standard vocabularies for the data, data quality and mapping information, all under the one standard based scheme (RDF) used in various healthcare projects[3] and frameworks[4]. I therefore need to ground this research in such a representation scheme for pragmatic reasons by designing a visualisation tool of linked data in an early-stage prototype that might be helpful to communicate what a final interface could deliver.

It is argued that the approach described in this thesis could be transferred to any other domain in order to enhance user engagement and ease data exploration, quality, and integration tasks.

1.2. Research Question

As the first stage of developing a user-friendly interface for Clinical Data Repositories, this MSc. by research argues the need to improve the users' requirements process so that it will enhance the clinician-researchers team’s digital

[3] https://fairvasc.eu/
[4] https://github.com/navarral/ijckg2021-serdif-paper

communications in support of data exploration, data quality and data integration tasks.

It is argued that maintaining a human-centred orientation in clinical research systems is critical to developing effective and sustainable clinical research. Thus, all users of the healthcare system (including the clinician-researchers team) can benefit from a human-centred approach [23] [24] [25] to user interface development. Of course, the benefits will be contingent upon the clinician researchers' ability to utilise clinical data interfaces.

The research question investigated in this thesis is:

To what extent can LDx, an electronic storyboard, facilitate the users' requirements gathering process to develop a user-friendly interface to enhance the clinician-researchers team's capacity with digital communication by supporting their data exploration, data quality and data integration tasks?

1.2.1. Research Objectives

In order to address the research question defined above, the following research objectives (RO) were defined:

RO1: Establish a state-of-the-art review of existing user interfaces and tools in the health domain.

RO2: Explore the benefits of including various qualitative data collection methods to enhance the users' requirements process.

RO3: Evaluate an electronic storyboard in the users' requirements process in terms of efficiency and satisfaction.

RO4: Apply and implement additional qualitative data collection methods to enhance and support the users' requirement process for the future development of a user interface.

The proposed electronic storyboard is called LDx, which stands for Linked Data Experience. The electronic storyboard LDx is intended to be used as an early-stage process (users' requirement) in developing a future User Interface that supports data exploration, data integration and data quality for the clinician-researchers team.

1.2.2. Contributions

The major contribution of this thesis is the proposed electronic storyboard called LDx with the potential of being a more generalisable design tool. The minor contribution includes implementing different qualitative data collection methods (such as interviewing and direct observation) to be used within the Triangulation methodology to support the users' requirements process.

Major contribution

The major contribution of this thesis is the development, demonstration and evaluation of an electronic storyboard, LDx.

The user interface of the electronic storyboard starts with a homepage that includes information regarding LDx. The homepage has three sections (Data Exploration, Data Quality and Data Integration).

In the Data Exploration section, the user uploads the metadata file (comprised of metadata about the data to be explored) to convert the machine-readable file into a friendly human-readable report about a dataset, that allows the user to explore what is in the dataset in a user friendly manner. The user can save the metadata report, which can be used in the Data Integration section. The Data Exploration section allows the user to personalise the report by choosing the information to be included.

In the Data Quality section, the user can perform quality assessment of the data at a variety of granularity level (dimension, category or data quality metrics).

In the Data Integration section, the user can choose the data sources to be integrated by selecting the saved metadata reports of the relevant datasets or uploading a new metadata file for a new dataset. To create the interlinks between the datasets at the schema level, the user can select the concepts and concept properties to be integrated from each data source (datasets). Then, the user can select the relationship type, followed by selecting the link type. There is a description of every relationship type and link type to guide the user. The Data Integration section provides a summary and a visual interpretation of the integrated data to support the user's understanding. The three sections require the user to add a narrative and provenance information for future needs.

In order to explore whether such a user interface could be used by domain professionals (who are members included in a clinician-researchers team), an experimental study was designed involving a number of medical professionals. The goal of the evaluation was to explore whether the medical professionals could use the electronic storyboard to explore semantic data, perform data quality assessment and create dataset interlinks by only uploading a metadata file.

The publication associated with this contribution is:

Hanlon, R., et al. Towards an effective user interface for data exploration, data quality assessment and data integration. in 2021 IEEE 15th International Conference on Semantic Computing (ICSC). 2021.

This paper proposes the development of an electronic storyboard to gather the users' requirements for developing a UI for domain professionals (included in any clinician-researchers team) that includes support for data exploration, data quality assessment and data integration. It is argued that a successful UI that surpasses user experience will help with the adoption of new technologies such as Linked Data by offering the easing of the need for a computer science background to undertake common dataset related tasks. This paper also discusses the results of evaluating the electronic storyboard based on usability by the target users.

Minor contributions

The minor contributions focus on including a state-of-the-art review of user interfaces/tools in the health care domain, and the triangulation technique in the users' requirements process for future development of a UI that supports data exploration, data quality and data exploration.

The inclusion of graphical elements in the design decision of the electronic storyboard, LDx, intend to address individual problems identified in the state-of-the-art review.

The inclusion of triangulation technique was incorporated in the second experimental study to analyse the results of the same study using interviewing and direct observation as methods of data collection. The second experimental study helps to enhance the validity of the previous experimental study, creates a more in-

depth picture of the clinician-researchers' team requirements, and interrogates different ways of understanding the clinician-researchers team needs.

In addition, the second experimental study helps to interrogate inconsistencies and data that are not expected to align with the previous experimental study.

1.3. Research Overview

This section provides an overview of the research approach taken in the investigation of the thesis, the methods applied to achieve the research objectives and the strategy for evaluating the research output.

1.3.1. Research Approach

A User-Centred Design Approach was applied to the research conducted as part of this thesis.

User-Centred Design

User-Centred Design (UCD), and the closely related field of Human-Computer Interaction (HCI), offer a set of strategies that seek to ground the design of innovation in information regarding the people who will ultimately use that innovation. User-Centred Design is defined as the process of designing a tool with the end-user in mind, putting the user at the centre of the design process. Similarly, HCI is defined as a field of study concerned with the design, evaluation, and implementation of interactive computing systems for human use and the study of significant phenomena associated with them [26].

There is a straightforward user-centred design philosophy; design systems with the end-users needs, wants, and limitations in the entire design process. The field of UCD holds considerable potential for increasing the usability and user experience by interacting with healthcare applications as the principles and strategies of UCD can be applied to the creation and improvement of software in the healthcare domain [23]. UCD has most frequently been applied to design new health services and technologies by including evidence-based practices for assessing, intervening with, and managing medical and behavioural health conditions [27].

To ensure that the adaptations (from users' feedback) improve compatibility and usability, it was suggested that the researcher (I) and target user (the clinician-researchers team) develop the user interface adaptations collaboratively while improving the users' requirement process in parallel. Thus, it is important to mention that this research followed a collaborative prototyping by involving the user actively at every phase of the users' requirements process.

The feedback from every experimental study undertaken was used to improve this research, and it can be used to develop a clinical research interface. Figure 1 shows the UCD approach used to enhance collaborative prototyping to develop a future user interface [4, 16, 22, 23, 28].

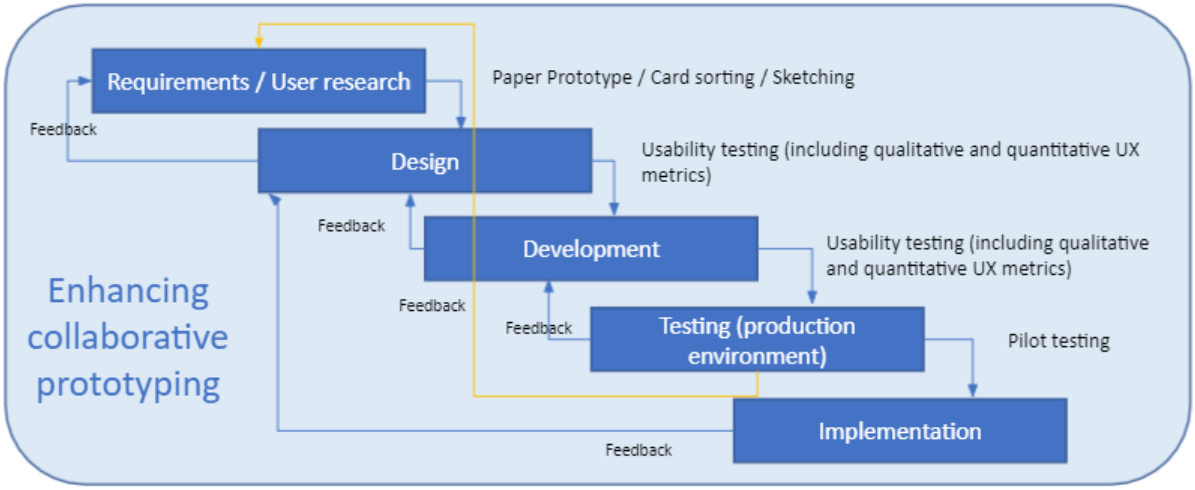

Figure 1: UCD approach to enhance collaborative prototyping

1.3.2. Technical Approach

In order to achieve RO1, a state-of-the-art review of user interfaces and tools in the health domain was undertaken. Similarly, to achieve RO2, this research investigated diverse qualitative data collection methods to enhance the users' requirement process. Adobe XD[6] was used to design the electronic storyboard Ldx (initial and final design) in order to reach RO3. Adobe XD was chosen as it is a robust UI/UX design and prototyping tool for applications. The users' feedback from evaluating the electronic storyboard, LDx, was used as the first users' requirements

[6] https://www.adobe.com/ie

data. The LDx electronic storyboard is available for view at https://xd.adobe.com/view/fc3f4815-b45c-4e0c-b451-121fa4ef5a2d-a96c/?fullscreen.

To support and validate the earlier users' requirement process and achieve RO4, a triangulation approach was conducted by including interviewing and direct observations as additional qualitative data collection methods. The results and validation of the information gathered through this users' requirement process can be used to develop a future UI that supports data exploration, data quality and data integration tasks.

1.3.3. Evaluation Strategy

Usability testing is reported as beneficial in the software development lifecycle by helping to see real user behaviour by watching what people do rather than just asking what people think.

Therefore, within usability testing, we are not looking for any statistical significance; instead, we are looking to identify and fix barriers for people using the application [29]. To illustrate this point, a usability definition from the ISO 9241-11 (1998)8 is defined as the extent to which specified users can use a product to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use. Based on this information, the application developer/researcher should ensure the learnability and understandability of the application whilst meeting all user requirements by including a pleasant interface design [30].

Usability Test – First Experimental Study – Concurrent Think-Aloud Method:

Participants are required to verbalise their thoughts and actions while interacting with a system using the Concurrent Think-Aloud Method [31, 32]. This provides information about the types of difficulties users encounter while utilising a system and information about the aspects of the system that users enjoy.

To evaluate the electronic storyboard (LDx), four participants were asked to think aloud while completing a set of three pre-defined tasks. After completing these tasks, participants participated in a post-test interview to discuss their experience with the electronic storyboard.

[8] https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en

Additionally, they were asked to complete the Post Study System Usability Questionnaire (PSSUQ)[9], a 19-item instrument for quantifying a system's usability. The PSSUQ results are classified into four categories: System Usability (SysUse: Items 1–8), Information Quality (InfoQual: Items 9–15), Interface Quality (InterQual: Items 16–18), and Overall (Items 1-19).

Triangulation Method – Second Experimental Study – Interviewing and Direct Observation:

Triangulation is a common strategy for enhancing the rigour of qualitative studies [21], and it is used in this research to support and validate the users' requirements process.

The second experimental study, using the triangulation method, focuses on verifying the findings from a different point of view by comparing different qualitative data collection methods (interviewing and direct observations) against the findings of previous experimental studies. The interviews and direct observations were recorded and transcribed for future analysis (using the Thematic-Analysis Method). If the triangulation method reveals deviations, the users' requirements information should be updated.

For this research, by applying the triangulation method, the researcher evaluated how the data exploration, data quality and data integration tasks will be compatible with the clinician-researchers needs and workflow. Additionally, the triangulation method helps identify barriers and possible solutions -workarounds- to the current applications tools used by the clinician-researchers team.

1.4. Thesis Overview

The remainder of this thesis is structured as follows:

Chapter 2: Background

This chapter provides useful preliminary information for readers of this thesis. It begins with information about Semantic Web and Linked Data. It then provides information about health research, the clinician-researchers team profile, usability

[9] https://cdn.uiuxtrend.com/wp-content/uploads/PSSUQ-Questionnaire-PDF-Template.pdf

and UX in the health domain. This chapter finalises by providing information about qualitative data collection methods used for the user requirements process.

Chapter 3: State-of-the-Art

This chapter provides an analysis of existing user interfaces used in the health domain, and the repositories and applications used by members of any clinician-researchers team.

Chapter 4: The electronic storyboard LDx

This chapter describes the electronic storyboard LDx.

Chapter 5: Evaluation

This chapter describes the methods used to evaluate the electronic storyboard LDx and gather and validate the users' requirements process. This chapter includes the Concurrent Think-Aloud Method, qualitative data collection methods (interviewing and direct observation) and the usability test.

Chapter 6: Conclusion

This chapter presents the key findings of the research described in this thesis. It discusses to what extent the research question has been answered and the research objectives have been met.

2. BACKGROUND

This chapter presents background information relating to the research of this thesis, mainly the Semantic Web, health research, clinician-researchers profile, usability and qualitative data collection methods.

2.1. Usability and User Experience in the User Interface Development

Usability and UX are two concepts related to human factors. According to ISO/IEC 9241-210[17], user experience refers to a person's perception and responses to the use of the product (including systems and services); usability is the extent to which a system (product or service) can be used to achieve the goals with effectiveness, efficiency, and satisfaction in a specified use of context.

Usability testing has long been considered a gold standard in evaluating the ease of use of software and websites in HCI by producing the metrics to benchmark the experience and identifying areas of improvement [54]. This standard is considered the usability guidance for a system evaluation.

It is essential to realise that usability is not a single, one-dimensional property of a product or user interface. However, usability has been defined in a non-consistent manner by some models [33-37] and standards (ISO/IEC 9241-11[18], ISO 9126-4[19]) where ISO/IEC 9126-1[20] defines usability in the context of quality in use. As shown in Table 1, the concept of usability has evolved by including a variety of dimensions.

Nielsen (1994)	**Schneiderman (2009)**	**Shackel (2009)**	**Constantine & Lockwood (2011)**	**Preece et al. (2015)**	**ISO/IEC 9241-11 (1998)**	**ISO/IEC 9126-1 (2001)**	**ISO/IEC 9126-4 (2004)**	**ISO/IEC 9241-210 (2010)**
Efficiency of use	Speed of performance	Effectiveness (speed)	Efficiency in use	Throughput	Efficiency	Functionality	Effectiveness	Efficiency
Learnability	Time to learn	Learnability (retention)	Learnability	Learnability	Effectiveness	Reliability	Productivity	Effectiveness
Memorability	Retention over time	Errors	Rememberability	Flexibility	Satisfaction	Efficiency	Safety	Satisfaction
Errors/Safety	Rote of errors	Attitude	User satisfaction	Attitude		Maintainability	Satisfaction	
Objective satisfaction	Subjective satisfaction	Learnability (time to learn)				Portability		

Table 1. Usability metrics of various well-known standards and models.

[17] https://www.iso.org/standard/52075.html
[18] https://www.iso.org/standard/16883.html
[19] https://www.iso.org/obp/ui/#iso:std:iso-iec:tr:9126:-4:en
[20] https://www.iso.org/standard/22749.html

2.1.1. Usability and User Experience: The Relationship

This section focuses on moving from general studies of UX to those specifically focusing on clinical interfaces.

The user interface is the way of communication between the users and the machines. The interaction between interface and machine is a personalised experience for each individual user [37]. The communication gives different results depending on how the user observes and interpret the interface. Hornbæk (2006) [38] conducted a study to identify the current practice in measuring usability.

Subjective usability measures concern the user's perception of or attitudes towards the interface, and objective usability measures concern aspects of the interaction that are not dependent on the user's perception. This study includes identifying challenges of subjective and objective measures of usability. The challenges include the need to understand better the relation between objective and subjective measures of usability. Hornbæk (2006) [38] suggested, and depending on the context, a balanced focus on subjective and objective measures may help improve user experience.

Kang et al. (2008) [39] performed the usability test to evaluate user experience and human behaviour by including three electronic devices and selecting some users to identify the behaviour. He concluded that usability is not enough when evaluating the usefulness and interaction.

Usability is an essential factor, but without UX, it is not feasible to develop an iterative, enjoyable, and functional product for users [40]. Similarly, Norman [41] discussed that the human-centred design is dependent not only on usability; but also on the UX of the product.

Constantinides (2000) [42] defined usability and interactivity as the functional components of any web application. He discussed that these two components are dependent on each other as interactivity is more enhanced if the UX is efficiently implemented.

Several studies have narrowed the interface evaluation by including only usability factors [12, 15]. Graham et al. (2008) [12] defines usability based on the interface consistency, response time, comprehensibility of system messages, help availability, comprehension of graphs and tables and the challenges to entering data. Similarly, Gillen (2004) [15] defines usability based on similar user interface factors such as accessibility, satisfaction and reliability of the system.

Usability has changed over time by highlighting the importance of including UX factors [6, 7, 43]. Zhang et al. (2014) [6], Gout et al. (2007) [7], Zumbruch et al. (2020) [44] and Zhao et al. (2004) define usability based on several factors such as the data exploration context and the ease-to-use for information seeking by relating the UX to the users' feeling while interacting with the UI. However, some authors have limited the scope of UX based on physical, cognitive and socio-behavioural dimensions. Table 2 summarises several important studies that defined usability and UX.

Authors	Usability	UX	Target device/service
Gout et al. (2007))	It is about the "ease-to-use" and information-seeking factors	It is about feelings, i.e. the unique UI features that facilitate the clinician-researcher search without the need for relational query expertise.	Clinical data repository
Zhang et al. (2014)	It is about the ease-to-use factor, based on the data exploration context	It is about feelings, i.e. the variety of data visualisations	Clinical data repository
Zhao et al. (2004)	It is about the "the ease-to-use" factor for information seeking	It is about feelings, i.e., to facilitate users interaction by navigating the data to a particular experiment	Clinical data repository
Graham et al. (2008)	Usability is based on interface consistency, response time, comprehensibility of system messages, help availability, comprehension of graphs and tables, challenges to entering data and comments regarding the entry of chronological information	Not fully represented.	Clinical Decision Support System
Walker et al. (2018)	Usability is based on user experience using the technology	Based on physical, cognitive and socio-behavioural dimensions.	Clinical inpatient portal
Gillen (2004)	Usability is based on accessibility, satisfaction, and reliability of the system	Based on users' workflow to reflect usability.	Data entry system for ClinicalTrials.gov
Zumbruch et al. (2020)	Usability based on safety, efficiency and effectiveness.	Based on a positive perception and experience.	Clinical Decision Support System for Volume Therapy
Cai et al. (2019)	Based on increasing the diagnostic utility of images.	Based on increasing user by improving the diagnostic accuracy.	Image retrieval system for medical decision

Table 2: Usability and UX definitions and relationships

2.1.2. Usability and User Experience Evaluation

Usability evaluation has a wide variation in methods and motivations. They can be formal or informal, think-aloud or not, use low-fidelity prototypes or working systems. In addition, they can primarily focus on task-level measurements (summative testing) or problem discovery (formative testing). This latter distinction is fundamental, as it determines the appropriate general approach to sample-size estimation for usability tests [45]. On one level, the notion that 'N' users are required for testing (whether 'N' be 5, 8, or some other reasonably small number) is an academic question. 'N' users will always be better than zero for whatever value of 'N' chosen in any research/study [46].

Popular evaluation methods also include heuristic evaluation [47], cognitive walk-throughs [48], and guideline reviews [49]. Heuristic evaluation [47] involves having a small group of usability experts evaluating a user interface using a set of guidelines and noting the severity of each usability problem and where it exists.

For example, Nielsen (1990) [47] found that the aggregated results of five to ten evaluators of four interfaces identified 55 to 90 per cent of the known usability problems for those interfaces. However, other studies [30] [50] highlighted the disadvantages of the heuristic method as the first disadvantage is that the evaluators must be experts and a second disadvantage is that several evaluation experts are needed, so it increases the cost.

Similarly, Jeffries et al. [50] compared the four best-known methods of usability assessment: empirical usability testing, heuristic evaluation, cognitive walkthrough, and software guidelines. The study reported that heuristic evaluation found more problems than any other evaluation method, while usability testing revealed more severe problems, recurring problems, and global problems than heuristic evaluation. Nowadays, some research has focused on using analytics instead of empirical methods to uncover problems in an interface [30, 51].

Several studies have focused on evaluating the clinical UI (including clinical data repositories, data entry, clinical trials systems, clinical decision support systems, and inpatient portals in the healthcare domain). This was accomplished by collecting data using the Concurrent Think-Aloud method in conjunction with interviews, and some studies evaluated the user experience by coding the qualitative data [10, 12, 52-54].

Some studies identified usability problems. To illustrate this, Graham et al. (2008) [12] and Kushniruk et al. (2004) [53] found that certain types of usability problems were associated with specific types of medical errors. Similarly, Hanlon et al. (2021) [10] identified that a negative interaction with the user interface could develop user frustration.

Some authors included a combination of protocols, Lundren-Laine et al. (2010) [32] identified the usefulness of including the CTAM at the beginning stage of UI development; however, it required a quantified method to explain the participants' performance.

Some authors included questionnaires to identify usability problems; Konduria et al. (2017) [55] found the system to be reliable, and the users were generally satisfied as it helped to improve patient care. Similarly, some authors included statistics, Gillen et al. (2004) [15] identified when usability issues that cannot be sufficiently addressed by modifying the screen design, the preferred solution is to report the issue.

Equally important, some authors identified improvements based on usability metrics [4, 18, 56]. Tunnel et al. (2017) [4] identified that the communication, efficiency, and effectiveness metrics were improved for clinicians who experienced the prototype by highlighting that a well-designed UI can bridge the chasm of understanding among different users; however, it requires compromises from a traditional usability perspective. Staggers et al. (2010) identified that the system could enhance its development processes by using established user-centred design principles and metrics. Similarly, Wanderer et al. (2012) [56] showed improvement in some usability metrics and highlighted areas for further revision. Table 3 summarises the methodologies of usability and UX in the analysis of clinical systems.

Author	Aim	Participants #	Methods	UX evaluation/other techniques	Results	Medical target
Ammenwerth et al. (2000)	Evaluate the prototype of a "multi-functional mobile information and communication assistant."	31	One-week simulation study, interviews, and questionnaires	Qualitative interview	Participants found the need for mobile computer implementation in clinical routine/ UI requires particular attention.	Clinical care
Konduria et al. (2017)	Evaluate the prototype of an "eHealth manager system."	1751	An adapted 12-item survey by using the multi-stage Delphi method to adapt to target users	Questionnaires based on user satisfaction, perceived reliability, workplace productivity	Users found the system to be reliable and were generally satisfied as it helps to improve patient care.	A web-based eHealth system for tuberculosis
Lundren-Laine et al. (2010)	To study the combination of the Think-aloud method and protocol analysis for a medical critical-care system	5+	Think-aloud method	Protocol analysis	The think-aloud method was helpful to find many usability problems and their causes. It can be used at the beginning stage of development. Performance data was not apparent as explanations of participants were not quantified	Clinical decision-making research
Tunnell et al. (2017)	To study how a patient-operated mHealth solution can be designed to improve clinician understanding of a patient's health status during a first face-to-face encounter	12	Interviews and actor-play role	Post-test control group based on efficiency, effectiveness and communication metrics	Communication, efficiency, and effectiveness were improved for clinicians who experienced the prototype. A well-designed UI can bridge the chasm of understanding among different users; however, it requires compromises from a traditional usability perspective.	mHealth solution for clinical care
Wanderer et al. (2011)	A usability evaluation of two user interfaces	20	A pre-interaction questionnaire, survey and interview	An ad hoc survey was used to assessing satisfaction and efficiency. Interview to provide feedback	User testing of the revised user interface showed improvement in some usability metrics and highlighted areas for further revision.	User interfaces in a simulated clinical environment
Staggers et al. (2010)	To conduct a usability assessment of an electronic health record system	12	Interviews and observations (actor-play role)	Only based on usability goals (effectiveness, efficiency and satisfaction)	The system could enhance its development processes through the use of established user-centred design principles	Ambulatory clinical system
Graham et al. (2008)	to study two existing and two new prototype designs for two CDSS to focus on how interface design might contribute to medical errors and potential adverse events	7	Think-aloud method	Coding categories to identify usability problems from the analysis of video-based data	Evaluation of CDSS will be of utmost importance in the future with increasing use of electronic health records	Clinical Decision Support System (CDSS)

	and how this can be detected.					
Kushniruk (2004)	An evaluation of errors associated with usability problems	10	Think-aloud method	Coding categories to identify content-problems and medical default errors.	It was found that certain types of usability problems are associated with specific types of medical errors. It requires extending the evaluation	Handheld application for prescribing medications
Walker et al. (2018)	To evaluate the user experience associated with an inpatient portal	19	Think-aloud method. Participants were given time to explore the portal freely and were instructed to describe their experience as they navigated the technology.	Applied a coding schema that draws from the Systems Engineering Initiative for Patient Safety (SEIPS) model, which is used to evaluate clinical and workflow changes	The extent to which inpatient portals can achieve goals is dependent on the user experience interacting with the technology.	Clinical inpatient portal
Gillen (2004)	To exhibit the degree of usability to enable clinical trial sponsors to submit and maintain information.	unknown	The user directly interacts with the application to uncover issues. The system includes an online user's guide to making the system easy enough to be used	Based on usage statistics.	When a usability issue arises that cannot be sufficiently addressed by modifying the screen design, the preferred solution is to report the issue.	Data entry system for ClinicalTrials.gov
Hanlon et al. (2021)	To evaluate an electronic storyboard to support the users' requirements gathering.	4	Think-Aloud Method	Not fully represented in the interviews.	It was found that the users developed frustration due to the wording used in the UI.	Clinician-researchers

Table 3: Studies using methodologies of usability and UX analysis in the healthcare domain.

As shown in Table 3, the lack of applying UX techniques to evaluate and quantify the users' experiences results in poor system usability. Based on research findings (table 3), continuous usability testing with UX factors can help discover errors and adapt to user needs and workflows.

2.2. Qualitative Data Collection Methods for User Requirements

There are many standard methods – such as triangulation - in qualitative measurement to gather user requirements. Triangulation is used as a methodology that includes more than one qualitative data collection method to support findings. These qualitative methods include person observation, direct observation, structured interview, and unstructured interview.

In fact, the methods are limited mainly by the researcher's imagination. This research focuses on implementing the triangulation methodology by only including interviewing and direct observation as the qualitative data collection methods.

2.2.1. Triangulation

Triangulation is a rigorous scientific approach that utilises multiple approaches to measure the same characteristic to compensate for methodological weaknesses in the study [20]. Triangulation should not be confused with a multimethod approach used solely to collect a large number of measurements to obtain richer information about the object of investigation's various characteristics.

Triangulation of methods, which includes an examination of potential divergences within the outcome, significantly boosts a study's confidence. The advantage of triangulation is that it can compensate for method weaknesses in situations where more robust methods are unavailable or impractical to apply.

Triangulation, as a technique for analysing the results of a single study using multiple data collection methods, is used for three primary purposes: to increase validity, develop a more detailed picture of a research problem, and examine alternative ways of understanding a research problem.

Triangulation frequently aids in the validation of research findings by ensuring that different methods or observers of the same phenomenon produce the same results. Additionally, it can be used to investigate inconsistencies and data that do not appear to be aligned.

2.2.2 Direct observation

There are several ways in which direct observation differs from other qualitative measurements to gather user requirements. Participant observation requires that the researcher become a participant in the culture or context being observed. On the other hand, a direct observation does not typically attempt to become involved in the context. However, the direct observer makes an effort to remain as inconspicuous as possible to avoid biasing the observations.

Second, direct observation implies a more dispassionate viewpoint. The researcher observes rather than participates. As a result, technology can complement direct observation. For instance, one can record the phenomenon on video or observe it through one-way mirrors.

Thirdly, direct observation is typically more targeted than other qualitative data collection methods such as participant observation. The researcher observes selected situations or individuals rather than attempting to immerse himself in the entire context. The method of direct observation is helpful in evaluation research or field research.

Finally, direct observation is typically less time-consuming than participant observation. For example, one might observe clinician-researcher interactions under specific conditions in a laboratory or setting while interacting with a user interface, paying particular attention to the nonverbal cues used.

2.2.3 Interviewing

Interviews are one of the most time-consuming and rewarding data collection techniques. They necessitate a high degree of personal sensitivity and adaptability and the ability to remain within the protocol's defined parameters. Interviewing includes structured and unstructured approaches.

A structured interview is a type of quantitative interview in which pertinent information about a research subject is gathered through the use of a standardised sequence of questions. This method is frequently used in user requirements and follows a predetermined sequence.

In a structured interview, the researcher prepares a list of interview questions in advance and asks them in the same order so that responses can be easily classified. Structured interviews are also referred to as patterned, planned, and standardised interviews.

Unstructured interviewing entails the researcher interacting directly with a respondent or group. It is fundamentally different from traditional structured interviewing in several ways.

First, while the researcher may have some initial guiding questions or fundamental concepts to investigate, there is no structured instrument or protocol.

Second, the interviewer is free to steer the conversation in any direction that piques his or her interest. As a result, unstructured interviewing is particularly advantageous for broadening a topic's scope or gathering user requirements. However, this lack of structure comes at a cost because each interview is typically unique, with no predetermined set of questions asked of all respondents, analysing unstructured interview data is typically more difficult, especially when synthesising across respondents.

2.3. The Semantic Web

The Semantic Web is the visionary extension of the existing World Wide Web (WWW). The term "Semantic Web" refers to W3C's vision of the Web of linked data. Its main objective is to enable people to create data stores on the Web, build vocabularies, and write rules for handling data[21] by making internet data machine-readable.

The considerable amount of data on the Web must be available in a standard format, reachable and manageable by Semantic Web tools by including the relationships amongst data. This relationship among data acts as a collection of interrelated datasets on the Web and can also be referred to as Linked Data, which lies at the heart of the Semantic Web. It is defined as large-scale integration of, and reasoning on, data on the Web[22].

Linked Data (LD) describes a set of principles and best practices for publishing, interlinking and engaging with data on the Semantic Web [57]. Thus, the main objective of any LD interlink is to enhance the discoverability and knowledge associated with a specific resource such as a person, concept and concept property. When LD is published under an open license, it is referred to as Link Open Data (LOD) based on a "five stars" rating scale, with the highest value referred to as

[21] https://www.w3.org/standards/semanticweb/
[22] https://www.w3.org/standards/semanticweb/data

optimal when the LD dataset contains interlinks to another data providing context. Figure 2 shows more details about the "five stars" rating system and the requirements for achieving each star.

Figure 2: Five Stars Linked Open Data

With the Web being one of the most common places where people search for information, several domain experts can use the Semantic Web for sharing and reusing data across applications which enhance data discoverability and visibility. Within the healthcare domain, an enormous amount of diverse data is generated daily as a result of routine clinical care. These clinical tasks can vary from accessing or integrating a diverse source of clinical data such as text, graphical, audio and video.

For example, the eventual goal to improve healthcare practices and the development of most ideal biomedical processes and products largely depend on the ability to share and link the wealth of collected medical data [58]. This goal includes a key challenge as it is not only the ability to integrate heterogeneous data sources but the inclusion of applications for data exploration and data quality through a friendly user interface (UI).

For data exploration, the usability of metadata files can increase the understanding of the vast amount of daily generated health data [9] and reduce the requirements of computational resources. The data exploration tasks is accomplished by summarising the necessary information regarding the data to be explored.

Best practices in Semantic Web technologies should consider the use of standardising vocabularies and the inclusion of information regarding structural,

descriptive and administrative data. Descriptive metadata is helpful to know how data is identified. Structural metadata explains how data relates to one another, and it is beneficial for data integration purposes. Administrative metadata tells us what type of restrictions are to be placed on the file.

Regarding data quality in terms of the Semantic Web, there are different ways of assessing data quality; and this is because the process of data quality assessment is supported by quality-related metadata by including provenance information, as well as data itself, and by identifying the notion of link quality by automatically detecting whether a link is useful or not [59].

However, one of the main shortcomings of Semantic Web technologies is that there are few user-friendly ways for displaying, browsing and querying semantic data. These drawbacks can be translated as the lack of effective interfaces for end-users which leads to further hindrance in adopting the Semantic Web [60].

2.4. Health Research

Health research offers value to society by providing critical information regarding disease trends and risk factors [61]. It is also associated with a significant impact on human health that contributes substantially to the national economy [62]. As an example, chronic diseases are a worldwide threat to public health, but the size of the problem is probably not fully appreciated [63].

National and international clinical registries offer an essential source of information on several aspects of many chronic diseases. The clinical registries can help characterise the population on replacement therapy due to end-stage disease, describing the prevalence and incidence of chronic diseases and trends in mortality and disease rates [64].

For example, chronic disease is defined as an abnormality of the human structure or function that persists for more than 90 days. A variety of different human disorders can cause it, and as a result, there is a wealth of data available to help understand human disorders [23]. By exploring all available patient data, it is also possible to increase awareness of any chronic disease [65], which results in early detection and treatment as a critical value to society and the medical force by including members of any clinician-researchers team.

[23] http://www.beaumont.ie/kidneycentre-forpatients-aguidetokidneydisease-wha

Besides this, the inefficient use of medical communication technology (by including graphical user interfaces) can cause medical errors. These medical errors can be a result of poor healthcare user experience, which highlights the problems with the user interface (UI) [53] and which can lead to developing user frustration [10, 12].

Additionally, the benefits in health research depend on clinicians' ability to effectively use clinical data interfaces and explore and enter data accurately and timely. A user-friendly design for the clinical data repository can easily enable users to search across the repository without the need for computer expertise [6, 7, 43].

Consequently, clinical data interfaces may require customisation to support clinical research workflow. The customisation can be done by conducting interviews with the target users to gather as much information as possible during the user requirements process. Then, the clinical research workflow can be evaluated through different methods [66, 67] by including the visualisation of the workflow [68, 69].

As a result of compatibility with clinical research workflow before UI implementation, the electronic systems used in clinical research studies should be user-friendly while also ensuring the highest data quality and easy usability [12, 56].

2.4.1. The Clinician-Researchers' Team Profile

Dual-role experiences – conducting research and providing direct services - are typical for any member of a clinician-researchers team [70]. The dual-role involves research processes by including planning, implementation, data exploration, monitoring and reporting. The nature of data within the clinician-researchers team dual-role includes data related to demographics, clinical trials, administrative data and ad-hoc study data to reflect the domain requirements. Also, the different decisions required from any clinician-researchers team member require different information as each member requires clinical context [4].

Regarding the clinician-researchers team tasks, members of a clinician-researchers team interact with patients, observe the clinical manifestations of their diseases, and design science experiments to test novel hypotheses generated by this experience. Their information needs include demographic and socioeconomic information [65], dietary interventions, hyperlipidemia management with statins [71],

glycemic control [72], the use of angiotensin system blockade [73], sodium-glucose cotransporter-2 inhibitors [74], rare disease data[24], environmental factors data [25] and clinical data banks (e.g. The Kidney Donor Risk Index [11]).

Subsequently, the clinician-researchers team workflow includes the interaction with a user interface to conduct the data exploration of clinical registries to understand what data is available, what data is needed, the registry data quality, and to uncover initial patterns, characteristics and points of interest.

Equally important, with ease-of-use as one of the metrics to measure satisfaction, this involves attitudes towards the user interface and user experience [38], and a poor user experience may lead to discouraging the use of a clinical application tool by any member of a clinician-researchers team [10].

Consequently, usability and user experience (UX), aside from the traditional human factors, are two-of-many human factor concepts that complement each other to work with the clinician-researchers team member dual-role because usability elements are factors that significantly influence UX. To illustrate this, a user interface that matches users' needs and outperforms UX facilitates the adoption of new technologies such as the Semantic Web.

Equally important, the interaction with technological tools by any member of a clinician-researchers team is essential. To elaborate on this, several clinical data repositories include user interfaces to only uploading, visualising and exporting data [8]; however, in recent years, the development of user interfaces have adapted to the clinical research needs to maximise the data exploration of clinical data by providing a variety of data visualisation options, data standardisation[26], data quality (i.e. by identifying outliers/missing data),[27] and facilitating users search without the need of computer expertise [6, 7, 43].

Hanlon et al. [10] started the process of understanding the clinician-researchers team context and workflow by identifying the need for a user-friendly interface. The need included exploring data in order to prevent health problems, develop new medications, diagnose health problems, cure diseases, monitor health problems, assist in increasing knowledge, assist in transforming existing processes

[24] https://fairvasc.eu/registries/
[25] https://www.tcd.ie/medicine/thkc/avert/
[26] http://www.hkupp.org/
[27] https://www.nephroseq.org/resource/login.html

to serve better-changing needs, perform data analysis and identify information such as quality of data (missing values).

2.5. Requirements Engineering for Software Development

Requirement engineering is the process of eliciting stakeholders needs and wants, and transforming them into an agreed-upon, thorough set of requirements that can serve as the foundation for all subsequent development efforts. The objective of requirements engineering approaches is to ensure that the proposed solution is correct, reasonable, and effective, as well as to make the problem statement clear and comprehensive [75]. Hanlon et al. (2021) [10] started using an electronic storyboard to start the requirements gathering and design processes (prototyping).

Requirement engineering is strongly tied to UCD, where user needs are viewed as part of the design exploration, prototyping, and assessment with the user, as opposed to the software engineering community's preference for a more linear "specify-design-implement" method [76].

The engineering requirement for this thesis focuses only on the development of an electronic storyboard, LDx, to start the requirements gathering and design processes.

2.6. Chapter summary

Chapter 2 provided an introduction to usability and user experience in the user interface development and qualitative data collection methods for gathering user requirements, the Semantic Web and health research,. The following chapter (Chapter 3) provides an analysis of existing user interfaces used in the health domain, and the repositories and applications used by members of any clinician-researchers team.

3. STATE-OF-THE-ART

In line with the clinician-researchers team's understanding of user interfaces in the healthcare domain, the following chapter provides a state-of-the-art of existing repositories and applications used by the clinician-researchers team (Section 3.1). Also presented is a critical review and comparison of papers where the systems included a user interface with outstanding features to be included/improved in developing a user interface that adapts to each member of a clinician-researchers team (Section 3.2). The tools included in the state-of-the-art review were discovered by searching Google Scholar[28], ACM Digital Library[29], ScienceDirect[30], SpringerLink[31], and IEEE Xplore Digital Library[32].

3.1. User Interfaces in the healthcare domain

For the medical professional, the ability to access the spectrum of clinical data has increased. This is highly motivated by the availability and the implementation of medical UI that can organise and visualise the information to follow the clinician workflow by improving patient diagnostics and user satisfaction. Some papers have been selected and reviewed to reflect a critical analysis that can be depicted as follows.

Shakshuki et al. (2015) [77] presented, paper A, at the 5th international conference on current and future trends of information and communication technologies in healthcare in 2015. It presents the architecture of a Canadian multi-agent system designed to manage information regarding patients with poor vision or poor motor skills. This system focuses on key adaptive UI elements such as learning the component and the user model by implementing reinforcement learning (RL).

Shakshuki et al. (2015) [77] tested their implementation through two user model scenarios. Firstly, by observing the data and subsequent changes in the proposed system when the user, a patient with poor motor skills, finds some challenges in operating the UI. Secondly, when the user finds ambient level

[28] https://scholar.google.com
[29] https://dl.acm.org
[30] https://www.sciencedirect.com
[31] https://link.springer.com
[32] https://www.ieee.org/publications/explore

challenges that need to be corrected by adjusting the screen's contrast and brightness.

Bui et al. (2007) [78] published, paper B, in the IEEE transactions and information technology in biomedicine journal in 2007. It is a medical system based on a problem-centric and time-based visualisation of medical data where its UI presents patients' data from distributed data sources. It provides both an access interface for patient records and clinical data.

Bui et al. (2007) [78] tested their implementation by building a platform called TimeLine that involves a pilot study of five thoracic radiologists focused on reviewing an unseen patient case. Findings disclosed that physicians were more confident regarding their conclusions because the UI did not influence their clinical decisions.

Zheng et al. (2007) [79] presented, paper C, at the 12th conference of the world congress on health (Medical) informatics in 2007. This paper illustrates the optimisation of an adaptive UI by including a sequential pattern analysis to analyse and learn previous users' events based on their navigation patterns.

Zheng et al. (2007) [79] tested their application by using ten months of generated records. Therefore, the application was used by 40 internal medicine residents. Findings depicted that Assessment and Plan are the most salient activity patterns discovered, which led to the improvement of the UI navigation.

Craig et al. (2011) [80] presented, paper D, at the international conference on collaboration technologies and systems (CTS) in 2011. It describes a web-based user application to gather data from different collaborative sources. It highlights the ability to access several patients' information without navigating through an endless number of menus. This paper was not tested as it remained as a prototype.

Jorritsma et al. (2015) [81] published, paper B, in the international journal of human-computer studies in 2015. Jorritsma et al. [81] aimed to evaluate the feasibility of adaptive customisation support in real radiology life by using a Picture Archiving and Communication System (PACS). For testing, this study concludes by supporting the efficiency of adaptive customisation to UI because it allows medical practitioners to customise their interface based on their current workflow.

Table 4 summarises the critical analysis of the selected papers.

Author(s)	Year	Paper	Critical Analysis
Shakshuki et al.	2015	A	It describes a Canadian multi-agent system for managing patient information with limited vision or motor abilities. This system focuses on adaptive UI features like component and user model learning via reinforcement learning (RL).
Bui et al.	2004	B	The authors tested their implementation by making a platform called TimeLine. In a pilot study, five thoracic radiologists looked at a patient case they had never seen before. The results showed that doctors were surer of their conclusions because the UI did not affect the clinical decisions they made.
Zheng et al.	2007	C	The authors used records made over ten months to test their application. Because of this, 40 residents in internal medicine used the app. Findings showed that Assessment and Plan are the most important activity patterns found. This made it possible to improve the UI navigation.
Craig et al.	2011	D	The authors described a web-based user application that pulls information from different sources that work together. It shows how you can get information about several patients without having to go through a lot of menus. This paper was not tested because it was kept as a model.
Jorritsma et al.	2015	E	In their conclusion, the authors said that adaptive customisation of UI is effective because it lets doctors change their interface to fit their current workflow.

Table 4: Summarising the Critical Analysis of the selected papers.

3.1.1. Critical Review and Comparison of the Papers

UI design in the healthcare domain focuses on offering a technological advantage in the medical spectrum. The following user interface metrics were chosen because they can improve medical efficiency by supporting the medical professional to never loses focus on the current patient [77-81].

Adaptive Presentation – Based on Granularity

Time-based granularity can represent a patient's clinical history because the clinical events are information that is frequently a temporal dimension specified at different accuracies [13]. Shakshuki et al. (2015) [77], Zhen et al. (2007) [79] and Jorritsma et al. (2015) [81] do not specify whether the architecture is meant to support granularity as it only exemplifies the user and system interaction.

Bui et al. (2007) [78] and Craig (2011) [80] are very similar regarding graphical time-based granularity because they display the content of a patient's events during a certain period by allowing for an increase or decrease in detailed information. The bottom half of its interface is dominated by timelines representing data over time. In addition, in both papers, a data viewer pane is included to reflect a general area for displaying textual reports and images or record notes, plus the

inclusion of permanent demographics to provide elementary information about the patient.

Adaptive Presentation – To Adapt to All Web Platforms

Web applications that support many platforms (such as www, tablets and mobile phones) can enhance operability among users. Shakshuki et al. (2015) [77] focus their application on mobile phones as there is a continuous health monitoring between the user and its medical practitioner. However, it does not justify how the clinician accesses the patient's data. In contrast, Jorritsma et al. (2015) [81] tested efficiency by performing the normal daily routine on standard workstations.

Bui et al. (2007) [78] offer adaptiveness for reshaping the ideal time-frame graph and targeted presentation platform. Their application uses a three dimensions dictionary where the axes are defined by medical problems, data type and visual metaphor. Each record can specify whether the data is included in the interface based on defined rules that correspond to display to a target platform. This system stands out because of its ability to customise the visualisations to different users' needs and platforms.

Craig (2011) [80] and Bui et al. (2007) [24] follow a similar approach regarding adaptive presentation; however, Craig (2011) currently renders fine in most web-browsers by only excluding Microsoft Internet Explorer Version 8, without installing any additional plugins. Similarly, paper C [79] was reengineered into a fully web-based application where all information can be navigated by mouse scroll wheels.

Adaptive Presentation – By Following a User Workflow or User Model

All papers support the medical workflow. Shakshuki et al. (2015) [77] create a UI that follows a user model and describe users' actions and behaviour. For example, every time a new user record is received, it is compared with the historical behaviour patterns in the current user model.

TimeLine [78] was initially created for the domain of thoracic oncology based on visual records of tumour response and its treatment. The current TimeLine system addresses the challenges of problem-centric applications by offering a

general technique to customise UI in any single medical problem. Similarly, paper C [79] and paper E [81] were optimised with the participation and feedback of clinicians by highlighting the training received by radiologists during the software implementation.

Craig (2011) [80] describes how the application allows the inclusion of notes because the interaction between physicians and patients follows a narrative to improve user workflow.

Adaptive Navigation – By Icons Inclusion

Narrowing the navigation paths is essential because clinical users are severely time-frame oriented. Including clinical icons can facilitate user navigation as a faster way to access and manipulate data. Shakshuki et al. (2015) [77] do not disclose many visual UI examples. However, some clinical icons are shown when the user interacts with the cardiograph interface screen.

Bui et al. (2007) [78] enhance the adaptive navigation and reinforces the medical context by providing folder icons where a group of information is stored for future analysis. This implementation can collate older items together whilst allowing new data items to be shown separately.

Paper C [79] and paper E [81] do not offer an adaptive navigation improvement; however, paper C [79] includes a navigation menu on an adjacent frame to enable fast switches over different features, whilst paper E [81] improves navigation by customising the toolbars. Paper D [80] does not justify the inclusion of medical icons to improve navigation; however, visual and behavioural improvements have been suggested in the prototype to allow rapid access to patients' records.

Adaptiveness – By Visualization Engine

An adaptive visual engine can discover hidden and recurring patterns within large sequences of user events, improving adaptive presentations and adaptive navigations to fulfil the clinician's workflow.

Paper A [77] offers adaptiveness by using a user model component that contains data related to the users' habits by including both their actions and errors. The RL component tracks users' historical actions and includes the errors in the UI. Thus, the RL component is responsible for learning, evaluating and adapting the UI.

Similarly, paper E [81] offers adaptiveness by tracking and logging users' events which are reported and suggested to the user to enhance efficiency.

Paper B [78] implements adaptiveness by including a visualisation engine that is added to construct the adaptive UI view. This engine divides the task into two parts by using a knowledge base to select which timeline and individual components alongside its user's profile are reflected as a visual output and outputting the matched display to a specific target presentation platform.

Paper C [79] includes a consecutive sequential pattern algorithm that analyses the sequences recorded in the system. The most frequent sequences that comply with the minimum threshold are interesting to inform the UI redesign.

On the other side, paper D [80] does not offer adaptiveness through any visualisation engine or so however, it implements a "projector" metaphor in which each dot can project personalised content onto the viewer pane, plus adding coded dots with different shapes and sizes to support physicians with colour vision deficiencies.

Paper E [81] offers adaptiveness by customising a toolbar based on the most frequent events and effectiveness metrics. This is like paper C [79]; however, in paper E [81], the user can accept or decline the personalised suggestions by adding functions to the customisable regions.

3.1.2. Discussion

The success of any UI in the healthcare domain relies on providing the medical practitioner with a quick understanding of the enormous spectrum of clinical data sources and easy access to key patient data within a proper context and time. Most of the selected papers are tailored to specific medical conditions [77, 81]. However, some of them (Bui et al., 2007) [78] emphasise the framework to provide a generalised UI methodology that can be applied to any medical topic rather than a specific field.

Paper B [80] and paper D [82] highlights the importance of using granularity in electronic medical records. An advantage of implementing visual time-based granularity on UI shows that a large amount of data is accumulated during and after

a patient visit. Thus, it can show if a patient has not been monitored or needs more frequent visits.

Table 5 summarises the key user interface metrics among the selected papers.

	Time-based granularity	Based on users' workflow	Improving navigation through inclusion of medical icons	Supporting all web-based platform	Supporting adaptiveness – visual engine
Paper A (Shakshuki et al., 2015)	?	●	?	▪	●
Paper B (Bui et al., 2007)	●	●	●	●	●
Paper C (Zheng et al., 2007)	?	●	○	●	●
Paper D (Craig, 2011)	●	●	?	●	●
Paper E (Jorritsma et al., 2015)	?	●	○	▪	●

Legend

● Completely fulfils

▪ Partially fulfils

○ Does not fulfil

? Not specified

Table 5: Key metrics among the selected papers.

Based on the summary of the paper, all papers comply and include the system design based on medical practitioner workflow alongside the offering of adaptiveness. Specifically, paper A [77] makes it imperative for metrics because the interface would not be able to adapt to each team member without the metrics.

3.2. Clinician-Researchers Team Tasks – Repositories and Applications

The following tools were chosen as they are the most popular, useful for evaluation from a UI perspective and closest to what I want to do to offer the benefits to members of the clinician-researchers team. At the end of this section, the chosen tools will be discussed and compared to show the current gap in user interfaces used by any clinician-researchers team. Equally important, the presented systems were chosen for this state-of-the-art review as these are the type of systems that a UI design can possibly improve.

CKDdb

By performing literature data mining and manual curation, the Chronic Kidney Disease database (CKDdb) [8] is an integrated and clustered information resource that covers multi-omic studies (microRNAs, genomics, peptidomics, proteomics, and metabolomics) of Chronic Kidney Disease (CKD) and related disorders – see figure 3. From 377 manually curated studies of 230 publications, the CKDdb database comprises differential expression data from 49395 molecular entries (redundant), of which 16885 are unique molecules (non-redundant).

This database was created to allow disease pathway analysis using a systems approach to yield biological meaning by integrating all available data. As a result, it has the potential to unravel and gain a thorough understanding of the key molecular events that modulate CKD pathogenesis. This repository includes a user interface to query data, upload and export data, and navigate and search data by using filtering search rules.

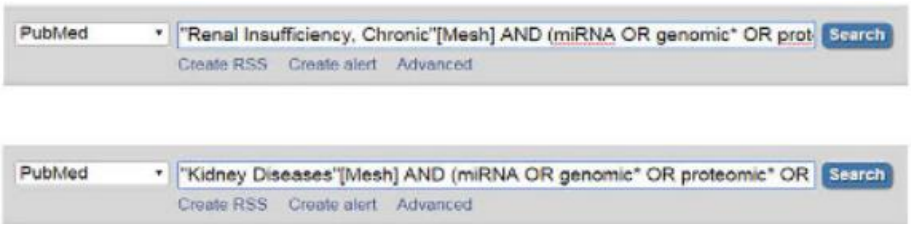

Figure 3: CKDdb user interface

Nephroseq

Nephroseq is a free platform for integrative data mining of genotype/phenotype data for the academic and non-profit communities, with optimised workflows that take you from search to visualisation and from query to answer to the next question.

Nephroseq combines a sophisticated analysis engine and powerful online application built for data mining and visualisation of gene expression data with various publicly available renal gene expression profiles — including Entrez[33], NCIBI, and many other sources. Clinical information is analysed and mapped to a defined ontology. After that, the gene expression values are normalised to make cross-dataset comparisons easier.

Each dataset is processed by an automated analysis engine, which generates various expression, co-expression, and outliers analyses and clinical property correlations. Figure 4 shows how Nephroseq incorporates some visualisations to give researchers a powerful toolkit for validating targets and identifying novel genes and possible biomarkers.

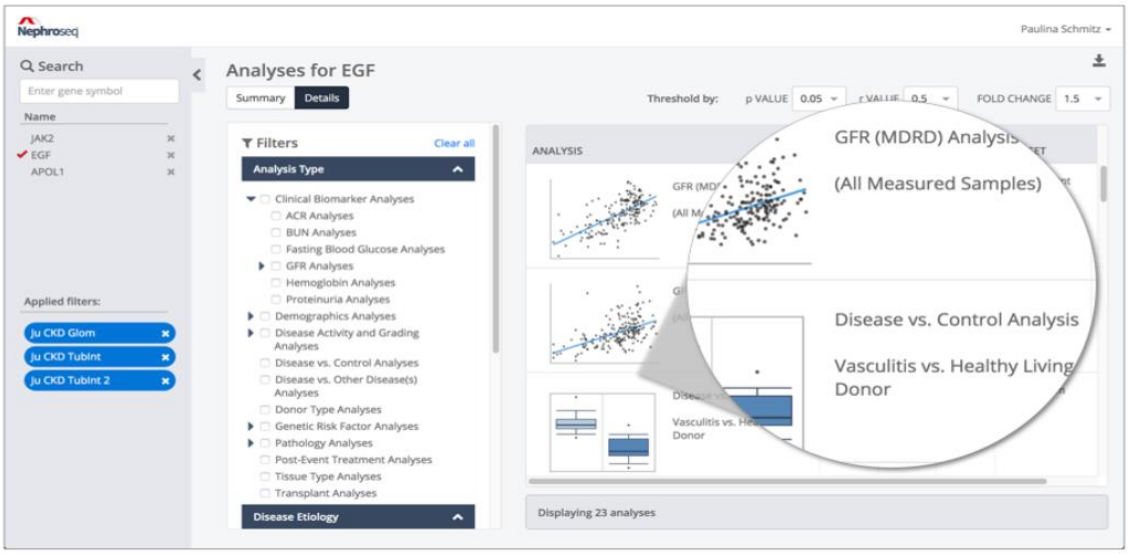

Figure 4: Nephroseq user interface

[33] https://www.ncbi.nlm.nih.gov/Web/Search/entrezfs.html

RGED

The Renal Gene Expression Database (RGED)[34] is a collection of gene expression profiles derived from high-throughput DNA expression profiling assays used in kidney disease research. The database has a built-in web-based tool that makes the information available to the renal disease research community. The user can look into the expression profile of a particular gene in renal disorders and compare two genes of interest (positively or negatively related, how close they are related).

This database component could reveal potential study recommendations on the processes of kidney illnesses, as the closely connected genes are thought to share a similar regulatory pathway.

One of the database's most valuable features is that it allows users to search for gene candidates closely related to the expression patterns of the genes they are interested in, implying the existence of a shared regulatory pathway between them.

Researchers may be able to discover novel gene functions in the control of molecular signals as a result of this [6]. The gene sets in the database were obtained from a variety of sources. Candidates from KEGG[35], BIOCARTA[36], and REACTOME[37] make up the gene set.

The primary goal of RGED is to assist researchers in finding gene expression profiles for diverse kidney diseases. The database's online interface was designed so that people may search the information without having to be computer experts (see figure 5).

The website's home page offers two options to query the database: one is to use a keyword to search for a gene of interest, and the other is to browse the data sets by disease classification. Users can also conduct a quick search by clicking on the tags of some well-known genes.

[34] http://rged.wall-eva.net
[35] https://www.genome.jp/kegg/kegg1.html
[36] www.biocarta.com
[37] https://reactome.org/

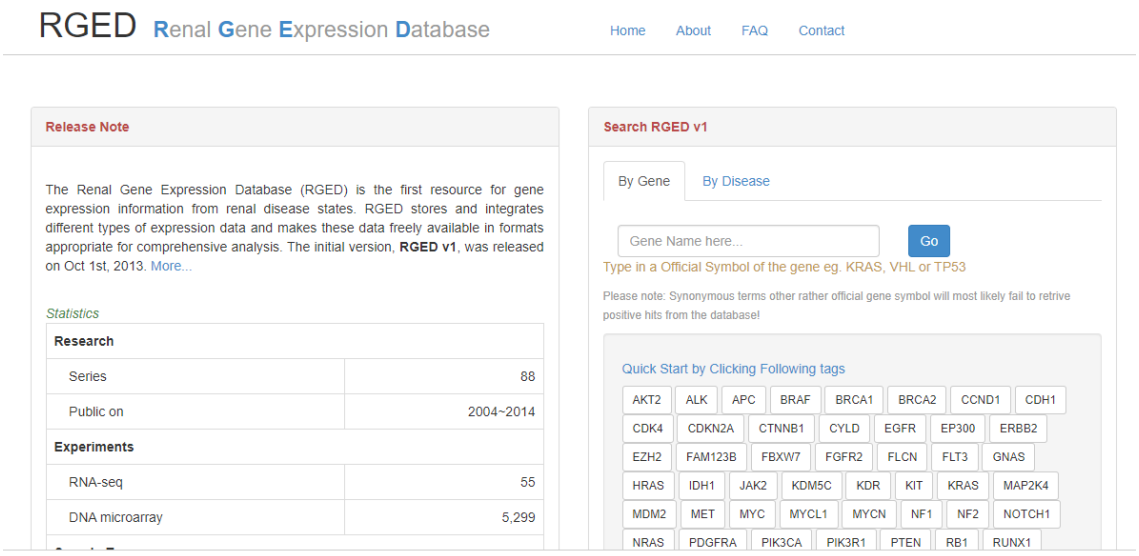

Figure 5: RGED user interface

miRbase

miRBase[38] is the public repository for all microRNA sequences and annotations that have been published. The MicroRNA Registry, previously known as miRBase, was founded in 2002 with the primary goal of assigning stable and consistent names to newly discovered microRNAs [82]. After an article reporting their discovery is accepted for publication in a peer-reviewed journal, novel microRNAs are submitted to miRBase.

miRBase distributes all published microRNA sequences through a web interface for browsing and searching by sequence and keywords. miRBase offers main references for each microRNA sequence entry and links to evidence supporting the microRNA annotation, genomic coordinates, and databases of predicted and validated microRNA target sites. Figure 6 shows how to search for entries by sequence, keyword, literature reference, and tissue expression.

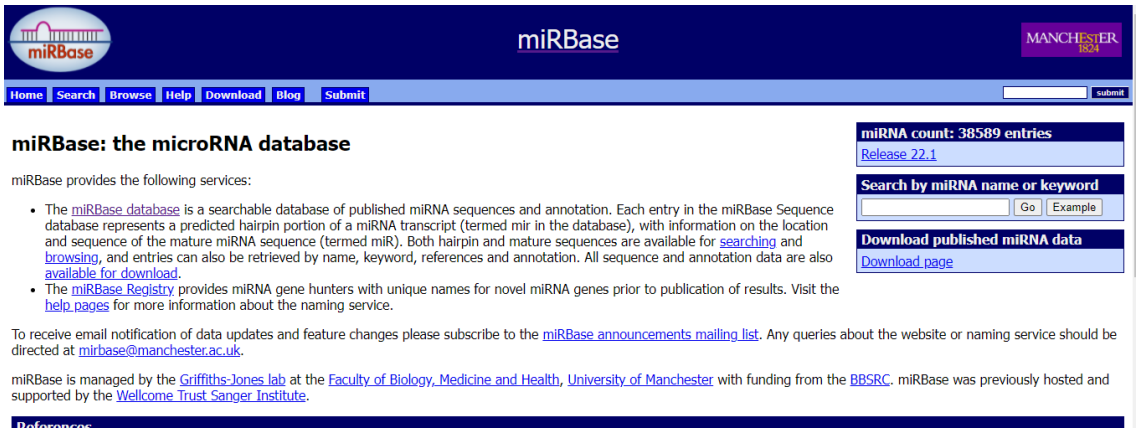

Figure 6: miRbase user interface

[38] www.mirbase.org

PKDB

The Polycystic Kidney Disease Mutation Database (PKDB)[39] is a consolidated, curated online library of published and unpublished data on PKD1[40] and PKD2[41] genetic variations. PKDB, like the PKHD1[42] database for autosomal recessive polycystic kidney disease and many other locus-specific databases that act as publicly accessible storage sites of information about variants in other genes, aims to help researchers and clinicians who are looking for information about the likely clinical significance of variants found within these genes.

A mutation checker has been installed on the PKDB server to allow contributors to test the accuracy of their PKD1 and PKD2 variant reports, as proper reporting of nucleotide variants is critical for ensuring the quality of data within PKDB.

Using standardised downloadable data entry forms, researchers and clinicians can use the PKDB portal to contribute their PKD1/PKD2 gene variations and any associated deidentified clinical data [7]. The entire facts of PKD1 and PKD2 gene variant reports reported in 73 peer-reviewed journals are now available in the PKDB. Users can query the database as needed using a range of user-friendly sophisticated search features.

Eight related tables make up the database structure. The published PKD1 and PKD2 gene variant datasets were normalised to the third normal form to obtain this structure. The PKDB web interface has a search function that allows searches for specific genomic variants within PKDB as needed and a variety of valuable links to the rare renal disease called ADPKD[43] and general genomic resources.

The search interface was created with users with no prior knowledge of relational query operations in mind. To that purpose, "pull-down menus" have been provided and, when appropriate, "radio buttons" in the search interfaces. Figure 7 illustrates how search results are displayed on a results page, consisting of a table of matches to the supplied search parameters.

[39] http://pkdb.mayo.edu
[40] https://medlineplus.gov/genetics/gene/pkd1/
[41] https://medlineplus.gov/genetics/gene/pkd2/
[42] www.humgen.rwth-aachen.de
[43] https://www.nhs.uk/conditions/autosomal-dominant-polycystic-kidney-disease-adpkd/

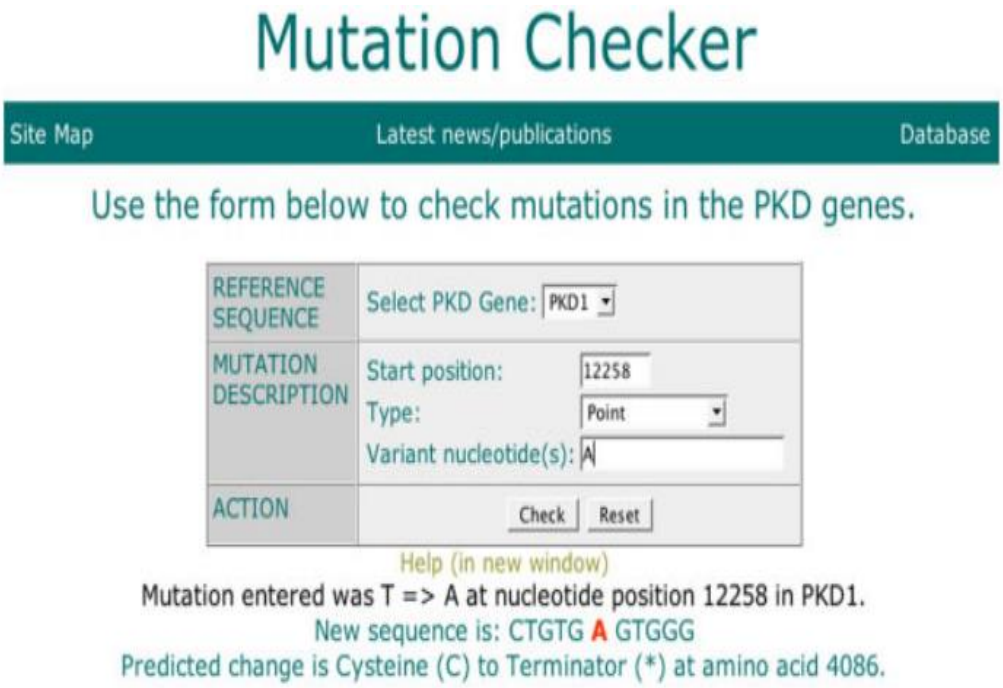

Figure 7: PKDB user interface

KGDB

The Kidney Genome Database (KGDB) [44] is a curated database that offers up-to-date information on genes or genomic regions involved in human kidney disease.

KGDB was created to support researchers and clinicians because of its functionalities [43]. These functionalities include data of genes that have been reported in the scientific literature to be involved in a variety of molecular, genetic, and epigenetic events in the kidney, such as gene amplification, mutation, and gross deletion, as well as genes that are exclusively expressed in the kidney as shown by SAGE[45] and EST[46] analysis.

KGDB content can be searched by molecular event or disease in terms of searching. Clinical databases such as MEDLINE, SAGEmap, dbSNP, and the GeneOntology are used by KGDB. Figure 8 shows how KGDB employs the free search engine http://www.htdig.org, which contains searchable fields including gene name and symbol, aliases, UniGene ID, OMIM ID, and LocusLink ID.

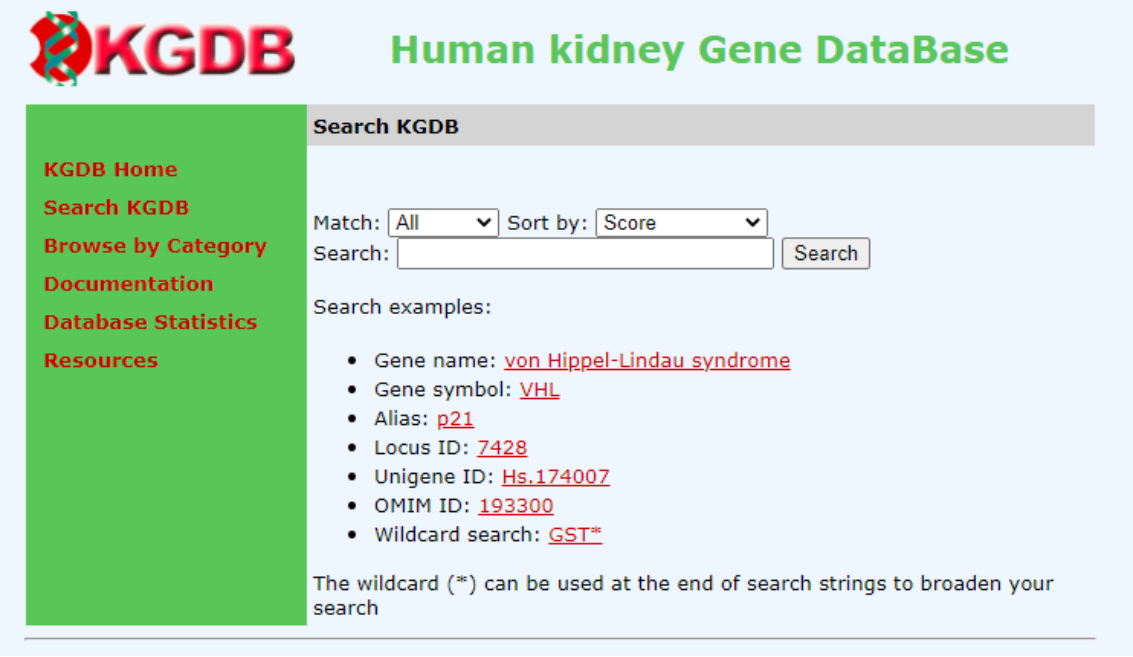

Figure 8: KGDB user interface

[44] http://www.urogene.org/kgdb
[45] https://www.ncbi.nlm.nih.gov/SAGE/
[46] https://www.ncbi.nlm.nih.gov/UniGene

LinkedCT

The Linked Clinical Trials (LinkedCT) project intends to create the first open semantic web data repository for clinical trial data. The LinkedCT database is created by converting existing clinical trial data sources into RDF[47] and discovering semantic linkages between the records in the trials data and a variety of other data sources [83].

The method employed in LinkedCT for semantic link discovery combines state-of-the-art approximation string matching algorithms with the ontology-based semantic matching of the data, all in a declarative and simple-to-use framework.

The purpose of LinkedCT is to develop a single web data source for clinical trial data that is well interconnected with existing medical data sources and can be queried using semantically rich and complex queries. Such a web data source could dramatically improve clinical trial discovery, allowing patients to be matched to trials, advanced investigations to be conducted, and personalised treatments to be developed. Figure 9 displays an example of interconnected items using LinkedCT.

[47] https://www.w3.org/RDF/

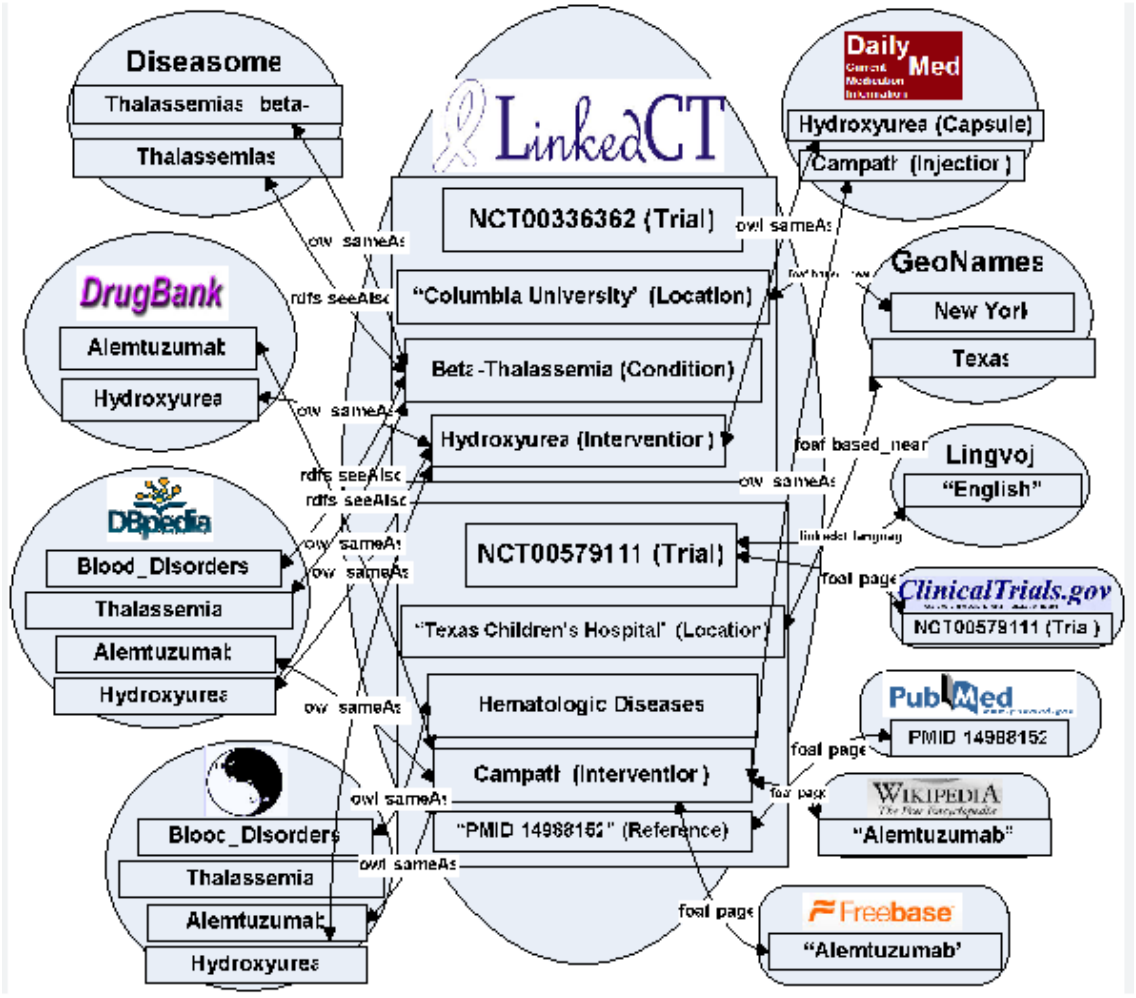

Figure 9: LinkedCT user interface

3.2.1. Discussion

User interfaces for just uploading, visualising, and exporting data are available in some clinical data repositories [8]; However, in recent years, user interface development has adapted to the needs of clinical-research teams by providing a number of data display options and data standardisation48, data quality (i.e. by identifying outliers/missing data), and facilitating49 users search without the need of computer expertise [6, 7, 43].

[48] http://www.hkupp.org
[49] https://www.nephroseq.org/resource/login.html

The databases' online interfaces were designed so that researchers and clinicians could search the information without being computer experts. Most of the website's home pages offer various options to interact with the data, such as two options to query the database: one is to use a keyword to search for a particular interest, and the other is to browse the data sets by disease classification.

Users can also conduct a quick search by clicking on the tags of some well-known patients' features. Table 5 compares the tasks available by using the above applications to support the clinician-researchers team with their manipulation of data. The requirements on the left side of Table 6 were chosen based on the review of the state-of-the-art in Section 3.1.

	Fernandes et al. (2017) **"CKDdb"**	**Nephroseq**	Renal Gene Expression Database **"RGED"**	Kozomara et al. (2013) **"miRbase"**	LinkedCT	Gout et al. (2007) **"PKDB"**	Zhao et al. (2004) **"KGDB"**
to query datasets	x	x		x	x	x	x
by filtering the search (i.e. by type of study/disease)	x	x	x	x	x	x	x
to upload and export data	x	x	x	x	x	x	
to navigate the data to a particular experiment	x		x		x	x	x
to identify data quality (i.e. outliers)		x	x				
to provide a variety of data visualisations		x	x				
to standardise data		x			x	x	
to integrate data		x	x		x		
to follow the clinician-researchers team's workflow			x		x	x	x

Table 6: A comparison of available tools and task to support the clinician-researchers team

Regarding the "to query datasets" feature, most of the reviewed systems include this feature as the interaction with data was an essential users' requirement in the development of the systems. RGED is the only reviewed system that does not support the "query datasets" feature, as one of the database's most valuable features focuses on searching for gene candidates closely related to the expression patterns of the genes they are interested in instead of querying data.

Regarding the "by filtering the search" feature, all the reviewed systems implement this feature as one of the clinician-researchers team's mandatory tasks, including filtering data to ease understanding of any clinical phenomena. Based on

the comparison of the systems above, the “by filtering the search” task feature was a mandatory feature to be included in the electronic storyboard, LDx.

Regarding the “to upload and export data” features, most of the reviewed systems include uploading and exporting data to facilitate the nature and integration of data. According to the comparison of the systems above, uploading and exporting data are some required daily tasks for the clinician-researchers team; then, these features were required to develop the electronic storyboard, LDx.

With regards to the “to navigate the data to a particular experiment” feature, Nephroseq and miRbase systems are the only ones that do not support these features as their web interface was designed for browsing and searching by sequence and keywords. Based on the comparison above, there is a potential gap that the electronic storyboard, LDx, intends to address,

Regarding the “to identify data quality” feature, most of the reviewed systems do not include this feature; for example, KGDB, CKDdb, and PKDB systems were designed to explore datasets for future analysis instead of assessing the quality of the data. Based on the comparison above, there is a potential gap that the electronic storyboard, LDx, intends to address,

Regarding the “to provide a variety of data visualisations” feature, Nephroseq and RGED are the only reviewed systems that include this feature. The rationale for including a visual representation of data feature is based on Nephroseq and RGED's most known and commercial – industry – applications. Based on the comparison above, there is a potential gap that the electronic storyboard, LDx, intends to address,

Regarding the “to standardise data” feature, most of the reviewed systems do not include this feature. Nephroseq, LinkedCT and KGDB are the only reviewed systems that include the standardised data feature, as Nephroseq is a system used in the industry that requires the standardisation of data to improve the system adoption to increase market share. On the other hand, LinkedCT is based on the Semantic Web premises that include standards vocabularies for the data. Based on the comparison above, there is a potential gap that the electronic storyboard, LDx, intends to address,

Regarding the “to integrate data” feature, only a few reviewed systems include this feature. The rationale behind the lack of including a data integration feature is based on the computational expertise required to conduct the integration

of data. Based on the comparison above, there is a potential gap that the electronic storyboard, LDx, intends to address,

Regarding the “to follow the clinician-researchers team’s workflow” feature, it is noticeable that only the RGED, LinkedCT, PKDB and KGDB systems were designed by matching the tasks with the users' requirements to improve the users' workflow. Based on the review of the chosen systems, the development of the electronic storyboard, LDx, intends to address,

Based on the review and comparison of the chosen systems (Table 4), the development of the electronic storyboard, LDx, intends to address the current gap by improving the system's features to enhance the digital communication of members of a clinician-researchers team to support data exploration, data quality and data integration tasks.

3.3. Chapter summary

This chapter presented a review of repositories and applications used by clinician-researchers team to conduct their daily tasks. Chapter 3 also presented a critical review and comparison of peer reviewed papers that include the development of user interfaces in the healthcare domain. The following chapter (Chapter 4) describes the electronic storyboard, LDx.

4. LDx, THE ELECTRONIC STORYBOARD

In line with the aims of this research and to initiate requirements gathering with the clinician-researchers team members an electronic storyboard was designed and called LDx, which stands for Linked Data Experience.

LDx is an electronic storyboard of an application that enables members of a clinician-researchers team to explore Linked Data files, assess the data quality of the datasets and perform data integration by only uploading metadata files. It is intended that a non-computer scientist will use the application.

Section 4.1 presents the graphical user interface by including the design decision which was distilled from the state-of-the-art review. Following this the implementation of the electronic storyboard LDx is discussed in Section 4.2. This chapter is then summarised in Section 4.3.

4.1. Graphical User Interface

4.1.1. Design Decision

User experience research improves the focusing on target users and their requirements by including realistic contexts and insights to design processes that start with the user research. Hence, designing with empathy and being sensitive to the user's pain points is key to every UX success.

The engineering requirement for this thesis focuses only on the development of an electronic storyboard, LDx, to start the requirements gathering and design processes.

The development of the electronic storyboard, LDx, was based on the following design decision (five elements):

- The surface plane: what the user sees on the surface of a website before start interacting with it.
- The skeleton plane: where the buttons, tabs, photos and blocks of text are placed.
- The structure plane: how the user will arrive on a particular page by including the arrangement of navigation items.
- The scope plan: how features and functions on the website fit together.
- The strategy plane: it includes what the target user's goals are.

The five elements above were considered in the development of the graphical user interface (GUI) to ensure a friendly UX. Because of their user-friendly interface and adoption, Nephroseq, RGED and PKDB systems were used as guidance systems to develop the electronic storyboard LDX. The guidance systems focus on improving the design decision of what the user sees, the arrangement of navigation items, how features and functions on the website fit together such as the font size, colours and positioning of the elements of the electronic storyboard LDx.

Adobe XD was used to design the electronic storyboard Ldx (initial and final design) in order to reach RO3.. This creative technology software provides a quick path to go from wireframes and mock-ups to static UI designs to interactive prototypes that simulate and enhance UX by facilitating the participants' interaction with the user interface while providing potential ideas early in the UI design process [84].

4.1.2. The LDx UI panes

The purpose of the electronic storyboard LDx UI focuses on starting the requirement gathering and design process to guide users through the steps proposed in the data exploration, data quality assessment and data integration by including visualisations of the tasks and data. Figure 10 and Figure 11 show the initial design of the electronic storyboard LDx.

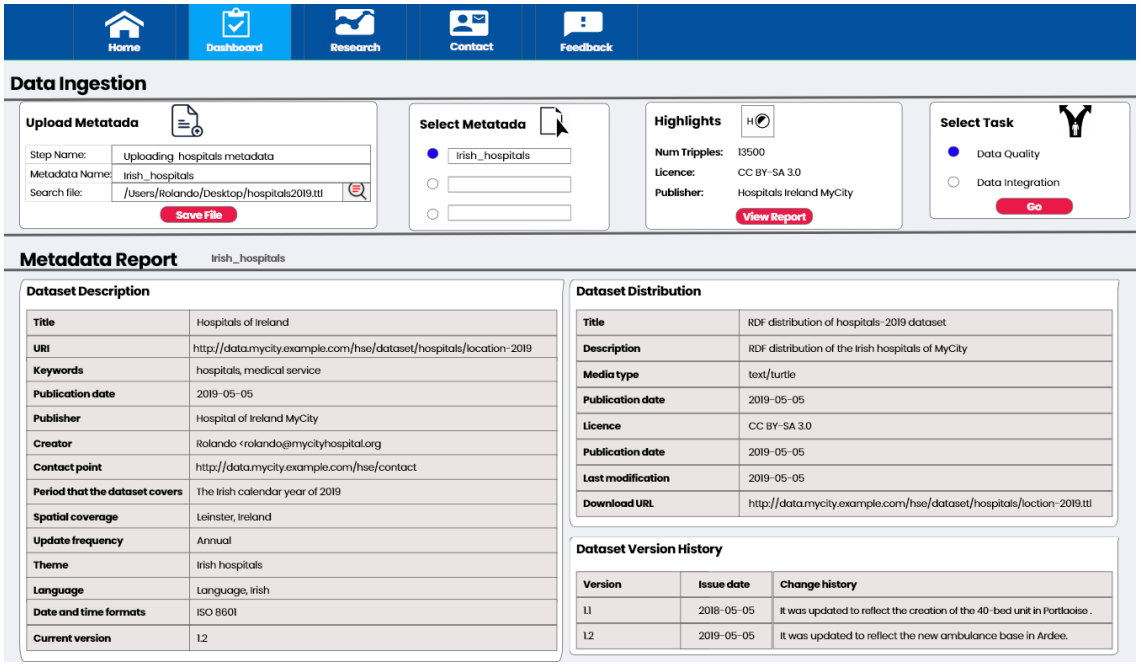

Figure 10: Initial design of the electronic storyboard LDx – Metadata Report

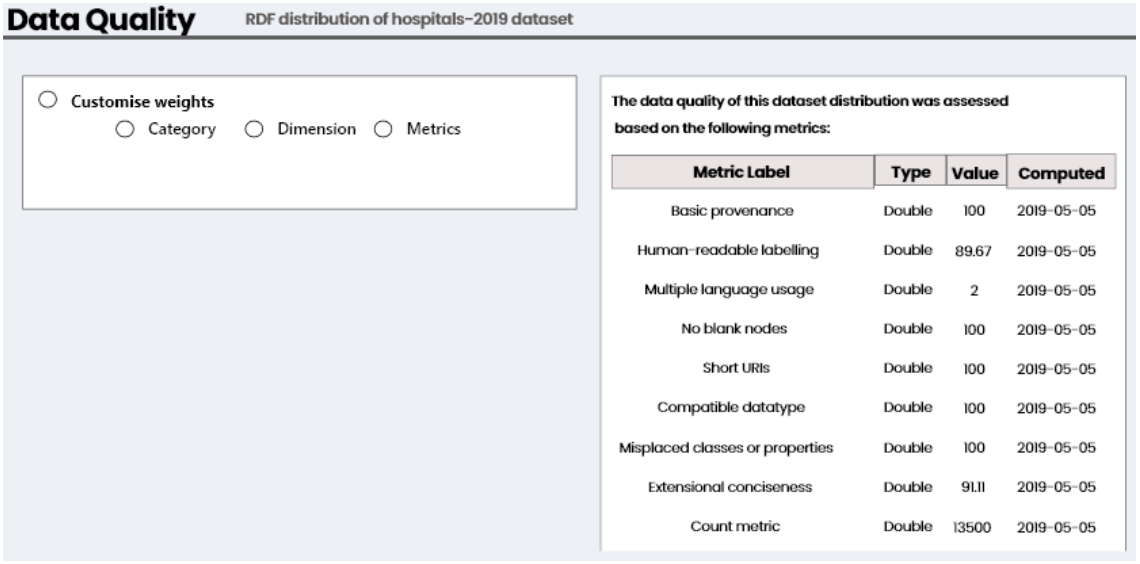

Figure 11: Initial design of the electronic storyboard LDx – Data Quality

Regarding the final design, the user interface starts with a homepage that includes information regarding the electronic storyboard. The homepage has three sections (Data Exploration, Data Quality and Data Integration). Figure 12 shows the electronic storyboard, LDx, homepage.

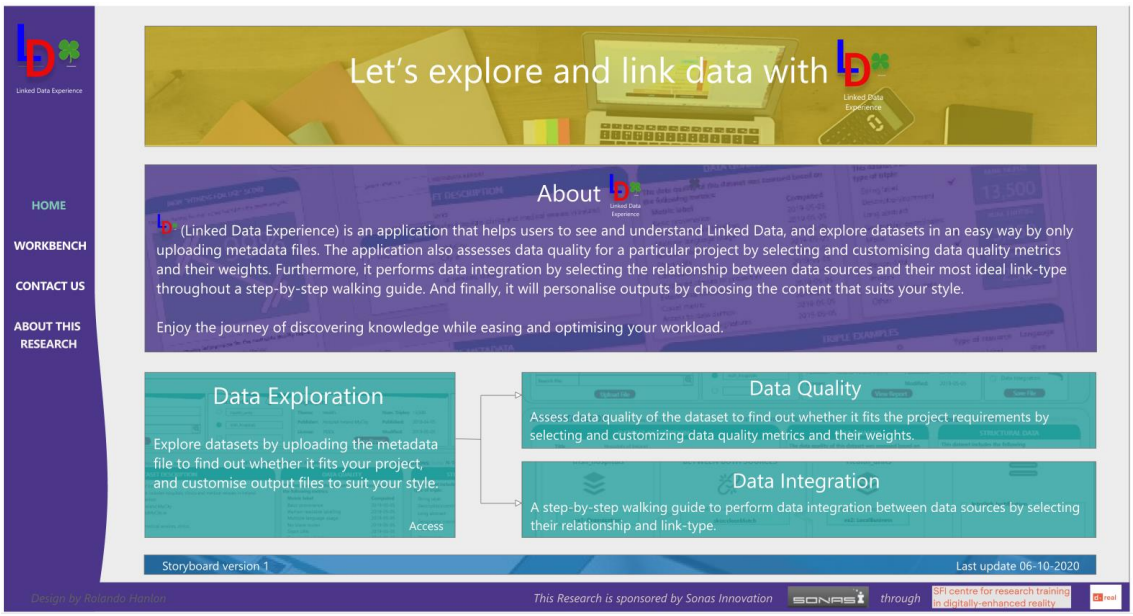

Figure 12: LDx - Homepage

Section 4.1.2.1, Section 4.1.2.2 and Section 4.1.2.3 describe with more details each section of the electronic storyboard LDx.

4.1.2.1. LDx UI – Data Exploration Section

In the Data Exploration section, the user uploads the metadata file to convert the machine-readable file into a friendly human-readable report. The user can save the metadata report, which can be used in the Data Integration section. If a previous metadata file was saved previously, the user can select it from the “Select Metadata” pane. The Data Exploration section includes the “Highlights" pane that summarises key information from the metadata files. The “Metadata Report” pane includes a summary of the metadata file. Figure 13 shows the LDx storyboard: Data Exploration section.

The Data Exploration section also allows the user to personalise the report by choosing the information to be included from the full metadata report. Figure 14 and figure 15 show an example of some information included in the full metadata report pane.

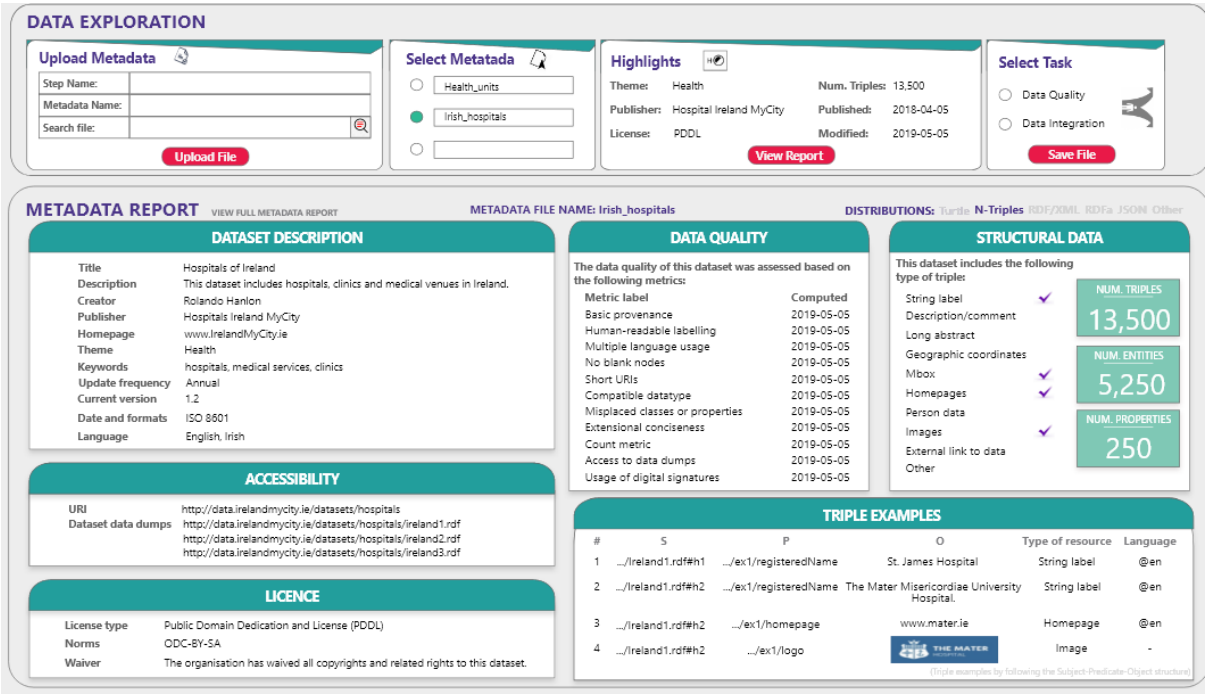

Figure 13: LDx electronic storyboard - Data Exploration section.

METADATA FILE NAME: Irish_hospitals **DISTRIBUTIONS:** Turtle **N-Triples** RDF/XML RDFa JSON Other

DATASET DESCRIPTION

Title	Hospitals of Ireland
Description	This dataset includes hospitals, clinics and medical venues in Ireland.
Creator	Rolando Hanlon
Publisher	Hospitals Ireland MyCity
Published	2018-04-05
Contact point	rolando@irelandmycity.ie
Homepage	www.IrelandMyCity.ie
Theme	Health
Keywords	hospitals, medical services, clinics
Update frequency	Annual
Modified	2019-05-05
Current version	1.2
Date and formats	ISO 8601
Language	English, Irish
Spatial coverage	Republic of Ireland
Source	NaN
Period that the dataset covers	The Irish calendar year of 2018 and 2019

LICENSE

License type	Public Domain Dedication and License (PDDL)
Norms	ODC-BY-SA
Waiver	The organisation has waived all copyrights and related rights to this dataset.

DATASET VERSION HISTORY

Version	Change history
1.1	It was updated to reflect the creation of the 2 new clinics in Portlaoise.

Figure 14: LDx - Full metadata report example 1.

STRUCTURAL METADATA

STATISTICS ABOUT THE DATASET

Term	Value
Num. of triples	13,500
Num. of entities	5,250
Num. of properties	250
Num. of classes	10
Num. of subjects	500
Num. of objects	500
Num. of links	NaN

Class	Num. of entities	Property	Num. of triples
ex1: Organization	4,250	ex1: registeredName	4,250
-	-	ex1: logo	3,800
-	-	ex1: homepage	400
-	-	ex1: mbox	500
ex1: Image	500	ex1: thumbnail	500

TRIPLE EXAMPLE

#	S	P	O	Type of resource	Language
1	.../Ireland1.rdf#h1	.../ex1/registeredName	St. James Hospital	String label	@en
2	.../Ireland1.rdf#h2	.../ex1/registeredName	The Mater Misericordiae University Hospital.	String label	@en
3	.../Ireland1.rdf#h2	.../ex1/homepage	www.mater.ie	Homepage	@en
4	.../Ireland1.rdf#h2	.../ex1/logo		Image	-
5	.../Ireland1.rdf#h2	.../ex1/mbox	info@mater.ie	mbox	-

VOCABULARY USED IN THE DATASET

Vocabulary	Vocabulary URI
EX1	http://www.example.com/concepts1#
SKOS	http://www.w3.org/2004/02/skos/core#

Figure 15: LDx - Full metadata report example 2.

The following features, based on the state-of-the-art review, were included in the design decision of the Data Exploration Section:

- Filtering the search.
- To upload and export data.
- To navigate the data to a particular experiment/study.
- To provide a variety of data visualization elements.
- To standardise data.
- To follow the clinician-researchers team's workflow.
- Improving navigation through the inclusion of medical icons.

4.1.2.2. LDx UI – Data Quality Section

The Data Quality section shows the data quality assessment report based on pre-defined data quality metrics [59, 85, 86] by including the data quality metric name and their value. Figure 16 shows an example of the data quality report.

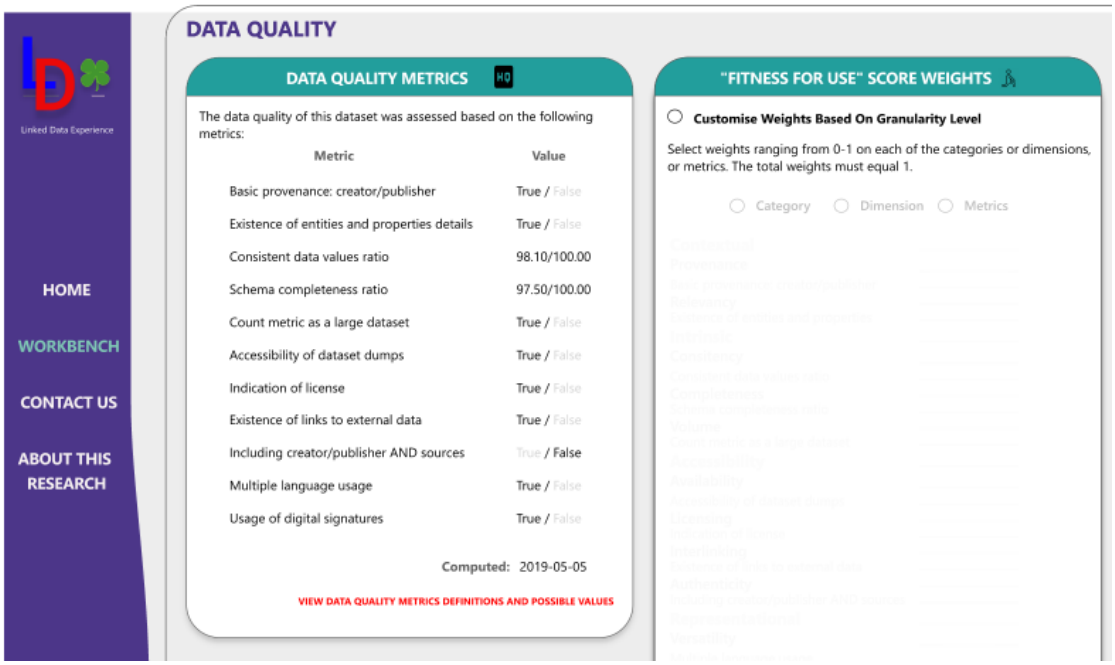

Figure 16: LDx, data quality report.

In the Data Quality section, the user can also perform the data quality assessment by choosing the granularity level (dimension, category or data quality metrics). A new “fitness for use “score will be calculated based on the chosen data quality metrics. Figure 17 shows an example of a customised data quality assessment and its “fitness for use” score.

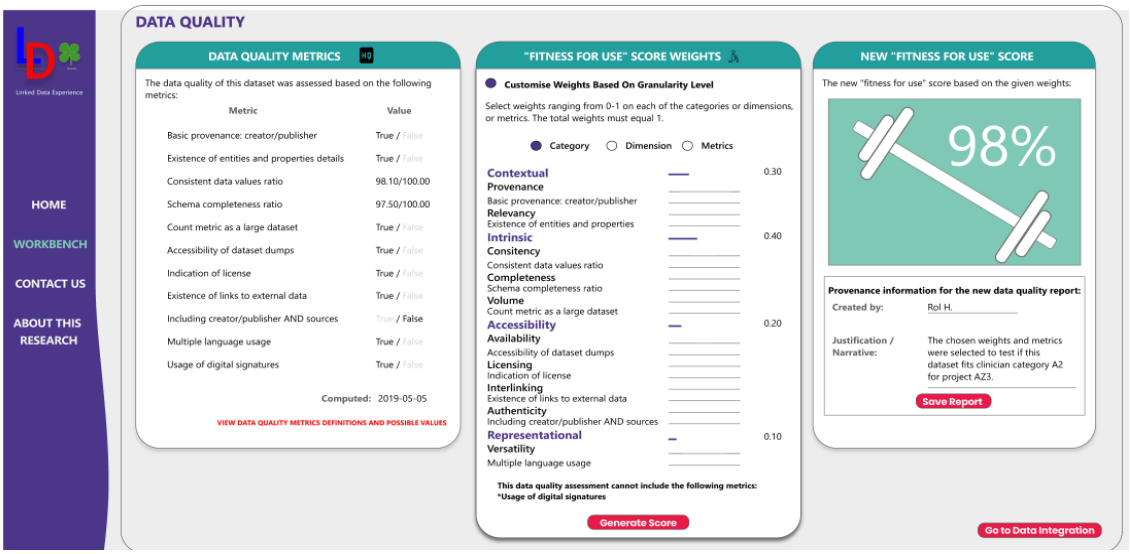

Figure 17: LDx, customised data quality example.

4.1.2.3. LDx UI – Data Integration Section

The LDx electronic storyboard includes a 3-step walkthrough process to facilitate the data integration task. Firstly, the user can choose the data sources by selecting the saved metadata reports or uploading a new metadata file. To create the dataset interlinks at the schema level, the user can select the concepts and concept properties to be integrated from each data source (datasets). Then, the user can select the relationship type for each concept and concept property. This first data integration step includes a description of every relationship type to guide the user. Figure 18 shows the first step of the LDx data integration process.

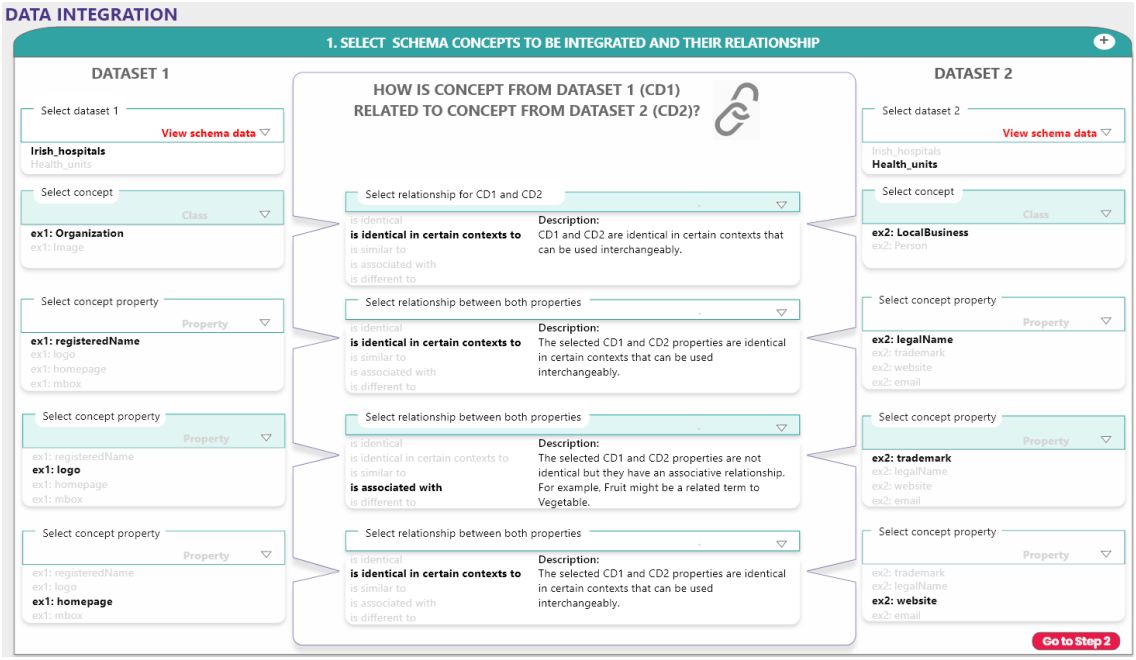

Figure 18: LDx, Data Integration process – Step 1

Secondly, the user needs to choose the link type based on the chosen relationship from step 1. There is a description of every link type to guide the user. Figure 19 shows the second step of the LDx Data Integration process.

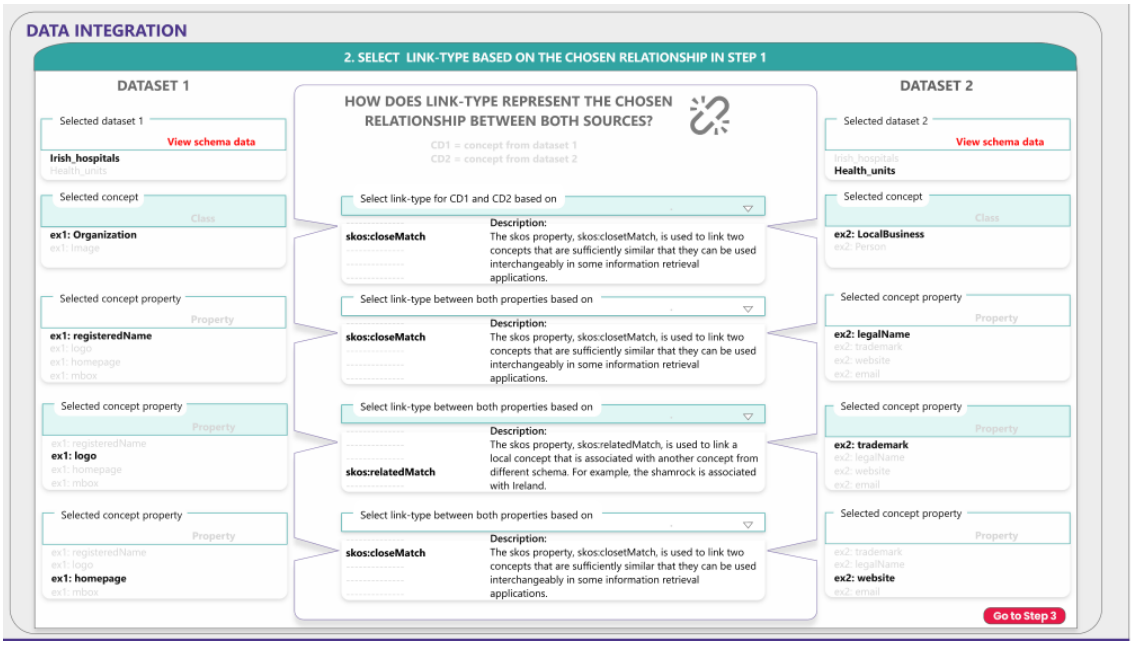

Figure 19: LDx, Data Integration process – Step 2.

Thirdly, the Data Integration section provides a summary and a visual interpretation of the integrated data to support the user's understanding. The third step requires the user to add a narrative and provenance information for future needs. Figure 20 shows the LDx storyboard data integration summary.

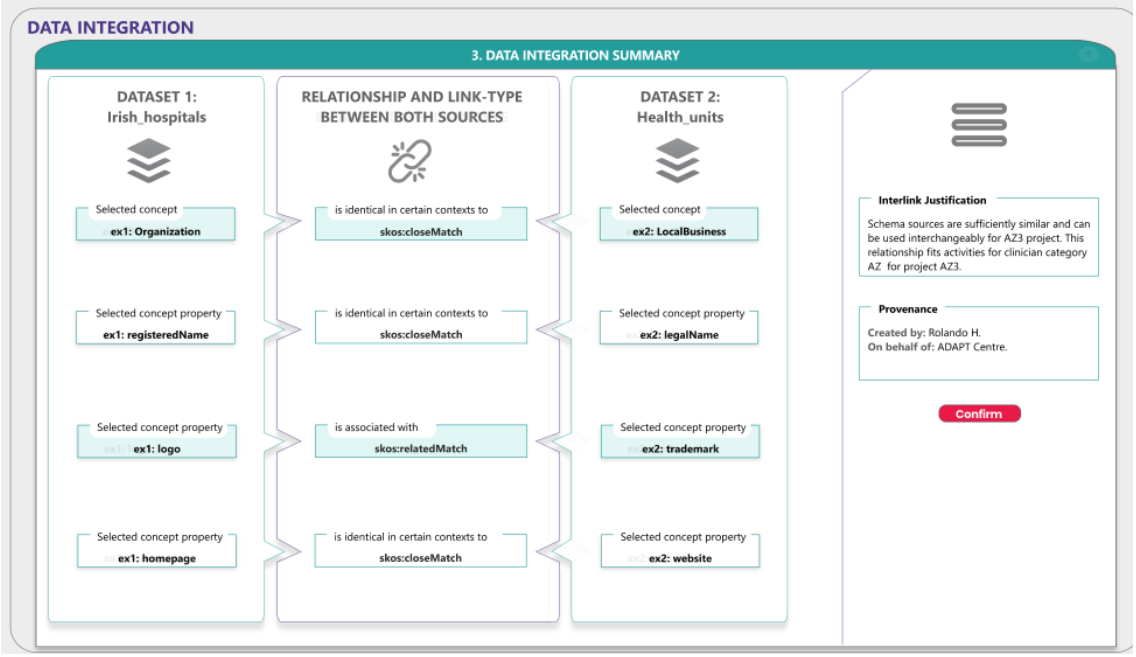

Figure 20: LDx, Data Integration summary – Step 3.

Figure 21 shows the visualisation of the data integration process to facilitate the understanding of the 3-steps walkthrough data integration process.

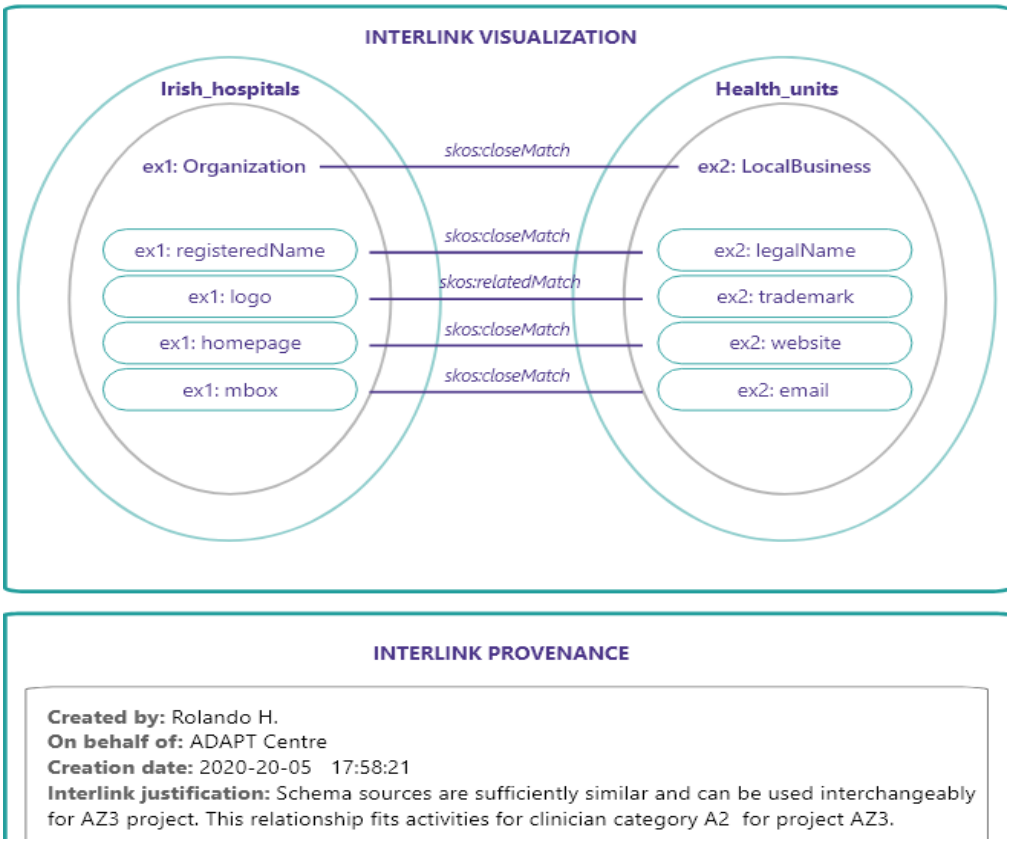

Figure 21: LDx, Data Integration process visualisation

To facilitate the initial interaction with user and users' requirement gathering the "to query datasets", "time-based granularity" and "supporting adaptiveness" features from the state-of-the-art review were not included in the initial LDx, electronic storyboard. These features can be included in the following versions of the LDx electronic storyboard and future user interface.

4.2. Implementation

The primary objective of storyboarding, which is to reduce complexity in uncertain environments and to create an early visualisation of complex systems, distinguishes it as an innovative technique for requirement elicitation [87]. Adobe XD was used to design the electronic storyboard LDx (initial and final design) in order to reach RO3. This creative technology software provides a quick path to go from wireframes and mock-ups to static UI designs to interactive prototypes that simulate and enhance UX by facilitating the participants' interaction with the user interface while providing potential ideas early in the UI design process [84].

LDx is viewable on any desktop/laptop, operating on all browsers. To maximise the experience, it is suggested to use a desktop/laptop with a screen of at least 13”. It was also recommended not to use it a smartphone/tablet for the experiments, so as to maximise the UX. Figure 22 shows the wireframe of the final design.

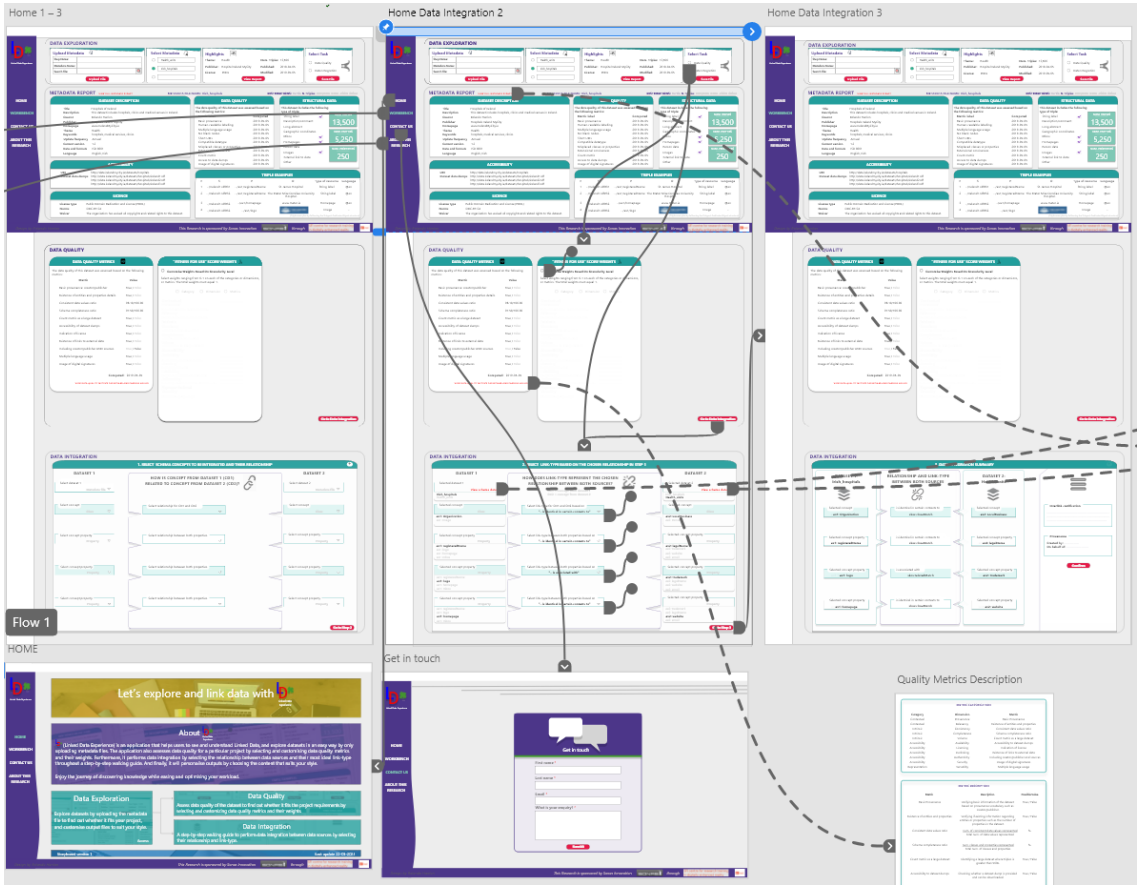

Figure 22: Wireframe of the final design

4.3. Chapter summary

LDx, the electronic storyboard, has been designed to meet the needs distilled as being important from the State-of-the-Art review. The following chapter (Chapter 5) presents the usability test and the triangulation methodology used to evaluate the electronic storyboard and to support and verify the user requirements.

5. EVALUATION

The selected evaluation methods for addressing the research question included a combination of qualitative and quantitative approaches. Quantitative analysis was used to understand how much/how many of the collected data represents the target users' preferences by including trends, while the qualitative analysis was used to understand the What's and Why's of a user behaviour. All the experimental studies undertaken in this research were approved by the Ethical Committee in the School of Computer Science and Statistics at TCD.

5.1. Pre-Interaction Questionnaire

A pre-interaction questionnaire was used in order to ascertain how participants rated their knowledge of Semantic Web technologies, Data Quality metrics, Data Integration and User Interfaces. Participants were asked to rate their knowledge on a five-point scale ranging from "Not at all Knowledgeable" to "Extremely Knowledgeable". The questionnaire also included whether the participants had ever been involved in the design of UI, and if so, the description of the circumstances. This questionnaire included a question on visual preference style in order to ascertain how participants prefer the inclusion of visual elements such as colours, font size, images, graphs, and the text box for adding narrative to engage with a UI. Participants were asked to select their preference on a three-point scale ranging from "It facilitates the interaction with the system" to "It does not offer benefits".

5.2. Concurrent Think-Aloud Method

With regards to qualitative approaches, the Concurrent Think-Aloud method, with a combination of video recording, was used to collect data about users' interaction for website usability testing [88] and to gather users' requirements. CTAM is a method used to gather data in usability testing in product design. This method allows using the tool while continuously thinking aloud and by verbalising their thoughts as the participants move through the UI. CTAM has been used in previous research where the participant's think-aloud statements and their additional feedback were gathered for designing a user interface [89]. Then, identifying usability issues can help to redesign the UI to adapt to user's needs. For this research, it involved recording the videoconference/interview between the participant and researcher interacting at

the same time using Microsoft Teams, adapting the regular operation of CTAM to take account of current Covid-19 restrictions.

By using the LDx storyboard, participants had access to a self-guided story which includes a scenario and requests for tasks that the participant should perform. It was requested that the tasks were performed in a 'Think Aloud' manner by trying to verbalise participants' thoughts and the way participants will perform given tasks. This first experimental study included three scenarios to perform eight tasks in data exploration scenario, six tasks in data quality scenario and eight tasks in the data integration scenario (see appendix 1). The participants explored as little or as much of the LDx storyboard that includes data exploration (highlights and full report), assessing data quality of dataset by customising the data quality metrics weights and performing the data integration of two data sources. The second experimental study focused on semi-structured interviews and brief direct observations performed by some of the participants.

There was no time limit imposed on participants to complete either experiment 1 or experiment 2. The users' experience ended when participants assess the data quality of the dataset or performed the data integration process through the storyboard tool. The user could verbalise as much as they wanted to, and the researcher could only use a gentle reminder, such as "keep talking", to break silences after a fixed silence time of 15 seconds. 15 seconds was deemed a sensible threshold that would not be intrusive.

5.3. Results Analysis: Thematic Analysis

Thematic analysis (TA) is a method of analysing qualitative data. It is applied to a set of texts such as interview transcripts. The researcher focuses on examining the data to identify common topics (themes), ideas and patterns of meaning that repeats often. This method is dynamic that can be used in many disciplines and fields, applied in lots of different ways, to many different datasets to address a variety of different research questions. It was firstly introduced in 2006 within the psychology domain [90]. TA is the right approach used in research to find out something about people's views, opinion, knowledge and experiences from a set of qualitative data.

TA offers a deductive and inductive approach. For this experiment, an inductive approach is chosen to allow the data to determine the themes. This

selection will avoid bias as some preconceived themes can influence findings. At the same time, the TA offers a semantic and latent approach. To avoid extrapolating the assumptions of the researcher, this experiment will use a semantic approach of the TA to analyse the explicit content of the data.

The most common TA form follows the next six-steps process [90]:

- Familiarising with the data: transcribing data (if necessary), reading many times as need it by noting down initial ideas.
- Generating initial codes: interesting coding text features in a semantic fashion way across the entire dataset (by including all interviews), collating data relevant to each other.
- Searching for themes: collating codes into potential themes by gathering all data relevant to each potential theme.
- Reviewing themes: checking in the themes work about the coded extracts (Level 1) and the entire dataset (Level2), this allows the generation of a thematic 'map' of the analysis.
- Defining and naming themes: it follows and ongoing analysis to refine the specifics of each theme, to understand the overall story the analysis tells. It requires clear definitions and names for each theme.
- Producing the report: this is considered as the last opportunity for the analysis. It involves a selection of vivid, compelling extract examples, a final analysis of selected extracts, relating of the analysis to the research question and literature to produce a scholarly report of the analysis.

NVivo[51] software is used to perform data quality analysis. NVivo software offers the capability to make observations and gather evidence, learn about customers and preferences and to identify areas of needed improvement. NVivo uses the following terminology as equivalence with the Thematic Analysis terminology:

- Sources: documents and surveys.
- Coding: gathering data by topic, theme or case.
- Nodes: containers for coding by theme or topic.
- Cases: containers for coding and representing units of observation

[51] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software

5.4. Post-interaction Questionnaire

The Post-Study System Usability Questionnaire (PSSUQ) was selected to measure software usability and utility at the end of the study. The PSSUQ V3[52] consist of 16 statements about which the user rates agreements on a seven-point scale ranging from “Strongly Agree=1” to “Strongly Disagree=7”. Thus, lower scores indicate fewer usability issues. The PSSUQ also has an overall and three sub-scales shown as follows:

System Usefulness (SysUse): the average scores of questions 1 to 6.
Information Quality (InfoQual): the average scores of questions 7 to 12.
Interface Quality (InterQual): the average scores of questions 13 to 15.
Overall: the average scores of questions 1 to 16.

The PSSUQ was chosen over other questionnaires as it takes both system utility and system usability into account [89].

5.5. Post-Test Interview

For the first experimental study, a post-test interview was undertaken with each participant and consisted of five to seven questions which explored the participants’ needs, current workflow, software preferences and thoughts on the interaction with the LDx electronic storyboard.

[52] https://uiuxtrend.com/pssuq-post-study-system-usability-questionnaire/

5.6. Triangulation

Triangulation is a method used to increase the credibility and validity of research findings [20]. The advantage of triangulation is that it can compensate for method weaknesses when more robust methods are unavailable or impractical to apply. Based on the current worldwide health situation a more robust method was impractical to apply in this research.

Previous research has included Interviews and direct observations as triangulation methodology to support user requirements in the development of software development [21, 22]. The inclusion of the triangulation methodology in software development helps to target users' tasks to improve compatibility.

For the second experimental study, triangulation technique was used to verify and support the findings during the users' requirements gathering. The findings from the experimental study 1 were compared with the findings from experimental study 2.

5.7. Usability Test – First Experimental Study – Concurrent Think-Aloud Method:

5.7.1. Experimental Hypothesis

The hypothesis being investigated as part of this experiment is shown as follows:

Hypothesis (H): LDx electronic storyboard application will be useful for subject-matter experts in the healthcare domain and to gather users' requirements.

5.7.2. Participant Profile

Target participants for this experiment can be identified as members of a clinician-researchers team, such as subject-matter experts in the healthcare domain. The profile for each participant was suggested and verified in consultation with members of the ADAPT Centre medical cohort. Participants with this profile are time-challenged due to their daily workloads, and so this experiment was targeted to recruit four participants. Table 7 shows the participants' profiles, including their health domain expertise, gender, and age interval.

Participant	Gender	Age Interval	Health Domain Expertise
P1	Male	55-65	Nephrology
P2	Female	55-65	Neurology
P3	Male	45-54	Research
P4	Male	45-54	Nephrology

Table 7: Participants profile table for the first experimental study.

The first experimental study was open to the male and female gender regarding participant recruitment. The gender balance will be justified by being representative of the real-world target users. The age of participants will range from 18 to 65+.

5.7.3. Experiment Methodology

The Concurrent Think-Aloud Method (CTAM) was the chosen experimental methodology, as it allows the recruitment of a small number of participants. The method allows the uncovering of participants' behaviour rather than participants' opinions - with behaviour not varying as broadly as opinion [88]. Probabilistic sampling methods were not used to recruit participants. Rather the recruitment process started by sending a voluntary research invite to the target participants who are appropriate subject matter experts who are members of the ADAPT Centre.

5.7.4. Experiment Set-up

The experiment was set-up as follows (for the experiment documentation, see appendix 2):

Prospective candidates received an email invitation to participate in the experiment. This invitation included both the Participant Information Sheet (document #1) and the Informed Consent Form (document #2). It was necessary to sign and send back the Informed Consent Form (document #2).

After receiving the signed Informed Consent Form from prospective candidates, the scheduled interview time and date were arranged for the participants.

After arranging the meeting, the participants were given a URL by email shortly before the interview was scheduled to happen.

The participants were required to use the Google Chrome browser in Incognito Window mode when they were using a desktop or laptop.

The interviews were performed individually with only one participant per day and time. Having one interview per day allowed to take and transcribe necessary notes from the recording on the same day, as this practice would enhance future interview experience. The interview between the participant and researcher was recorded as both persons needed to interact at the same time during the experiment.

When sending the interview URL, the interview participant received a participant number to sign in. It was necessary for the signing in to select only audio, and the video was turned off. Microsoft Teams allowed sharing the screen without signing in by using video. Participants received guidance about using Microsoft Teams if required.

The participants were reminded that their screen-sharing and audio would be recorded as this experiment required the interaction between the participant and the researcher at the same time. At the videoconference, the participants were requested to share their screen and be notified when the recording of the videoconference was commencing.

When the signed Informed Consent Form had been received from the participant, an email was sent to each participant 15 minutes before the interview was scheduled to begin. The email included both the Experiment Instructions (document #3) and Pre-Interaction questionnaire (document #4). The Pre-Interaction questionnaire (document #4) was completed by the participant and then returned to the researcher.

After receiving the filled-out Pre-Interaction questionnaire (document #4) from the participant, they were sent an email that included the Experiment Tasks (document #5). A description of the most representative experiment tasks is outlined as follows:

- With regards to scenario 1: Data Exploration:
- Please, upload the RDF metadata file “Ireland.rdf”. As a first instance, can you confirm this dataset is related to health?

- As a first instance, can you confirm this dataset is not considered as big data (> 500K triples)? Then, it will not require additional computational resources if chosen.
- It is essential to know whether this metadata file includes any information about the licence and waiver to be used. Is this information included in the metadata report?
- Access metadata is useful to understand if the dataset can be downloaded from an existing source. Can this dataset be downloaded? And if so, how many files are required?
- Structural metadata is useful in data integration. Can you please identify at least two triple examples that can be useful for the project that involves Irish hospitals?
- Data source information is essential as it can support trustworthiness. Is this information included in the full metadata report?
- Withing the full metadata report, what is the period that the dataset covers?

With regards to scenario 2: Data Quality:

- Can you please identify at least three data quality metrics that were computed for this dataset?
- As consistent data is essential, can you please only identify the meaning/description of the “consistent data value ratio” metric?
- Within the customise weights section, can you please identify the granularity levels in which data quality can be assessed in LD**x** (aside from the category level)?
- The A project requires a data quality score (known as “fitness for use score”) of at least 97% out of 100%. Based on the project requirements and data quality metrics supported so far, in LD**x**, can you please generate the fitness for use score and assess whether this dataset is suitable for the A project (by using category as granularity level)?
- As applications and technology evolve, can you please identify whether there is a data quality metric that cannot be used currently,

but it can be included in future versions of LD**x** to generate the “fitness for use” score?

With regards to Scenario 3: Data Integration:

- Can you please identify whether there is a concept (class) aside from “Organization” in Dataset 1?
- Can you please identify whether there is a concept (class) aside from “LocalBusiness” in Dataset 2?
- After visualising the concept (class) and concept properties from both data sources, clinician A2 would like to interlink both data sources by creating a link between ex1:Organization (dataset 1) and ex2: LocalBusiness (dataset 2) as it fits project AZ3 requirements. Please, perform the interlinking of both levels, concepts and concept properties, by selecting their relationship and link-type.
- With regards to “How is the concept from dataset 1 related to the concept from dataset 2?”, can you please identify at least two types of relationships?
- Please select the ideal link-type of data sources based on the relationship chosen in the previous question. Can you please identify two link-types?
- Please, continue with the data integration process and fill in the interlink justification and provenance data.
- Please, confirm the data integration process, which offers a visual interpretation of the performed data integration task that includes a fourth concept property used to integrate both data sources.

The participant was invited to start performing the experiment tasks using Think-Aloud method. For this experiment, the researcher acted as moderator and observer by following an active observation.

After performing the Experiment Tasks (document #5) and returning the completed document to the researcher, the Post-Interaction questionnaire (document #6) was sent to the participant by email.

After receiving the completed Post-Interaction questionnaire (document #6) from the participant, the researcher explained more of the reasons behind the experiment.

The Post-Interaction Interview was performed to receive more feedback from participants and give the participant a chance to ask questions.

5.7.5. Experiment Results

Four participants conducted the experiment. Two participants participated in the afternoon whilst the remaining two preferred to participate in the evening time. The results for each user-study component are outlined below.

5.7.5.1. Pre-Test Questionnaire Results

The results of the pre-test questionnaire have been summarised in Table 8. Table 7 includes previous participant's knowledge in areas such as Semantic Web, data quality metrics, data integration and user interfaces, and previous users' participation in UI development.

Participant	Topic	Not at all Knowledgeable	Slightly Knowledgeable	Moderately Knowledgeable	Very Knowledgeable	Extremely Knowledgeable	Previous Work on UI Development
1	Semantic Web			X			Yes
	Data Quality Metrics			X			
	Data Integration			X			
	User Interfaces		X				
2	Semantic Web	X					Yes
	Data Quality Metrics	X					
	Data Integration		X				
	User Interfaces		X				
3	Semantic Web		X				Yes
	Data Quality Metrics			X			
	Data Integration		X				
	User Interfaces			X			
4	Semantic Web		X				No
	Data Quality Metrics		X				
	Data Integration			X			
	User Interfaces			X			

Table 8: Knowledge Evaluation

5.7.5.2. Think-Aloud Method Results

The results of the TAM evaluation have been summarised in table 9. Here the average time (in minutes) that it took each participant to complete the task scenarios is documented. Also included is whether the participant was able to complete the task and if assistance was required. Table 9 includes the information of the eight tasks related to data exploration, six tasks related to data quality and eight tasks related to data integration.

AR = Assistance Required

0= No completed

1=Completed

		Data Exploration							
	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Avg Time [min]
P1	1	1	1	0	0	1	0	1	1.14
AR	No	No	No			Yes		No	
P2	1	1	1	1	0	1	1	1	1.38
AR	No	Yes	No	Yes		Yes	No	Yes	
P3	1	1	1	1	1	1	1	1	1.26
AR	No	No	No	No	Yes	Yes	Yes	Yes	
P4	1	1	1	1	1	1	1	1	1.32
AR	No	No	No	Yes	Yes	Yes	No	No	

	Data Quality						
	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Avg Time [min]
P1	1	1	1	1	0	1	0.88
AR	No	Yes	No	No		No	
P2	1	1	1	1	0	1	1.025
AR	Yes	Yes	No	No		No	
P3	1	1	1	1	1	1	1.00
AR	No	Yes	No	No	Yes	No	
P4	1	1	1	1	1	1	1.05
AR	No	Yes	No	No	Yes	No	

	Data Integration								
	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Avg Time [min]
P1	1	1	1	1	1	1	1	1	1.33
AR	Yes	Yes	Yes	Yes	Yes	No	No	No	
P2	1	1	1	1	0	1	1	1	0.925
AR	Yes	Yes	Yes	Yes		No	No	No	
P3	1	1	1	1	1	1	1	1	1.01
AR	Yes	Yes	Yes	Yes	Yes	No	No	No	
P4	1	1	1	1	1	1	1	1	1.30
AR	Yes	Yes	Yes	Yes	Yes	No	No	No	

Table 9: Think-Aloud Method Evaluation

5.7.5.3. Thematic Analysis Results

The Thematic Analysis was conducted on the Think-Aloud Method and post-test interview data. Not a single code was rejected as this experiment involved a small

population of 4 participants, and all the codes were related to the experiment. The coding activity recognised 26 codes. Figure 23 shows a coding snippet sample.

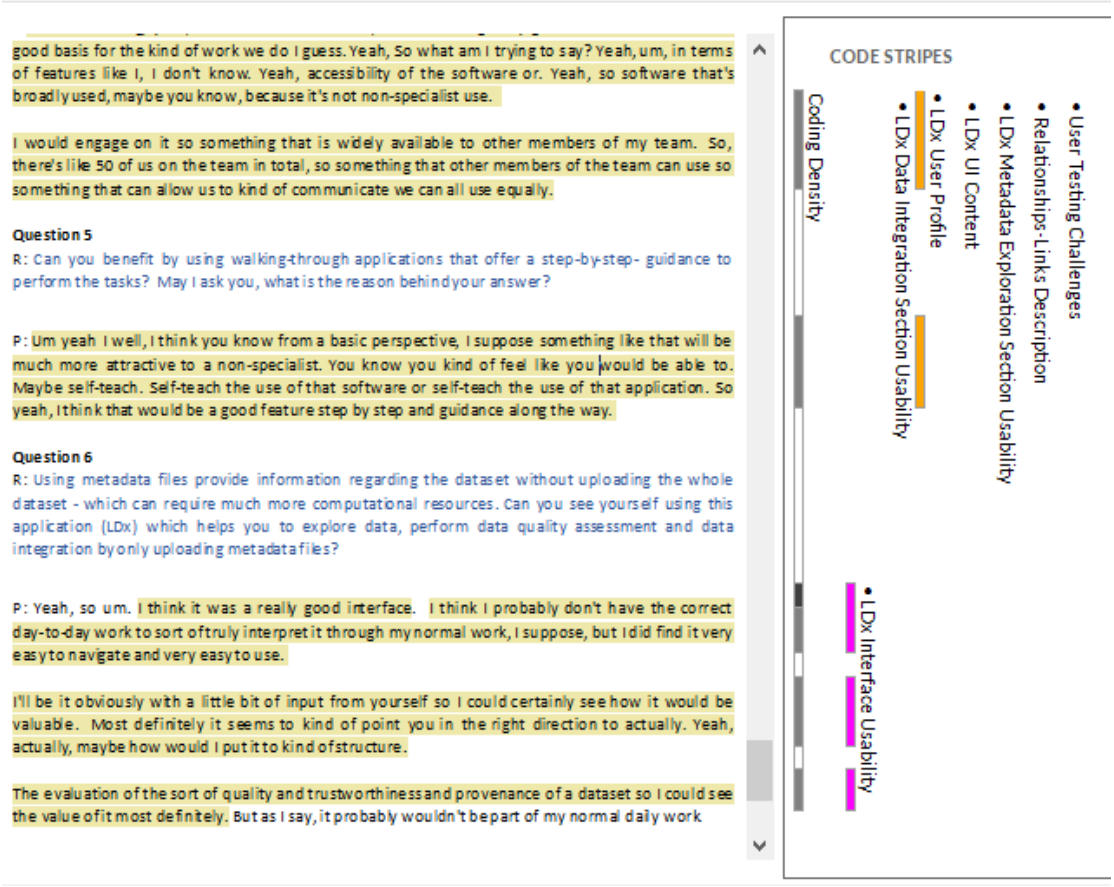

Figure 23: Coding Snippet

The themes were chosen to help to answer the research question which involves UI Usability (5 themes) and to understand more about the current user as part of the user research within the UX design process (2 themes).

The seven themes distilled from the data include:

1. Highlights of the LDx Data Integration Usability and Utility Process → 4 codes.
2. Challenges and Benefits of Data Quality Assessment → 2 codes.
3. Highlights of the LDx Interface Usability and Utility Process→ 4 codes.
4. Highlights of the LDx Metadata Exploration Usability and Utility Process → 3 codes.
5. Highlights of the LDx User Profile (Persona) → 5 codes.
6. Highlights of the User Expectations-Needs → 2 codes.
7. User Testing Challenges → 4 codes.

All themes and codes distilled from the transcript data are detailed in table 10 below. This table also includes the code description, the number of participants who referred to the code (NP), the number of references to the code in the transcripts (NR), and a random supporting quote to demonstrate how the codes and themes were derived from the transcript data.

	Name	Description	NP	NR	Selection of Quotes
Theme 1: Highlights of the LDx Data Integration Usability and Utility	Data Sources for Data Integration	With regards to the data sources to be integrated.	4	13	"I can only choose one. Yeah yeah yeah. And then we move to the next concept property to link", P1.
	Intuitive Path for Data Integration Tasks	With regards to the creation of an intuitive way to perform data integration of semantic data.	3	8	"But I think for you to assess that you need to create some kind of mechanism in the mind of the user that would reflect how they would use it", P1.
	Relationships-Links Description	With regards to the description used as a guide to choose the data integration relationship of concepts/properties.	4	16	"Yeah, so there yes. The way I'm interpret this is the yeah, we're trying to link the two datasets, find commonality too", P3.
	Visual Communication for Data Integration	With regards to the visuals to develop trustworthiness to perform data integration of semantic data.	3	5	"Yeah I confirm that the visual interpretation of performed data integration test. We are using four concepts here", P4.
Theme 2: Challenges abd Benefits of Data	Data Quality Assessment	With regards to the granularity levels/activities performed to generate the "fitness for use score".	4	8	"So, I presume I have to click here. So apart from the category level, we also have the dimension level and metrics level", P3.

	Name	Description	NP	NR	Selection of Quotes
Quality Assessment	Data Quality Metrics	With regards to the data quality metrics chosen in this section.	4	21	"So, is this something outside the storyboard that you think I should add it?", P1.
Theme 3: Highlights of the LDx Interface Usability and Utility Process	Benefits of Using LDx	With regards to the benefits by using LDx app.	4	5	"Yeah, I could see that working. Yeah, so just from the kind of it, I will probably need to be a bit of a kind of education piece", P4.
	LDx UI Content	With regards to the information content shown in the UI.	4	28	"OK, so. It does provide a description here. OK, OK, perfect", P1.
	LDx UI Navigation	With regards to the navigation experience by using the UI.	4	11	"I think I probably don't have the correct day-to-day work to sort of truly interpret it through my normal work, I suppose, but I did find it very easy to navigate and very easy to use", P3.
	LDx UI Provenance Information	With regards to the provenance information shown in the UI.	4	16	"The evaluation of the sort of quality and trustworthiness and provenance of a dataset so I could see the value of it most definitely", P3.
	LDx UI Set-up	With regards to how the UI was set-up.	4	6	"It's one of those things that's a nice-looking interface can help. And yeah, I thought it was good", P4.
	LDx UI Unused Sections	With regards to the unused sections when the users perform the tasks.	2	2	"P1 does not use the highlight section".
Theme 4: Highlights of the LDx Metadata Exploration Usability and Utility Process	Dataset Download	With regards to how the dataset can be downloaded by using an URL.	4	8	"I don't see a mechanism for downloading the file that", P1.
	Metadata Report Information	With regards to the usability when the user uses the information in the metadata report.	4	16	"So, there's a detailed dataset description", P1.
	Metadata Report Personalisation	With regards to how the user can personalise the metadata report in a PDF document.	4	7	"I can personalise the save file by selecting the bits that I want. Save that file. Not quite sure where it's gone", P1.
Theme 5: Highlights of the LDx User Profile (Persona)	User Engagement Software Features	With regards to the features used by users to engage with their current software.	3	3	"They are able to provide the statistical mechanisms for analysing the data. We can relate that help to achieve your tasks", P1.
	User Job Responsibilities	With regards to the current job responsibilities of participants.	4	7	"so, I wouldn't do that stuff myself, but on the lower level kind of similar data integration", P4.
	User Workflow - Daily Tasks	With regards to the current job daily-tasks performed by the participants.	4	4	"What we do is we collect information about patients, and we store that information somewhere and often initially on a paper spreadsheet. And then we can

	Name	Description	NP	NR	Selection of Quotes
					transfer it into an Excel file, usually or in SPSS file", P2.
	Users' Statistical Software to Perform their Current Daily Task	With regards to the current software used to perform a user's tasks.	4	6	"Then I use a lot of statistical software such as SPSS Graphpad Prism, Microsoft Excel", P1.
	Walk-Through Application Preference	With regards to the software that offers a walking-through approach to perform the tasks.	4	5	"well. I think it's now difficult to read large manuals and If there was a no detailed description in a manual well. Basically, a busy clinician would not read it. They much prefer to just have something that walks them through", P1.
Theme 6: Highlights of the User Expectations-Needs	User Data Integration Needs	With regards to the user's needs based on data integration.	4	10	"I mean what I spend a lot of time doing is trying to integrate those three sources. And we do it manually and so If there was a solution that would make us not do it manually. I think that would be really useful", P1.
	User Data Quality Needs	With regards to the user's needs based on data quality.	3	5	"I thought the provenance information was laid out quite well and it was good that it was accessible, so that would make that search a lot easier, but there's certainly nothing else that jumps out at me as being needed in terms of its provenance", P3.
Theme 7: User Testing Challenges	LDx Development Assumptions	With regards to the assumptions considered by developing LDx.	3	7	"Yeah, so I think it's uh, perhaps the big assumption to make that the data sources will have these metadata files already", P1.
	LDx UI Wording	With regards to the language used by creating the UI.	4	14	"I'm not familiar with the term triples, so I'm sort of… I'm flying blind a little bit there", P3.
	Semantic Data Knowledge	With regards to the semantic data knowledge required by participants to perform the tasks.	1	1	"Yeah. But I don't know. I don't think I should know as a non-semantic web user. ", P1.
	User Frustration	With regards to the user frustration while performing the experiment tasks.	3	19	"And so, it's very frightening when people present you with these sorts of terms. You know, such as that exercise that we just did so you know", P2.

Table 10: Thematic Analysis Evaluation – Experimental Study 1

5.7.5.4. Post-Interaction Questionnaire (PSSUQ) Results

The combined average scores for each category of the PSSUQ can be seen in table 10. As mentioned previously, the PSSUQ is scored from 1-7 with lower scores indicating fewer usability issues. The PSSUQ table offers the participant the "not applicable score = NA" if necessary. Table 11 also highlights the minimum and maximum scores given by the participants after the interaction with the LDx electronic storyboard.

	Question	p1	p2	p3	p4	avg	std
1	Overall, I am satisfied with how easy it is to use this system.	4	3	2	1	2,5	1,12
2	It was simple to use this system.	5	3	2	2	3	1,22
3	I was able to complete the tasks and scenarios quickly using this system.	4	3	3	2	3	0,71
4	I felt comfortable using this system.	5	3	3	1	3	1,41
5	It was easy to learn to use this system.	3	4	2	1	2,5	1,12
6	I believe I could become productive quickly using this system.	6	-	5	1	4	2,16
7	The system gave error messages that clearly told me how to fix problems.	3	-	5	2	3,333	1,25
8	Whenever I made a mistake using the system, I could recover easily and quickly.	2	4	2	1	2,25	1,09
9	The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.	3	-	1	1	1,667	0,94
10	It was easy to find the information I needed.	4	4	2	2	3	1
11	The information was effective in helping me complete the tasks and scenarios.	4	-	2	1	2,333	1,25
12	The organisation of information on the system screens was clear.	3	4	2	1	2,5	1,12
13	The interface of this system was pleasant.	2	2	2	1	1,75	0,43
14	I liked using the interface of this system.	2	2	2	1	1,75	0,43
15	This system has all the functions and capabilities I expect it to have.	-	6	3	1	3,333	2,05
16	Overall, I am satisfied with this system.	3	5	2	1	2,75	1,48
	TOTAL	53	43	40	20		
	OVERAL SCORE	3,53	3,58333	2,5	1,25	2,717	0,95
	NA.	1	4	0	0		
	SYSUSE	4,5	3,2	2,8	1,33	**2,97**	1,13
	INFOQUAL	3,17	4	2,3	1,33	**2,71**	0,99
	INTERQUAL	2	3,33333	2,3	1	**2,17**	0,83

Table 11: PSSUQ Results.

5.7.6. Discussion

The research question of this experiment focuses on facilitating subject-matter expert to engage with the process of data exploration, data quality assessment and data integration, and based on the pre-interaction questionnaire; it can be seen that most of the participants have a slightly/moderate knowledge for each of the four concepts (Semantic Web, data integration, data quality and the user interface), although, Semantic Web and data quality metrics are the concepts with the lowest participant's knowledge. Also, it is noticeable that all participants had some prior awareness and knowledge of data integration, but that none rated themselves as 'extremely' knowledgeable in any of the four concepts. Three out of four participants had previously participated in the development of a UI.

With regards to the TAM results, the Data Exploration scenario took the longest time for each participant to complete the tasks with an average of 1.275 minutes per task. This was somewhat to be expected given that the task required the participant to look for, locate and interact with the information.

Based on the requested assistance from the participants to complete the tasks, the Data Integration scenario is the one that required the most assistance to perform the tasks as three out of four participants were not familiar with the integration of semantic data. For the Data Exploration scenario, two out of four participants requested assistance to identify at least two triple examples based on the data content shown in the UI, and the remaining two participants could not complete the tasks. For the Data Quality scenario, two out of four participants requested assistance to identify a data quality metric that cannot be used currently to perform the data quality assessment, and the remaining two participants could not complete the tasks. The requested assistance from the participants while performing the tasks is backed-up and confirmed by the pre-interaction questionnaire data.

With regards to the Thematic Analysis, the interviews were held with three male participants and one female participant. All names were changed to protect participants confidentiality by using p1 as participant 1, p2 as participant 2, p3 as participant 3 and p4 as participant 4.

Theme 1: Highlights of the LDx Data Integration Usability and UtilityProcess

Theme 1 encapsulates all the positive and negative participants' interaction with the Data Integration Usability by using LDx electronic storyboard. For example, participants have a vague understanding of the data sources to be integrated. P1 stated: "*I can only choose one. Yeah yeah yeah. And then we move to the next concept property to link*", this is supported by p4: *"From what I'm thinking, data integration and thinking, how are these? Different files integrated. So, then I will be thinking in terms of …. So, into the magic data. But then I'm thinking what the common features of these datasets are.."*

Theme 1 highlights the lack of an intuitive path for data integration tasks. For example, p1 states*: "But I think for you to assess that you need to create some kind of mechanism in the mind of the user that would reflect how they would use it".* Theme 1 also shows how the relationships and link-types are not understandable

concepts for this target users, even though both (relationships and links) included a description. P2 stated: "*…and so I'm not sure what the question is.. when it looks like it's the same thing in relation to another question. So, I don't understand the difference in the links so. I don't see the different sources or so."*

However, p4 mentioned how the visual communication helped by offering an understanding of the performed task: "*Um? Yeah, I see the usefulness over here by using the interlink visualisation.",* this is supported by the inclusion of the data integration summary which was mentioned by p2 : "*… good idea is that will give you a summary of what we can just performed."*

Theme 2: Challenges and Benefits of the Data Quality Assessment

In terms of data quality, theme 2 encapsulates codes that reflected the challenges and benefits of the data quality assessment. Participants were able to see the benefits of performing data quality assessment based on different granularities levels. This includes p3:" *So, I presume I have to click here. So apart from the category level, we also have the dimension level and metrics level."*, which is supported by p1:" *Generating the score. The score is probably 98%, yeah. So, that would be fine with us".* However, participants could not see the usability and understandability of having diverse data quality metrics aside from provenance information as the data quality metrics created confusion because the participants were not familiar with them. For example, p4 stated: "*.. stuff like that, but this is obviously very specific metrics. Which I don't know"*, which is supported by p1: *" It is not clear where the user can find the meaning of the data quality metric"*. This feedback is beneficial to improve the awareness and description of data quality metrics to the target users.

Theme 3: Highlights of the Interface Usability and Utility Process

A third theme focuses on the LDx interface usability and utility by highlighting a positive user's perception by defining the UI as a helpful visual tool that was nicely set-up. For example, p4 stated: *" It's one of those things that's a nice-looking interface can help. And yeah, I thought it was good"*, which is supported by p1: *"The interface is very nice, it's very nicely set up, there is a beautiful metadata report",* p3 also stated: *" I think it was a really good interface"*. However, there is always room for improvement, as p2 explained: *"The user interface is easy, but the actual meaning behind the tasks. I didn't understand it".*

Theme 3 also shows the benefits that LDx intends to provide to the participants. For example, p1 mentioned: *" And well I mean, if it gives the results without as you say large computational cost. Then it seems like a good idea but what we tend to do in practice as we do analyse the whole dataset"*. However, some training or additional support is required by the participants to see the full benefits as p2 mentioned: *"Yeah, well. That sounds like a good idea. But again, you are assuming a level of knowledge that most people at my level wouldn't have"*, which is supported by p3: *"I'll be …obviously with a little bit of input from yourself so I could certainly see how it would be valuable"*, and seconded by p4*: "Yeah, I could see that working. Yeah, so just from the kind of it, I will probably need to be a bit of a kind of education piece.."*.

Based on the findings of the researcher as an observer, it was possible to identify some unused areas in the UI by the users while performing the tasks. For example, p1, p2 and p3 did not use the "Highlights section" when looking for the information requested in the tasks. This behaviour reflects a personal methodology to resolve tasks by the users by deciding to go directly to the metadata report instead of looking for the information in the "Highlights section". It was also possible to identify that p1, p2 and p3 struggled to find access to the "Full Metadata Report". These observations are crucial to redesign the UI by improving the information content and navigation as p1 stated: "*..it is kind of difficult to navigate".*

In general, participants found the information content useful by highlighting the inclusion of the dataset license. P4 mentioned: *"So yeah, I presume it is suggesting that is Open Access and they waive rights to restricted …"*, which is supported by p2: *"OK, there was wait. Yes, it's waived all copyrights. The license yes"*.

Additionally, participants noticed the inclusion of provenance information of the data sources as highly crucial for trustworthiness. As an example, p1 stated: *“ Provenance is referred to data source. Right? I can see here there is an option called source”*. P2 supports this explanation by stating: *“ Yes, yeah, OK so the idea here is after we perform data integration. We will include the provenance information as well. So we just want to know what we have done“*. However, some participants emphasised that the evaluation of data goes beyond their tasks, p3 explained: *“The evaluation of the sort of quality and trustworthiness and provenance of a dataset so I could see the value of it most definitely. But as I say, it probably wouldn't be part of my normal daily work”.* To illustrate this, figure 24 shows the importance of provenance information with regards to data quality among all the participants as provenance information was a common topic.

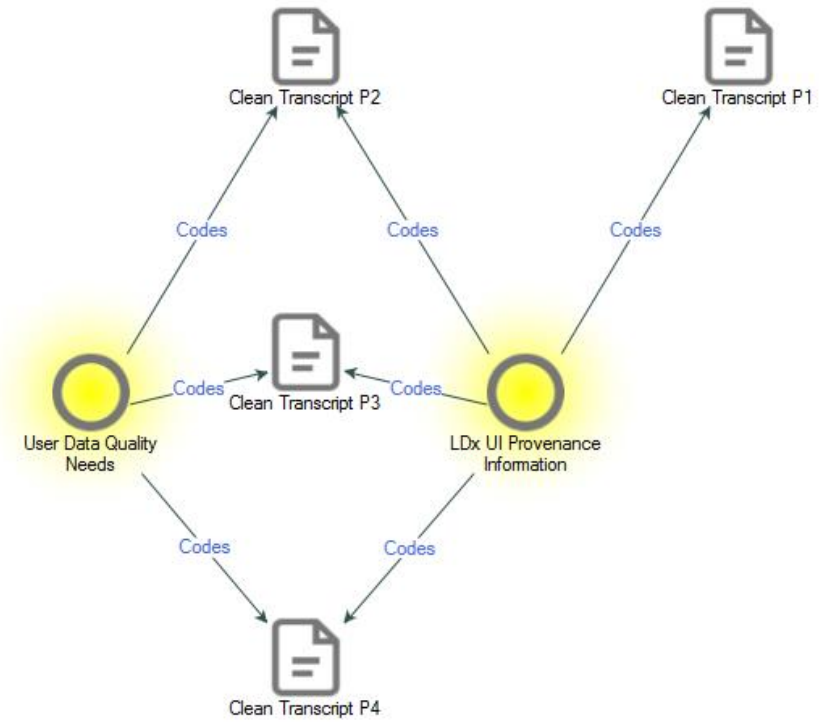

Figure 24: Provenance Information Perception

Theme 4: Highlights of the LDx Metadata Exploration Usability and Utility Process

Theme 4 pertains to codes regarding LDx Metadata Exploration usability and utility. Participants were questioned about downloading the dataset based on the information in the metadata report. The metadata report includes a section called “Accessibility” which contains the simulation of four links to download the dataset. However, the “accessibility” word was not identified as a synonym of “downloading files” by most of the participants. For example, p1 stated: “I don't see a mechanism for downloading the file ...”, which is supported by p3: *“ I suppose like accessibility is what my eye is drawn to in the report here. Sorry, I don't think that's relevant for the moment..”.*

Within theme 4, it also includes a code with regards to showing the full metadata report information by converting the machine-readable file (metadata file) into a human-friendly version. For example, p1 mentions: “So, there is a detailed dataset description”. The metadata report also includes the personalisation section, where participants noticed the benefit and easy way to personalise and download the metadata report. To illustrate this, p1 commented: *“So, this is the metadata report comes up. And I can save this file. I can personalise the file by selecting the bits that I want”*, which is supported by p3: *“OK personally, so I guess I'm looking at the full data report, um. Damn. Oh yeah, here we go. OK, so personalise your PDF file by selecting the metadata information to be included …this is quite simple and then it saves file and then that's it. It indicates that's completed for me”.* These participants’ feedback will be used to modify the wording in the UI to ease the participants' interaction with the final application.

In general terms, Theme 1, Theme 2, Theme 3 and Theme 4 appear to link to the concept of LDx usability and utility to explore data, assess data quality and perform data integration. Codes for these themes indicate that participants had a generally positive experience using the LDx electronic storyboard, and it is necessary to perform some changes in the UI content and UI navigation to fulfil users’ expectations. Figure 25 shows the word cloud of these themes by highlighting the importance of these keywords in the four semi-structured interviews.

Figure 25: Thematic Analysis Word Cloud

Theme 5: Highlights of the LDx User Profile (Persona)

Theme 5 focuses on understanding more about this subject-matter expert profile by relating the participants with their current workflow/job duties. From table 9, it is possible to create a user model (Personas) based on the participant's profile. Most of the subject-matter experts, who participated in this experiment, do not perform data integration as one of their daily tasks because someone at a lower grade is usually the one with the responsibility of integrating data. For example, p3 mentioned: *" That wouldn't be a typical day for me. That wouldn't be a typical task for me. Not, you know, not really..to be honest..."*, which is supported by p2: *"What we do is we collect information about patients and we store that information somewhere and often initially on a paper spreadsheet. And then we can transfer it into an Excel file, usually or in SPSS file".*

Based on participants' job responsibilities, the participants know that the data is integrated by another member of their team who has the data integration capabilities. To illustrate this, p2 mentioned: *"So, there are four or five members or more in my group who would be able to do that for me… but most people at my level would have a group of people who would have a background in these sorts of data analytics ….that allow us to perform those sorts of data tasks"*, which is supported by p3: *"I wouldn't spend a huge amount of time doing the types of tasks that we just did there, so I probably wouldn't feel hugely qualified in saying that. We*

have various researchers of ours that would maybe interact with different datasets", and seconded by p4: *"so, I wouldn't do that stuff myself, but on the lower level kind of similar data integration".*

This subject-matter expert is mostly into performing statistical analysis where the datasets are integrated by someone else as a previous "data cycle step". For example, p1 stated: *"Then I use a lot of statistical software such as SPSS, Graphpad Prism, Microsoft Excel..".* However, participants are interested in performing data exploration to understand what data is available to be used for their research and clinical questions. To illustrate this, p1 mentioned: *"Well, I'd like to use this approach to explore the data. And to run perhaps some simple queries that would help me to describe or answer some simple research questions".*

Participants can also see the benefits of using walk-through applications to perform the tasks step-by-step, which can offer opportunities to start using new applications and technologies to enhance their productivity. Additionally, the participants were asked whether they could see themselves using this application (LDx) that intends to follow a walk-through process and only requires uploading a metadata file. The four participants answered positively. For example, p1 mentioned: "*well. I think it's now difficult to read large manuals and If there was a no detailed description in a manual well. Basically, a busy clinician would not read it. They much prefer to just have something that walks them through"*, which is supported by p3: *" Um yeah I well, I think you know from a basic perspective, I suppose something like that will be much more attractive to a non-specialist"*, and seconded by p4: "*Some people are savvier than others, but compared to guys who would be novices, you within the academic clinician group, there's lots of people who would rarely use software. So, step by step thing would work for them. OK, think of it".*

Theme 6: Highlights of the Users' Expectations and Needs

Theme 6 relates to the identification of participants' needs and expectations based on data quality and data integration tasks. Participant's needs were mentioned by users; though, they have a clear understanding of the nature of the current data. For example, p3 mentioned: *"… and yeah I would like to combine datasets, but they would generally be of the same, mmm the same source, and that source would be generated by various members of our research team as opposed to pulling kind of*

large datasets together from different sources", which is supported by p2*: "But most conditions at the moment are about working from Paper. So, we're not actually required to integrate data except in our heads".*

It was also highlighted by p1 the need for developing an automatic way to perform the data integration without manual user interaction, by saying*: "I mean what we spend a lot of time doing is trying to integrate those three sources. And we do it manually and so If there was a solution that would make us not do it manually. I think that would be really useful".*

With regards to data quality expectations, participants mentioned that before trying to perform any data integration, the data quality of dataset should be optimal, and it should include a way to identify missing data. To illustrate this, p2 mentioned: *"That we would like to be able to integrate those data. OK, you integrate data, and you know that the quality of the data should be very good",* which is supported by p4: *"but in general you know I was thinking more about missing data or misaligned data"*. It includes a good information content with regards to provenance data as mentioned by p3: *" I thought the provenance information was laid out quite well and it was good that it was accessible, so that would make that search a lot easier, but there's certainly nothing else that jumps out at me as being needed in terms of its provenance".*

Theme 7: Highlights of the User Testing Challenges

Theme 7 pertains to the users' challenges while using the UI. This theme also highlights the LDx development assumptions, which were even noticeable by the participants by mentioning the assumption of having a metadata file to explore the data. To illustrate this p1 stated: " *Just what I'm not clear is where did the metadata get generated. who generates that? … yeah, so I think it's uh, perhaps the big assumption to make that the data sources and the team will have these metadata files already",* which is supported by p2 by stating the assumption of knowing terminology used in this UI: *" .. but again, you are assuming a level of knowledge that most people at my level wouldn't have".*

Theme 7 also reflects the unanimous feedback that emphasised the use of very technical language within this UI. For example, p1 mentioned: *"Although it is*

hard to navigate because there's a lot of tech and terms used there that are not accessible to the non-RDF user. Concepts, relationships and those kinds of things", which is supported by p2: *" we have to sit down and think through what that actually means because we're not used to those sorts of terminologies".*

Figure 26 shows how the incorrect wording is linked with user frustration as the feedback was unanimous in saying that the language used in the application was very technical. To illustrate this, p2 stated: *" In order to test the application, you would have to give us a half an hour introduction around the concept of metadata and the concepts of some of the term. Provenance and the various concepts. You know, we wouldn't be really familiar with it all, so I think the first thing would be to give an explanation. Did you even explain the technical terms? Most people wouldn't even know what metadata are. I'm more technical than most people of my generation, so I can fix my own computer, but it's very frightening when people present you with these sorts of terms. You know, such as that exercise that we just did so you know..",* which is supported by p3: *" I'm not sure what to search…I'm not familiar with the term triples, so I'm sort of… I'm flying blind a little bit there..".* These comments will be considered as a high preference when developing the final UI and where the application intends to fulfil users' needs by considering a pleasant UX.

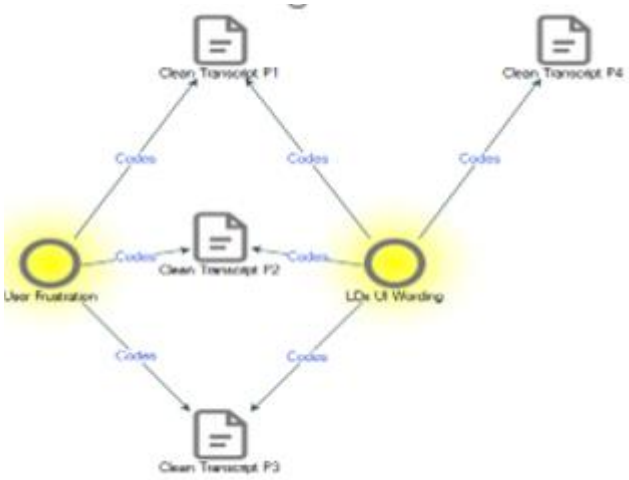

Figure 26: Thematic Analysis: User Challenges

PSSUQ Discussion

PSSUQ questions are scored from 1 to 7, with lower scores indicating more positive perceptions. At the same time, for the purpose of this experiment, sufficient usability was considered to be scores strictly lower than 4. Based on the scores in table X, it can be seen that the mean score for each question is below 4 with the exclusion of question 6:*"I believe I could become productive quickly using this system"*. The scores lower than 4 indicate that participants were generally in agreement with the PSSUQ questions, and the sufficient usability was achieved for all questions.

With regards to PSSUQ sub-scales (SysUse, InfoQual and InterQual), the average score for each of the components was between 2-3. Lower PSSUQ values indicate a better perfection of a system. This reflects that participants were generally in agreement with the questionnaire statements, and it suggests only mild usability issues with the GUI.

Participants were also able to indicate where a question was not applicable (NA), this can be reflected in the information quality (InfoQual-Question 11): *"The information was effective in helping me to complete the tasks and scenarios". It is supported by theme 7: User Testing Challenges by mentioning that the language used in the UI was very technical for a non-computer scientist.*

It is important to note that the most optimal scores were given to the questions related to the interface quality (InterQual-Question 13): *"The interface of this system was pleasant"*, and it is supported by theme 3: LDx Interface Usability and Utility that contains a code related to "LDx Friendly UI Set-up".

On the other side, the lowest scores were given to the question related to the system usefulness (SysUse-Question 6*): "I believe I could become productive quickly using this system"*, this also includes a not applicable (NA) question score by one of the participants. It is also supported by theme 5: LDx User Profile (Persona) that contains a code related to "User Workflow/Daily Tasks" by mentioning that three participants do not perform data integration/data quality activities in their daily tasks.

The overall scores were lower than 4, indicating that sufficient usability was achieved for subject-matter experts when using LDx storyboard. In the CTAM, most of the tasks were completed by the user, and the average time to complete each

task fluctuated between 0.88 and 1.38 minutes. It is worth noting that the tasks in the Data Integration scenario required a significant number of required assistance interventions in order to complete the tasks, and this is supported by theme 1: LDx Data Integration Usability and Utility that contains a code that relates to “A More Intuitive Path for Performing the Data Integration Tasks”.

Table 12 outlines how efficiency and satisfaction were measured in this experiment. From table 12 the participants' feedback on the efficiency of LDx electronic storyboard was mostly positive as the thematic analysis is backed up by the PSSUQ: SysUse score.

With regards to satisfaction, there was a somewhat mixed result as the SysUse portion of the PSSUQ had positive results. However, the thematic analysis, theme 7: User Testing Challenges, reinforces how a very technical wording can impact the participants understanding by developing frustrations that lead to incomplete tasks or requesting more assistance as some information does not follow the participant's ‘lingo’ with regards to their daily workflow. By having these two varying feedbacks regarding the same topic, it is possible to note that this electronic storyboard with an average PSSUQ-SysUse score below 4 can still improve participants’ satisfaction by performing modifications based on participants’ feedback such as changing the wording. It may lead to adopting the final application as participants can notice that the researcher/software developing team uses the given feedback to improve usability within the continuous collaborative prototyping process.

Area	Measure	Results
Efficiency	Time to complete the three scenario tasks.	The average time to complete scenario 1: Data Exploration, fluctuates between 1.14 and 1.38 minutes. The average time to complete scenario 2: Data Quality, fluctuates between 0.88 and 1.25 minutes. The average time to complete scenario 1: Data Integration fluctuates between 0.925 and 1.33 minutes. There were no outliers for these tasks aside from the non-completed tasks.
	PSSUQ: SysUse score	The SysUse score of the PSSUQ includes items which assess efficiency. The mean SysUse score was 2.96, indicating that participants had a mostly positive perception of these items.
	Thematic Analysis	A code in Theme 3 indicated that the content in the UI is good because it offers a description of the information used to perform some tasks such as data quality assessment or metadata personalisation.
Satisfaction	PSSUQ: InterQual and Overall	The InterQual portion of the PSSUQ investigates whether a system meets the user's expectations. The mean InterQual score was 2.02, indicating that users had a mostly positive experience by using LDx with regards to usability and utility.
	Thematic Analysis	Several codes emerged from the data, which indicate that the participants were mostly satisfied with the LDx electronic storyboard. The codes include: • Benefits of using LDx • UI content • UI provenance information • UI set-up • Visual communication for data integration. However, it also shows codes related to user challenges such as: • User frustration • Wording very technical • Development assumptions.

Table 12: Efficiency and Satisfaction Measures

5.7.7. Overall discussion

The hypothesis stated that LDx electronic storyboard application would be useful for members of a clinician-researchers team such as subject-matter experts in the healthcare domain. Overall, from the findings it is deduced that the hypothesis should be rejected.

The rejection of this hypothesis is supported by a quantitative, and a qualitative analysis. With regards to quantitative analysis, the lowest scores were given to the question related to the system usefulness (SysUse-Question 6*): "I believe I could become productive quickly using this system"*. With regards to qualitative analysis, the creation of theme 5: LDx User Profile (Persona) that contains a code related to “User Workflow/Daily Tasks”, and the code related to “Users’ Statistical Software to Perform Daily Tasks” confirm that these subject-matter experts (three out of four participants) do not perform data integration/data quality activities in their daily tasks. They receive the integrated data from another member of the team and this integrated data is then uploaded for data exploration and statistical analysis.

It is worth noting however that in addition, based on the findings, that the LDx electronic storyboard may be useful for the subordinates of these subject-matter experts, and for subject-matter experts with different attributes such as knowledge engineers or data scientist. As mentioned by some participants and reflected in theme 5: LDx User Profile (Persona), the data integration process and data quality assessment is performed by someone else in their team such as data analysts mentioned by participant 2, and researchers mentioned by participant 3.

It is worth mentioning the positive values of using the LDx electronic storyboard. Unanimously, the UI received very positive feedback regarding data content and data navigation. The PSSUQ sub-scales scores support the feedback by stating that the UI design is good, and the flow is friendly. However, there is always room for improvement, and the unused areas in the UI can be used to improve data content and enhance the data navigation path in a more intuitive way.

Participants mentioned the need for exploring data to improve the patient’s diagnosis or answer clinical questions. Then, the data exploration section should remain in the UI by changing the wording and the data content in the unused areas to exceed users’ expectations.

The users can see the value of including a data quality assessment in the UI. However, the experiment tasks requested the users to perform a data quality assessment based on a category level. It is important to note that the users got confused by trying to understand each data quality metric which may generate frustration when the user performs the data quality assessment by using only the "metrics" level instead of category or dimension level. Additionally, users can identify trustworthiness with provenance information. Based on this, the provenance information is imperative to be included, and the data quality metrics must be grouped into a more friendly way that helps users to understand the meaning quickly.

The data integration section is the one that will need a significant number of changes in order to exceed user expectations by improving usability. As the users identified the benefits of using a walk-through application to perform the tasks step-by-step, the data integration path must be more intuitive by providing a better understanding of the data sources used in linking data (such as concepts and concept properties), and by developing a walk-through application where the user is fully guided from the start to the end of the data integration task regarding schema-level. The relationships and link-types will also be differentiated in a friendlier way by providing a better description and meaning of these components without using complex language. The summary of the data integration task and its visual communication will remain as they offered a better understanding of the process.

The suggested modifications, based on participants' feedback and analysis, will help with the adoption of the final application as it reinforces the collaborative prototyping within the UX design process and target users. This experiment also helped to understand more about the user research within the UX design process by identifying the user model (Persona) that may not be suitable for using this application.

Finally, in drawing these overall experiment findings remarks to a close, it is important to emphasize the value of including data exploration, data quality assessment and data integration information in the UI. It is considered worthwhile, and it is recommended to continue with the user research process and users' requirements for such a UI, by recruiting different members of a clinician-

researchers team such as principal investigators, data scientists, and the subordinates of the subject-matter experts who participated in this experiment.

5.8. Triangulation Method – Second Experimental Study – Interviewing and Direct Observation:

Having a different set of users who are closer to the tasks (data exploration and data integration) prompted to use direct observations to facilitate the collection of evaluative information in which the evaluator (researcher) watched the subject (participant) in his/her usual environment without altering that environment. These observational research findings are considered strong in validity because the researcher is able to collect a depth of information about a particular behaviour.

5.8.1. Experimental Hypothesis

The hypothesis being investigated as part of the second experimental study is shown as follows:

Hypothesis (H): Implementing a triangulation methodology will be helpful to support and verify the clinician-researchers team requirements in the development of a user interface that supports data exploration, data quality and data integration tasks.

5.8.2. Participant Profile

Target participants for this experiment can be identified as members of a clinician-researchers team in the healthcare domain. Participants with this profile are time-challenged due to their daily workloads, and so this experiment was targeted with the recruitment of five participants. Due to changes in this research, the participants' profile for this second experimental study differs from that of the first experimental study. For this second experimental study, the participants were explicitly selected from a cohort group interested in data integration tasks (such as Linked Data to other outputs).

The interviews (to conduct the user requirements and user needs) were held with two male participants and three female participants. The direct observations were held with one male participant and one female participant. Table 13 shows the participants' profiles, including their domain expertise, gender, age interval, job role and data integration expertise.

Participant	Gender	Age Interval	Job Role	Domain Expertise	Data Integration Expertise
P1	Male	55-65	Principal Investigator	Nephrology	With additional support
P2	Female	45-54	Principal Investigator	Paediatrics & Child Health	No
P3	Female	45-54	Principal Investigator	Immunology	No
P4	Female	25-34	Research Fellow	Paediatrics	Yes
P5	Male	25-34	Research Fellow	Statistics	Yes

Table 13: Participants' profiles for the second experimental study.

This research and personal studies/experiments were open to the male and female gender regarding participant recruitment. The gender balance is justified by being representative of the real-world target users. The age of participants will range from 18 to 65+.

5.8.3. Experiment Methodology

The Concurrent Think-Aloud Method (CTAM) was the chosen experimental methodology, as it allows the recruitment of a small number of participants. The method allows the uncovering of participants' behaviour rather than participants' opinions - with behaviour not varying as broadly as opinion [88]. Probabilistic sampling methods were not used to recruit participants. Rather the recruitment process started by sending a voluntary research invite to the target participants who are appropriate subject matter experts who are members of the ADAPT Centre. The profile for each participant was suggested and verified in consultation with members of the ADAPT Centre medical cohort.

5.8.4. Experiment Set-up

The experiment was set-up as follows:

- Prospective candidates received an email invitation to participate in the experiment. This invitation included both the Participant Information Sheet (document #1) and the Informed Consent Form (document #2). It was necessary to sign and send back the Informed Consent Form (document #2).
- After receiving the signed Informed Consent Form from prospective candidates, the scheduled interview time, and date were arranged for the participants.
- After arranging the meeting, the participants were given a URL by email shortly before the interview was scheduled to happen.

  It was required for the participants to use the Google Chrome browser in Incognito Window mode when they were using a desktop or laptop.
- The interviews and direct observations were performed individually with only one participant per day and time. Having one interview/direct observation per day allowed to take and transcribe necessary notes from the recording on the same day, as this practice would enhance future interview/direct observation experience. The interview/direct observation between the participant and researcher was recorded as both persons needed to interact at the same time during the experiment. For the direct observation meetings, the participant was requested to conduct some data exploration and data integration tasks on excel (or participant's data exploration software), and sharing the screen with me. Then, I was taking notes of the nature and

sequence of the interactions/tasks and the use of any graphical element, if any. The data could be anonymised or fake as I was only interested in understanding how the participants conducted some data exploration and data integration tasks.

- To facilitate the direct observation, it was suggested to the participant to conduct at least one of the following data exploration and data integration tasks:
    - identifying missing values.
    - identifying specific encounters of interest (i.e. remission with > 12 months of follow up).
    - performing any other scenario when the participants need to use filters to filter data.
    - analysing data over a period of time.
    - identifying data to be extracted and attached to another database/file.
    - identifying the data quality in the excel file.
    - understanding the data by checking its descriptive statistics.
    - identifying the way to enrich data
    - performing any graphical representation of data.
    - performing any task to understand and unlock the value of the participants' data.
- When sending the interview/direct observation URL, the interviewed participant received a participant number to sign in. It was necessary for the signing in to select only audio, and the video was turned off. Microsoft Teams allowed sharing the screen without signing in by using video. Participants received guidance about using Microsoft Teams if required.
- The participants were reminded that their screen-sharing and audio would be recorded as this experiment required the interaction between the participant and the researcher at the same time. At the videoconference, the participants were requested to share their screen and be notified when the recording of the videoconference was commencing.
- When the signed Informed Consent Form had been received from the participant, an email was sent to each participant 15 minutes before the interview/direct observation was scheduled to begin.

- After receiving the Consent Form, the participants were asked about their profile and user needs. Some of them decided to conduct a daily task so the direct observation could be performed as well.
- The interviews and direct observations were recorded for future analysis.

5.8.5. Experiment Results

5.8.5.1. Thematic Analysis Results

The Thematic Analysis was conducted on the Concurrent Think-Aloud Method, user requirements and direct observations data. Not a single code was rejected as this experiment involved a small population of five participants, and all the codes were related to the experimental study. The coding activity recognised 17 codes.

The themes were chosen to help answer the research question and understand user requirements and needs in more detail. The five themes distilled from the data include:

1. Similarities in Current Applications → 3 codes.
    a. Essential usability of dates to analyse data.
    b. Current workarounds due to workflow disruption.
    c. Unfriendly current application.
2. Affinity in Current Data Challenges → 5 codes.
    a. Unsatisfactory data quality.
    b. Exporting data challenges
    c. Data integration challenges.
    d. Data collection challenges
    e. Representation of data challenges.
3. Requirements Specifications for the Expected New Applications → 5 codes.
    a. User requirements and user needs.
    b. Expected technological scope.
    c. Expected data integration feature inquiry.
    d. Expectation of analysing data over a period of time.
    e. Automatic data integration tool feature inquiry.
4. Coincidence Regarding the Nature of the Data → 2 codes.
    a. Nature of users' longitudinal data.
    b. User's data sources overview.

5. Team Skills and Tasks Management → 2 codes.
    a. Users' hierarchy to allocate tasks among team members.
    b. Team members collaboration

All themes and codes distilled from the transcript data are detailed in Table 14 below. Table 14 also includes the code description, the number of participants who referred to the code (NP), the number of references to the code in the transcripts (NR), and a random supporting quote to demonstrate how the codes and themes were derived from the transcript data.

Theme	Name	Description	NP	NR	Selection of Quotes
Theme 1: Similarities in Current Applications	Essential usability of dates to analyse data	With regards to the usability of dates to conduct data analysis (such as filtering data)	4	10	"...and she's also designed the scripts to pull out the date of that first relapse 30 April, the interval of that from diagnosis is 19 months. And the date that the patient was last followed up 22, July 2021. And this is the date of the encounter, 31st of August 2012.", PB1.
	Current workaround due to workflow disruption	With regards to the workarounds performed as solution implementations.	3	12	"…but at the moment, there's a manual step whereby you run an R script and it takes the export ...", PB1.
	Unfriendly current application	With regards to the unfriendliness of using the current application (such as the lack of visual elements).	3	4	"...but for that system to be useful, it has to be user friendly, it can't be a system that only a programmer can, you know, access, it has to be something that someone who's like me and immunologist sitting in the lab can just log on to the system, clicking in real time and add in", PB3.
Theme 2: Affinity in Current Data Challenges	Unsatisfactory data quality	With regards to the unsatisfactory data quality (such as missing data or provenance).	3	10	"And it's from the neonatal part that so the one we have a few gaps because it was four or five years ago.", PB4.
	Exporting data challenges	With regards to the difficulty of exporting data into a common format.	4	7	"So if you pull everything, it's huge, absolutely huge. But she's taken a select few that are probably the most important fields that describe what's happened.", PB1.

	Data integration challenges	With regards to the challenges to perform data integration.	4	11	"...but it doesn't connect without Vermont Oxford, and it doesn't connect with the new Children's Hospital. And it doesn't connect with the X ray system. I suppose that's the kind of problem for us as we cannot integrate data easily." ,PB2
	Data collection challenges	With regards to the involved challenges to collect data.	5	10	"... how do I connect all these datasets?, the hospital also has a database, which is really poor, electronic, old fashioned system and connecting all of those, because what we do at the moment is we get the patient's chart, and we literally spend five hours going through it for research, because it's not captured roughly", PB2.
	Current representation of data challenges	With regards to the lack of representing data (such as graphical elements).	3	5	"..and well, there's no real graphical interaction, so you can't make a new vaccine to boost an immune response until you understand the immune response.", PB3.
Theme 3: Requirements Specifications for the Expected New Application	User requirements and user needs	With regards to the user requirements and user needs to be implemented in the expected new application.	4	12	"So for somebody like me, who's a scientist, not a clinician, not a data science. So as an immunologist, trying to do clinical research, what I need is a system that allows me to, first of all, gather the data, the clinical data, easily at the source where the sample has been collected.", PB3.
	Expected technological scope	With regards to the technologies used by the users (such as semantic web).	5	5	"We don.t use semantic web, I think the main thing is just being able to get the data as a CSV file", P5.
	Expected data integration feature inquiry	With regards to the requested data integration feature to be included in the expected new application.	5	12	"...what we would like to do is yes, integrate it with that database, but make it richer from our own data.", PB2.
	Expectation of analysing data over a period of time.	With regards to the expectations of analysing data over a period of time by using the expected new application.	5	13	"So you can see that, that as the as the patient moves through time we have things changing. Okay. So parameters are changing, measurement of levels of stuff is changing. And what we want to do is explore that.", PB1.

	Automatic data integration tool feature inquiry	With regards to the inclusion of an automatic tool feature instead of a manual feature to perform data integration	3	4	“I think if there was a possibility to develop an API or something into RedCap or into the freezer works database to avoid doing the tasks manually ...”, PB1.
Theme 4: Coincidence Regarding the Nature of the Data	Nature of users' longitudinal data	With regards to understanding the nature and type of the longitudinal data used in the current patients' analysis.	4	8	“… and the patient information is created for the first time. So we'll have the date and time of birth here because this is really important for us.”, PB4.
	Users' data sources overview	With regards to the data sources.	4	16	“I'm looking to download clinical data, and weather data, and pollution data and all that stuff.”, PB5.
Theme 5: Team Skills and Tasks Management	Users' hierarchy to allocate tasks among team members	With regards to the allocation of tasks among team members based on the team hierarchical structure.	5	8	“I don't do that as I have the clinician, I have the laboratory research assistant and I have the statistician”, PB3.
	Team members collaboration to complete the tasks	With regards to the team collaboration to complete and support daily tasks.	5	19	"Now, I am not very good at using R. So, it's one of my fellows, Jen S. designed that.", PB1.

Table 14: Thematic Analysis Evaluation – Experimental Study 2

5.8.6. Discussion

All names were changed to protect participants' confidentiality by using PB1 as participant 1 in the second experimental study, PB2 as participant 2 in the second experimental study, PB3 as participant 3 in the second experimental study, PB4 as participant 4 in the second experimental study, and PB5 as participant 5 in the second experimental study.

Theme 1: Similarities in Current Applications

Theme 1 encapsulates the similarities among the current users' applications by including the essential usability of dates to analyse data. For example, participants use dates to filter specific medical encounters to identify disease patterns. PB1 stated, "…and she's also designed the scripts to pull out the date of that first relapse 30th April, the interval of that from diagnosis is 19 months. And the date that the patient was last followed up 22nd, July 2021. And this is the date of the encounter, 31st of August 2012.”.

Theme 1 also highlights the execution of workarounds as solution implementations due to the current user's application do not match the user's needs and workflow. PB1 stated, "…but at the moment, there is a manual step whereby

you run an R script, and it takes the export ..." similarly, PB3 stated, "…sometimes she would have to go all because our system is not robust. You would have to go all the way back to the clinicians…".

Additionally, theme 1 shows the unfriendliness of the current users' applications when the users interact with them. PB3 stated, "...but for that system to be useful, it has to be user friendly, it can't be a system that only a programmer can, you know, access, it has to be something that someone who's like me and immunologist sitting in the lab can just log on to the system, clicking in real time and add in …". Similarly, PB4 stated, "… and we are hoping this application will make it easier for us to analyse the data…".

Theme 2: Similarities in Current Data Challenges

In terms of similarities in current data challenges, theme 2 encapsulates codes that reflect the challenges faced by the clinician-researchers team when interacting with their data. Firstly, participants have noticed unsatisfactory data quality by including missing values and provenance data. PB4 stated, "And it's from the neonatal part that so the one we have a few gaps in data because it was four or five years ago." Similarly, PB3 stated, "Oh, why are there missing values here? And then you go back to Tracy and Tracy would either have an answer.".

Theme 2 shows the challenges of exporting data into a standard format by emphasising the difficulty of exporting data. For example, PB1 stated, "So if you pull everything, it's huge, absolutely huge. But she's taken a select few that are probably the most important fields that describe what's happened.". In the same way, PB5 stated, "If you have more complicated datasets, and you have maybe more complicated analysis. You know, trying to figure out what the best format is, might be kind of difficult.".

Equally important, theme 2 includes a code that reflects the challenges faced by the users when performing data integration tasks. To illustrate this, PB2 stated, "...but it doesn't connect without Vermont Oxford, and it doesn't connect with the new Children's Hospital. And it doesn't connect with the X ray system. I suppose that's the kind of problem for us as we cannot integrate data easily." Similarly, PB5 stated, "…and also because these researchers left, so the information is a bit

fractured, I guess the work is in different places, you know, different files, so it is difficult to perform data integration ".

It is apparent that every participant experienced data collection challenge, which is reflected in the coding in theme 2. PB2 stated, "... how do I connect all these datasets?... the hospital also has a database, which is really poor, electronic, old fashioned system and connecting all of those, because what we do at the moment is we get the patient's chart, and we literally spend five hours going through it for research, because it's not captured roughly". Similarly, PB4 stated, "… sometimes it's not that easy to get the information from the hospital. Then this is also we need to build …".

Another essential point highlighted in theme 2 is the lack of representing data. For example, the lack of graphical elements, PB3 stated, "...and well, there's no real graphical interaction, so you can't make a new vaccine to boost an immune response until you understand the immune response.". Similarly, PB1 stated, "…because it's really very difficult to represent the data in RedCap".

Theme 3: Requirements Specifications for the Expected New Application

Theme 3 encapsulates the requirements specifications for the expected new application by clearly denoting the real users' needs that must match the users' workflow. For example, PB3 stated, "So for somebody like me, who's a scientist, not a clinician, not a data science. So as an immunologist, trying to do clinical research, what I need is a system that allows me to, first of all, gather the data, the clinical data, easily at the source where the sample has been collected.".

Similarly, PB5 stated, "if they have a sort of tool that where it's just as easy for them to request the data, and just, you know, download it, and just hand it off to me... that will be useful.".

Equally important, theme 3 shows the technical scope expected by users. The technical scope mainly focuses on using spreadsheets to manipulate data. To illustrate this, PB5 stated, "We don't use semantic web, I think the main thing is just being able to get the data as a CSV file and then work on it.". The usability of spreadsheets to manipulate data suffices the technological scope highlighted by most of the participants (PB2, PB3, PB4 and PB5). However, one participant (PB10) required the inclusion of semantic web technologies.

Theme 3 also shows the need of including a data integration feature in the same expected new application. The five participants highlighted this need. To illustrate this, PB2 stated, "...what we would like to do is yes, integrate it with that database, but make it richer from our own data.". Similarly, PB5 stated, "… it lets you download a CSV file that stitches together environmental data and pollution data. And that will be really useful.".

It is important to mention that the five participants will expect to analyse data over a period of time (by using filters) when using the expected new application. To illustrate this, PB1 stated, "So you can see that the patient moves through time, so parameters are changing, measurement of levels of stuff is changing. And what we want to do is to analyse that.".

Additionally, the users requested the inclusion of an automatic tool feature instead of a manual feature to perform data integration. To illustrate this, PB1 stated, "I think if there was a possibility to develop an API or something into RedCap or into the freezer works database to avoid doing the tasks manually ...". This is seconded by PB5 as follows "… but when they are integrating the information, they have to do that manually. Sometimes it is not a problem, but it is a huge amount of work.".

Theme 4: Similarities Regarding the Nature of the Data

Theme 4 focuses on the similarities between the users' data sources and the nature of the data used to analyse patients and disease patterns. However, it mainly focuses on longitudinal data. To illustrate this, PB4 stated, "… and the patient information is created for the first time. So, we'll have the date and time of birth here because this is really important for us.". Similarly, PB2 stated, "… and we just literally have 1000s of data points at the top, we go through everything all the way through birth, and every single number, we try to make this as numerical as possible. But we do use free text as well.".

In addition, theme 4 also reflects the user's data sources. Aside from the longitudinal data, the clinical, laboratory research, weather and pollution data are also included as users' data sources. To illustrate this, PB5 stated, "I'm looking to download clinical data, and weather data, and pollution data and all that stuff.". And it is seconded by PB1 as follows "we then use data from the RedCap, biomarker and Freezer work databases".

Theme 5: Team Skills and Tasks Management

Theme 5 clearly reflects how the hierarchical structure in the team defines the allocation of the tasks to be performed. To illustrate this, PB3 stated, "I don't do that as I have the clinician, I have the laboratory research assistant and I have the statistician". Similarly, PB2 stated, "… putting it into the database, that is done by someone other than myself…".

Additionally, theme 5 encapsulates how the team members collaborate with each other's to complete the tasks. To illustrate this, PB1 stated, "Now, I am not very good at using R. So, it's one of my fellows, Jen S. designed that.". Similarly, PB5 stated, "… Tracy is the one that actually integrates into a nice format and then that is sent to us …".

5.8.7. Overall Analysis

The hypothesis stated that implementing a triangulation methodology will be helpful to support and verify the clinician-researchers team requirements in the development of a user interface that supports data exploration, data quality and data integration tasks. From the findings presented in this section, it can be deduced that the hypothesis should be accepted.

The qualitative analysis supports the acceptance of this hypothesis. Participants mentioned the need for integrating data to improve the patient's diagnosis or answer clinical questions. Then, the data integration section should remain in the UI by including an automatic process (such as an API) to add an automatic technical feature to the application to avoid integrating data manually.

The users can see the value of including a data quality assessment in the UI and a data exploration section in the user interface. However, by conducting direct observations, the users emphasized the inclusion of data integration as a high priority instead of the others (data exploration and data quality) suggestions. Regarding data integration, the participants emphasized the need to include a very intuitive way to conduct data integration without computer expertise.

Equally important, the findings from the first experimental study did not match the findings from this second experimental study. A possible reason is that the selected users for the second experimental study were chosen from a particular

group of members, which could bias the findings of the second experimental study. To illustrate this, findings from the first experimental study showed that participants really needed a user interface that supports data exploration tasks instead of data integration tasks; however, by selecting participants from a specific cohort group interested in data integration, the findings of the second experimental study biased to depict the need for a user interface that supports data integration tasks instead of data exploration tasks.

To finalise this section, from the first experimental study, the medical subject-matter experts saw benefits in the functionality and how the User Interface was presented; however, it was not clear if the User Interface really supported the data exploration and data integration tasks as the participants did not personally do data integration tasks. This prompted me to do a second experimental study focused purely on the team members who do the data exploration and data integration tasks.

5.9. Chapter summary

This chapter presented and discussed the results of two experimental studies used to evaluate and verify the users' requirements gathering of the electronic storyboard, LDx. The first experiment consisted of the Concurrent Think-Aloud Method, which was used to evaluate the first iteration of the electronic storyboard, LDx, by enhancing the users' requirements gathering. The second experiment consisted of implementing a triangulation methodology (interviews and direct observations) to support, verify and enhance the users' requirements gathering to develop a future user interface. The development of the electronic storyboard LDx was useful to start the requirements gathering and design processes as it collected crucial information to generate the Thematic Analysis Themes.

The seven TA themes distilled from the first experiment data included:

- Highlights of the LDx Data Integration Usability and Utility Process → 4 codes.
- Challenges and Benefits of Data Quality Assessment → 2 codes.
- Highlights of the LDx Interface Usability and Utility Process→ 4 codes.
- Highlights of the LDx Metadata Exploration Usability and Utility Process → 3 codes.
- Highlights of the LDx User Profile (Persona) → 5 codes.

- Highlights of the User Expectations-Needs → 2 codes.
- User Testing Challenges → 4 codes.

The five TA themes distilled from the second experiment data included:

- Similarities in Current Applications → 3 codes.
- Affinity in Current Data Challenges → 5 codes.
- Requirements Specifications for the Expected New Applications → 5 codes.
- Coincidence Regarding the Nature of the Data → 2 codes.
- Team Skills and Tasks Management → 2 codes.

The results of these experiments reinforced the need for such a task to be supported in a future UI and refined the requirements for how it might be best supported based on the observations arising from the second experimental study.

6. CONCLUSION

This chapter draws conclusions from the research presented throughout this thesis. Section 6.1 discusses the extent to which the research objectives of this thesis, outlined in Chapter 1, have been achieved. The contributions of the research are revised in section 6.2. Final remarks are presented in section 6.3.

6.1. Research Objectives

The extent to which the objectives posed to address the research question of this thesis were achieved is briefly analysed in this section.

The research question investigated in this thesis was:

To what extent can LDx, an electronic storyboard, facilitate the users' requirements process to develop a user-friendly interface to enhance the clinician-researchers team capacity with digital communication by supporting data exploration, data quality and data integration tasks?

The first research objective (RO1) was to perform a state-of-the-art review of existing user interfaces and tools in the health domain. This objective was achieved by analysing existing user interfaces used in the health domain and the repositories and applications used by members of any clinician-researchers team in chapter 3. The state-of-the-art review indicated a need for further research in user interfaces that support members of the clinician-researchers team in the healthcare domain. Chapter 3, sections 3.1 and 3.2, offer more details by including comparison tables of the user interfaces and papers used in this chapter.

The second research objective (RO2) was to explore the benefits of including various qualitative data collection methods to enhance the users' requirements process. This objective was achieved by including background information regarding quality data collection methods used in the triangulation technique. Section 2.4 describes the benefits of various qualitative data collection techniques by inspiring this research to implement a triangulation methodology to support the users' requirements process.

The third research objective (RO3) was to evaluate the electronic storyboard in terms of efficiency and satisfaction. This objective was achieved by conducting

the first experimental study on designing and evaluating the LDx electronic storyboard. More details about the design and evaluation are shown in sections 4.1 and 5.7.

The fourth research objective (RO4) was to apply and implement additional qualitative data collection methods to enhance and support the users' requirement process for the future development of a user interface. This research objective was achieved by conducting a second experimental study to verify and support previous findings (from the experimental study 1). More details about the implementation of the triangulation methodology are shown in section 5.8.

6.2. Contributions

The major contribution of this thesis is the proposed electronic storyboard called LDx. LDx advances the state-of-the-art by including a user interface that supports the users' requirements process to develop a future user interface to support the data exploration, data quality and data integration tasks and the adoption of the Semantic Web technology for non-computer experts. The main findings of the first experimental study showed that the intended electronic storyboard LDx can be used as an early-stage process (users' requirement) in developing a future UI that supports data exploration, data integration and data quality for the clinician-researchers team. Because of the complexity of the wording used in the design of the electronic storyboard, I can argue that the electronic storyboard LDx can be used in any user requirements process - for the Semantic Web. This electronic storyboard (LDx) can collect plenty of data (positive and negative) from prospective candidates that are not defined as computer experts.

The minor contributions include the state-of-the art review of user interfaces/tools in the healthcare domain to identify individual problems in the development of user interfaces, and implementing different qualitative data collection methods (such as interviewing and direct observation) to be used within the triangulation methodology to support the users' requirements process. The findings from the first experimental study did not match the findings from this second experimental study. Hence, the application of the triangulation methodology (using the interviews and direct observations for the user requirements process) truly helped to verify and support the findings from the first experimental study. In addition, the findings from the second experimental study showed how

participants emphasized the need to include a very intuitive way to conduct data integration without the need for computer expertise – by suggesting the inclusion of an automatic tool to avoid performing the tasks manually.

To conclude, the inclusion of an electronic storyboard, the state-of-the-art review of user interfaces in the healthcare domain, and a triangulation methodology really offer essential value in the users' requirements process in developing future user-friendly interfaces where emerging technologies, such as the Semantic Web, are looking for adoption by non-computer experts.

6.3. Final remarks

It is hoped that LDX, the electronic storyboard, can benefit the users' requirements process in developing future user-friendly interfaces where emerging technologies, such as the Semantic Web, are looking for adoption by non-computer experts.

It is also hoped that the electronic storyboard, LDx, would benefit the research community by exposing the negative consequences of using complex wording in future user interfaces developments, leading to user frustration.

As the selection of exclusive cohort participants (prospective target users) can bias the findings of experimental studies, future researchers should implement a triangulation methodology to verify, support and enhance the users' requirements process.

For future research, the "to query datasets", "time-based granularity" and "supporting adaptiveness" features from the state-of-the-art review can be included in the following versions of the LDx electronic storyboard or as a guidance for a future user interface in the healthcare domain.

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APPENDICES

Appendix 1 - Think-Aloud Method Tasks

Scenario 1 – Data Exploration – Data Ingestion – Metadata Report

Scenario: A clinician-researcher is interested in exploring a dataset with regards to Irish hospitals which can be very beneficial for project A. LDx is the suggested tool to perform the activity by converting machine-readable files into friendly human-readable files. The clinician-researcher has access to metadata file named “Ireland” in RDF format and it is available to be explored.

1. Please, upload the RDF metadata file “Ireland.rdf”. As a first instance, can you confirm this dataset is related to health?
2. As a first instance, can you confirm this dataset is not considered as big data (> 500K triples)? then, it will not require additional computational resources if chosen.
3. It is important to know whether this metadata file includes any information about the licence and waiver to be used. Is this information included in the metadata report?
4. Access metadata is useful to understand if the dataset can be downloaded from an existing source. Can this dataset be downloaded? And if so, how many files are required?
5. Structural metadata is useful in data integration. Can you please identify at least two triple examples that can be useful for the project that involves Irish hospitals?
6. Data source information is important as it can support trustworthiness. Is this information included in the full metadata report?
7. Withing the full metadata report, what is the period that the dataset covers?
8. Please save your personalised metadata report.

“Each question/task is optional. Feel free to omit a response to any question, however, the researcher would be grateful if all questions and tasks are responded to”

Scenario 2 – Data Quality

Scenario: A clinician-researcher is interested in assessing whether Irish hospitals dataset fits the data quality requirements for project A. The metadata file contains data quality assessment information of the dataset based on the data quality metrics chosen by the metadata file creator. Please, access to the data quality section and answer the following questions:

1. Can you please identify at least three data quality metrics that were computed for this dataset?
2. As consistent data is important, can you please only identify the meaning/description of the “consistent data value ratio” metric?
3. Within the customise weights section, can you please identify the granularity levels in which data quality can be assessed in LDx (aside from the category level)?
4. The AZ3 project requires a data quality score (known as “fitness for use score”) of at least 97% out of 100%. Based on the project requirements and data quality metrics supported so far, in LDx, can you please generate the fitness for use score and assess whether this dataset is suitable for the A project (by using category as granularity level)?
5. As applications and technology evolve, can you please identify whether there is a data quality metric that cannot be used currently but it can be included in future versions of LDx to generate the “fitness for use” score?
6. Please remember to add a narrative to your data quality findings and save the file by including provenance information.

“Each question/task is optional. Feel free to omit a response to any question, however, the researcher would be grateful if all questions and tasks are responded to”

Scenario 3 – Data Integration

Scenario: A clinician-researcher is interested in enriching the existing data with regards to Irish hospitals. A second metadata file, “Health_units”, was uploaded previously and complies with the project requirements. In order to enrich the existing data, both data sources need to be integrated (“Irish_hospitals” and “Health_units”) by including their relationship and link-type. Please, access to the data integration section to perform the data integration (interlinking linked data) and answer the following questions.

Note: LDx offers descriptions of relationships and link-types that suit the data integration of data sources. The data integration is performed at concept (schema) level.

1. Can you please identify whether there is a concept (class) aside from “Organization” in Dataset 1?
2. Can you please identify whether there is a concept (class) aside from “LocalBusiness” in Dataset 2?
3. After visualising the concept (class) and concept properties from both data sources, clinician A2 would like to interlink both data sources by creating a link between ex1:Organization (dataset 1) and ex2: LocalBusiness (dataset 2) as it fits project AZ3 requirements. Please, perform the interlinking of both levels, concepts and concept properties, by selecting their relationship and link-type.
4. With regards to “How is concept from dataset 1 related to concept from dataset 2?”, can you please identify at least two types of relationships?
5. Please select the most ideal link-type of data sources based on the relationship chosen in the previous question. Can you please identify two link-types?

6. Please, continue with the data integration process and fill in the interlink justification and provenance data.
7. Please, confirm the data integration process which offers a visual interpretation of the performed data integration task that includes a fourth concept property used to integrate both data sources.
8. Please download the new interlinking-RDF file.

Appendix 2 – Experimental Study Documentation

Consent Form

TRINITY COLLEGE DUBLIN

INFORMED CONSENT FORM

LEAD RESEARCHER: Rolando Hanlon

School of Computer Science and Statistics

ADAPT Centre, Trinity College Dublin

Email: rolando.arceolivares@adaptcentre.ie , arceolir@tcd.ie

BACKGROUND OF RESEARCH:

This research is conducted as part of a PhD in the area of semantic web technologies, user experience (UX) and Human-Computer Interaction (HCI) through the SFI D-REAL CRT programme.

Clinician-researchers are constantly faced with dealing with the challenge of integration of diverse data sources related to patients. These can include personal clinical data, patient-generated data, third-party curated data and third-party services data.

Additionally, the quality of the integrated data needs to be assured by only including sources that are trustworthy on an ongoing basis. This research project will explore how to engage the clinician-researcher in the data integration process through their participation in the user interface (UI) design of the application called LDx (Linked Data Experience).

This experiment intends to receive feedback from participants (who are assumed to be non-semantic web experts) on an electronic storyboard of the design (called 'LDx storyboard') before the actual application is developed. It is important to note this experiment does not intend to test participants' ability in semantic web technologies, it focuses on the participants' interaction with the proposed application.

PROCEDURES OF THIS STUDY:

After consenting to participate, you (the participant) will be provided access to 'LDx storyboard' which is an electronic storyboard that intends to explore Linked Data files, assess the data quality of datasets and performs data integration by only uploading metadata files.

With regards to data collection, this experiment will be performed by using the Think Aloud Method (TAM)[53] through recording the videoconference/interview between the participant and researcher interacting at the same time when using 'LDx storyboard' (to comply and adapt to the current Covid-19 rules). It is important to note, the video recordings and questionnaires will be stored by using TCD IT services called MyZone Google Drive that complies with GDPR rules. All data collected from you will not be identifiable to any other participant.

A pre-interaction questionnaire is optional and intends to rate your knowledge in the technologies used in this research and visual preference style. It takes approximately 5 minutes to complete.

When using the LDx storyboard tool, you will have access to the self-guided story which includes a scenario and requested tasks to perform. The tasks are suggested to be performed in a "Think Aloud" manner by trying to verbalize your thoughts and how you will perform given tasks. There is no time limit to complete the task.

A post-interaction questionnaire (PSSUQ) is optional and intends to assess your interaction with the storyboard tool. It will take approximately 10 minutes to complete.

To sum up, the whole process will take approximately 45 minutes to complete. You can quit the experience at any time if you do not wish to participate and support this research.

At the end of the experiment, we will explain more of the reasons behind the experiment and will give you a chance to ask questions. We will email the final report to all participants.

It is important to note that we do not anticipate any data breach risk to participants. The only identifying information collected is the voluntary information you kindly provided in the questionnaires and the recording of the videoconference (shared-screen and audio only) while performing the tasks using the Think Aloud Method. This information will be managed by following the GDPR rules, Data Protection Act and TCD Good Research Practice guidelines.

PUBLICATION:

The research results will be published in a PhD dissertation and may also be published in selected conference presentations.

53 Charters E. The use of think-aloud methods in qualitative research an introduction to think-aloud methods. Brock Education J 2003; 12: 68–82.

CONFLICT OF INTEREST:

Please be advised that this research is being conducted by a member of ADAPT Centre who is also a PhD student in Trinity College Dublin. Mr. Rolando Hanlon, the lead researcher, declares there is no conflict of interest in this research since his status in this research - and in Trinity College - is deemed as student.

Individual results will be aggregated anonymously, and the research will report on aggregate results.

DECLARATION:

- I am 18 years or older and am competent to provide consent.
- I have read, or had read to me, a document providing information about this research and this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction and understand the description of the research that is being provided to me.
- I agree that my data is used for scientific purposes and I have no objection that my data is published in scientific publications in a way that does not reveal my identity.
- I understand that if I make illicit activities known, these will be reported to appropriate authorities.
- I understand that I may refuse to answer any question and that I may withdraw at any time without penalty.
- I understand that I may stop electronic recordings at any time, and that I may at any time, even subsequent to my participation have such recordings destroyed (except in situations such as above).
- I understand that, subject to the constraints above, no recordings will be replayed in any public forum or made available to any audience other than the current researchers/research team.
- I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights.
- I understand that my participation is fully anonymous and that no personal details about me will be recorded.
- I understand that if I or anyone in my family has a history of epilepsy then I am proceeding at my own risk.
- I have received a copy of this agreement.

By signing this document, I consent to participate in this study, and consent to the data processing necessary to enable my participation and to achieve the research goals of this study.

PARTICIPANT'S NAME: _____

PARTICIPANT'S SIGNATURE: _____

Date: 01st - October - 2020

Statement of investigator's responsibility: I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

RESEARCHERS CONTACT DETAILS: rolando.arceolivares@adaptcentre.ie, arceolir@tcd.ie

RESEARCHER'S SIGNATURE:

_____

Rolando Hanlon

Date: 01st - October – 2020

Information Sheet for Prospective Participants

TRINITY COLLEGE DUBLIN

INFORMATION SHEET FOR PROSPECTIVE PARTICIPANTS

You (the prospective participant) are invited to participate in this experiment which focuses on receiving feedback from participants (non-semantic web experts) on the design presented in the electronic storyboard of LDx before developing the actual application, based on that design.

This research project is conducted as part of a PhD in the area of semantic web technologies, user experience (UX) and human-computer interaction (HCI) through the SFI D-REAL CRT programme.

We are seeking participants who can be identified as clinician-researchers since this experiment targets these users as potential beneficiaries of using semantic web technologies to explore data and perform data integration to improve their workload.

You will be asked to sign an informed consent form because this experiment will be performed by you using the Think Aloud Method (TAM)[54] through recording a videoconference (screen-sharing and audio only) while interacting with the researcher. When a recording of an interview is made, it is saved to Microsoft Stream cloud storage for a retention period of a maximum of one week. Your data will not be identifiable since it will be coded with a participant number and stored using the IT services called MyZone Google Drive, which complies with GDPR rules. Only the lead researcher (Rolando Hanlon) and the lead researcher's supervisor (Prof. Declan O'Sullivan) will have access to these data until its publication in an open data repository.

After consenting to participate, a video conference/interview will be organized by scheduling the date and time. You will be asked to complete an optional pre-interaction questionnaire that rates your prior knowledge in semantic web technologies and your visual preference style. This takes approximately 5 minutes to complete.

At the day of the experiment, you will receive an URL that provides access to LDx which is an electronic storyboard that intends to explore Linked Data files, assess the data quality of datasets and performs data integration by only uploading metadata files. This electronic storyboard is viewable on any desktop/laptop by including all browser. For the experiment, it is suggested to use a

54 Charters E. The use of think-aloud methods in qualitative research an introduction to think-aloud methods. Brock Education J 2003; 12: 68–82.

desktop/laptop with a screen of at least 13". It is recommended not to use a smartphone/tablet for this experiment.

By using the LDx storyboard, you will have access to a self-guided story which includes a scenario and requests for tasks that you should perform. It is requested that the tasks be performed in a 'Think Aloud' manner by trying to verbalize your' thoughts and the way you will perform given tasks. You may explore as little or as much of the LDx storyboard that includes data exploration (highlights and full report), assessing data quality of dataset by customizing the data quality metrics weights and performing the data integration of two data sources.

There is no time limit to complete the experiment. Your experience ends when you assess the data quality of the dataset or perform the data integration process throughout the storyboard tool. It is expected that it will typically take approximately 20 minutes to complete. It is important to note, if a silent period of over 15 seconds exists, there will be an audible reminder of "please, keep talking".

You will be asked to complete an optional post-interaction questionnaire (PSSUQ) that intends to assess your interaction with the storyboard tool. This will take approximately 10 minutes to complete.

You are free to offer additional feedback and share any thoughts regarding the experience of using LDx storyboard tool. At the end of the experiment, we will explain more of the reasons behind the experiment and will give you a chance to ask questions. Additionally, we will email the final report to you. To sum up, the whole process will take approximately 60 minutes to complete.

All information will be managed by following the GDPR rules, Data Protection Act and TCD Good Research Practice guidelines. While participation will benefit the participants, the research will also support the development of better UI tools which can benefit the healthcare domain.

It is important to note that we do not anticipate any data breach risk regarding your participation. So, your participation is entirely voluntary, and you can withdraw until data is anonymized or until the results of the research have been published. The only identifying information collected is the voluntary information you kindly provided in the questionnaires and shared-screen with audio while performing the tasks by using the TAM. This information will be managed by following the GDPR rules, Data Protection Act and TCD Good Research Practice guidelines. To withdraw, simply email the researcher by giving the email you used to be in contact with, indicating that you wish to withdraw.

It is important to highlight that all questions in the questionnaires are optional, please feel free to omit a response to any question. However, the researcher would be grateful if all questions are responded to since the purpose of this research project is to receive feedback and engage users in the development of a UI that implements data integration.

The gathered data/feedback will be analyzed to design the UI. We plan to publish the results of this research in selected conference proceedings and PhD thesis. It is important to note, we will do this in a way which does not identify you, or any other individual participants.

Recordings will not be made available to anyone other than the researcher and his supervisor, nor will any such recordings be replayed in any public forum or presentation of the research. You can request your own video-recording for review.

While it is unlikely that illicit activities would be disclosed, if the participant does so, we would be obliged to report them to the appropriate authorities.

Please be advised that this research is being conducted by a member of ADAPT Centre who is also a PhD student in Trinity College Dublin. Mr. Rolando Hanlon, the lead researcher, declares there is no conflict of interest in this research since his status in this research - and in Trinity College - is deemed as student. Individual results will be aggregated anonymously, and the research will report on aggregate results.

If you have any queries, feel free to contact Rolando Hanlon at the following address:

rolando.arceolivares@adaptcentre.ie / arceolir@tcd.ie and I will be happy to answer questions regarding the experiment.

Experiment Instructions

Experiment (LDx storyboard tool)

LD**x** (Linked Data Experience) is an application that enables a clinician-researcher to explore Linked Data files, assess the data quality of the datasets and perform data integration by only uploading metadata files. It is intended that the application will be used by non-semantic web experts.

This electronic storyboard is viewable on any desktop/laptop by including all web browsers. It is suggested to use a desktop with a monitor of at least 13" to have the complete user experience (UX). It is advised not to use a smartphone/tablet to perform the experiment.

The focus of this experiment is on obtaining feedback from participants (non-semantic web experts) on the design presented in the electronic storyboard of LD**x**.

Let's explore and Linked Data with LD**x**.

Experiment Instructions

For this experiment please follow these instructions:

1. Please confirm that you have signed the informed consent form as this experiment will be performed by using the Think Aloud Method (TAM) through recording a video conference (audio and shared screen only).
2. Please fill in the pre-interaction questionnaire that rates your prior knowledge in semantic web technologies and visual preference style.
3. Please perform the experiment tasks in a 'Think-aloud' manner by trying to verbalise your thoughts and how you will perform given tasks.
4. It is important to note this experiment does not intend to test your ability in semantic web technologies. It focusses on obtaining feedback on the interaction with the application.
5. There is no wrong or correct answer. So, please verbalise your thoughts as much as you can.
6. If a silent period of over 15 seconds exists, there will be a kindly reminder of "please, keep talking".
7. Please fill in the post- interaction questionnaire (PSSUQ) to assess the LD**x** storyboard.
8. Participants can access to LD**x** storyboard tool at (https://xd.adobe.com/view/874c6362-87c2-44dd-6c7e-26f8d798296b-f17d/?fullscreen&hints=off).
9. Please feel free to request a brief interview and/or to offer additional feedback.
10. Each question/task is optional. Feel free to omit a response to any question, however in order to best support the research, the researcher would be grateful if all questions and tasks are responded to.
11. In the extremely unlikely event that illicit activity is reported, the main researcher/student will be obliged to report it to appropriate authorities.

Pre-interaction Questionnaire

"Each question is optional. Feel free to omit a response to any question, however, the researcher would be grateful if all questions and tasks are responded to"

Pre-Interaction Questionnaire

Please, use a tick to indicate your own knowledge about the following topics:

Topic	**Not at all Knowledgeable**	**Slightly Knowledgeable**	**Moderately Knowledgeable**	**Very Knowledgeable**	**Extremely Knowledgeable**
Semantic Web					
Data Quality Metrics					
Data Integration					
User Interfaces					

Have you participated in the design of a User Interface (UI) before?

Yes ____ No ____

If yes, please give a brief description of the circumstances.

_____
_____
_____
_____

Please, use a tick to indicate your own visual preference style when using ICT applications to perform daily tasks:

	It facilitates the interaction with the system.	It may facilitate the interaction with the system, but it is not needed	It does not offer benefits.
Colours			
Font/Size			
Image inclusion			
Graph inclusion			
Text box for adding a narrative			
Other			

If other, please explain. _____

Post-interaction Questionnaire

"Each question is optional. Feel free to omit a response to any question, however, the researcher would be grateful if all questions and tasks are responded to"

5.8.5.2.

5.8.5.3. PSSUQ (Post-Study System Usability Questionnaire)

Please answer the following questions based on a LIKERT scale of 1 to 7, **with 1 as highest and 7 as lowest rating**.

Strongly agree Strongly disagree

	1	2	3	4	5	6	7	N.A.
1. Overall, I am satisfied with how easy it is to use this system.								
2. It was simple to use this system.								
3. I was able to complete the tasks and scenarios quickly using this system.								
4. I felt comfortable using this system.								
5. It was easy to learn to use this system.								
6. I believe I could be more productive using this system.								
7. The system gave error messages that clearly told me how to fix problems.								
8. Whenever I made a mistake using the system, I could recover easily and quickly.								
9. The information (such as online help, on-screen messages, and other documentation) provided with this system was clear.								
10. It was easy to find the information I needed.								
11. The information was effective in helping me complete the tasks and scenarios.								
12. The organization of information on the system screens was clear.								
13. The interface of this system was pleasant.								
14. I liked using the interface of this system.								

15. This system has all the functions and capabilities I expect it to have.								
16. Overall, I am satisfied with this system.								

Thanks for supporting research by participating in this experiment.