Measuring the Effect of User-Generated External Representations during Sensemaking in Electronic Environments

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List of abbreviations and acronyms

ANOVA	Analysis of variance
ANT	Anchored narrative theory
ASK	Anomalous state of knowledge
DC	Distributed cognition
HCI	Human-computer interaction
HSD	Honesty significant difference
IR	Information retrieval
PCA	Principle component analysis
SPSS	Statistical Package for Social Sciences
VAS	Visual analogue scale
VAST	Visual analytics science and technology
WWW	World Wide Web

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Abstract

Sensemaking has been defined as the process of building understanding when facing complex situations. Creating a representation of a domain of interest is central to sensemaking, whether stored internally as a mental model or externally by using maps or tables, for example. The latter is generally assumed to be helpful, but little is known about the way in which external representations actually affect the sensemaking process. Despite the literature explicitly recognising the significance of external representations during sensemaking, it is not addressed in depth. Yet the prevalence of external representations supported by electronic environments, as developed by interaction designers, certainly warrants such interest. Understanding the role of external representations in the sensemaking processes can aid in the effective design of interactive computer-based tools.

This thesis investigates the way in which the use of external representations alters the process of sensemaking when searching for information in an electronic environment. Studies into sensemaking, which are often qualitative and exploratory in nature, have shed light on information behaviour and the underlying cognition involved in sensemaking, with exploratory characterisations usefully identifying certain key phenomena. By extending into more rigorous quantitative measurement, this study seeks deeper insight into what happens during sensemaking.

Four studies were conducted in the course of this research. Two controlled experiments involved participants searching for documents relevant to a task brief. In one condition, participants created an external representation in the form of a narrative and in another condition; they collected documents, which they judged as relevant, in a folder. The former controlled experiment was an exploratory study conducted to investigate the effects of using external representations in sensemaking, whereas the latter was conducted to replicate and expand on the findings of the former by testing additional hypotheses. The third study aimed at validating a metric of structuredness in the external representations created by users during sensemaking tasks. The fourth aimed to validate a questionnaire developed to measure levels of perceived sensemaking.

The results of this research suggest that the effect of user-generated external representations of sensemaking can be measured quantitatively – by using the developed paradigm, the sensemaking questionnaire and the metric for the measurement of structuredness, and by measuring the percentage of novel search terms. The results of the research also suggest that external user-generated representations involved in individual sensemaking tasks help to increase perceived sensemaking, reduce perceived uncertainty, and increase the generation of novel search terms. Moreover, the results show no relation between structuredness of the created external representations and perceived sensemaking, perceived uncertainty and keyword novelty.

This thesis makes a number of contributions, in that it provides: a paradigm for the study of the process of sensemaking; a reliable instrument to measure perceived sensemaking; a metric for structuredness of external representations created by users during sensemaking; empirical findings clarifying the relation between the effects of user-generated representations and structuredness on keyword novelty, perceived sensemaking and perceived uncertainty; and a theoretical explanation of the effect of user-generated representations on some of the sub-tasks involved in the sensemaking process (keyword novelty).

Concepts and variables used in the research questions and hypotheses

Variables/concepts	**Meaning**
Externalise thinking	During sensemaking, people tend to create structures/representations of a domain, whether internally (in the mind), or externally by using media, such tables and maps when thinking of the task at hand. The main interest in this thesis is investigation of the effect of creating external structures/representations in sensemaking. Therefore, in this thesis, *externalising thinking* refers to the process of user-generated representation – creating external “representations/structures”, particularly by using Microsoft OneNote software – while performing a sensemaking task.
User-generated representation condition	In this thesis, *user-generated representation* refers to the process of creating external structures/representations while performing a sensemaking task. It specifically refers to the process that occurred when participants created external representations by using Microsoft OneNote.
Non-representation	In this thesis, *non-representation* refers to the process that occurred when participants did not create external representations using OneNote; instead, they saved documents that they judged as relevant in a folder, without performing any structuring activities on them, e.g. changing the saved document sequence, or renaming documents.
Uncertainty	Kuhlthau (1993) defines *uncertainty* as a cognitive state that leads to the generation of emotions of confusion, frustration and loss of confidence among users.
Keyword novelty	The ability to generate keywords beyond those given in a task brief.
Structuredness	The amount of information and relations (considering the variable type of relations) included within an external representation.

CHAPTER 1: INTRODUCTION

Sensemaking is the process through which people attempt to make sense of complex, ambiguous and unclear situations. The concept has been studied in different domains, for instance in Human-Computer Interaction (HCI) (Russell, Stefik, Pirolli & Card, 1993), Library and Information Science (Dervin, 1998, 1992), Organisational Studies (Weick, 1995; Weick, Sutcliffe & Obstfeld, 2005), and in Naturalistic Decision-Making (Klein, Moon & Hoffman, 2006a, 2006b). Sensemaking has been defined as the process of building meaning by finding connections in information (Weick, 1995). In essence, sensemaking is the process of constructing an understanding when faced with complex situations (Attfield & Blandford, 2009; Klein, Moon & Hoffman 2006a).

Sensemaking has also been defined as "a motivated, continuous effort to understand connections (which can be among people, places and events), in order to anticipate their trajectories and act effectively" (Klein, Moon & Hoffman, 2006a, p. 71), and the process of finding representations and fitting information into those representations to solve particular problems (Russell et al., 1993). Klein, Moon and Hoffman (2006b) define *sensemaking* as the process of framing and reframing, where the frame is the constructed representation (presumably in the sensemaker's mind) that is used to comprehend a given situation. The created frame is used to determine relevant data, or, alternatively, the data that has been used to modify or change the frame.

Sensemaking tasks vary in their complexity, from less complex tasks (such as buying a new house or a car or planning a holiday to a country for the first time) to more complex tasks, such as conducting academic research in an unknown area or on a new topic, conducting a police investigation, or conducting intelligence analysis tasks. Nonetheless, information seeking is a central activity in the sensemaking process, irrespective of the complexity of sensemaking task.

Sensemaking has been described as an iterative process that involves two main loops: a foraging loop and a sensemaking loop (Pirolli & Card, 2005). In addition, "Sensemaking often involves gathering information, gaining an understanding of the information and then using the understanding to finish a task" (Sharma, 2006, p. 1).

The focus of this thesis lies in individual sensemaking, where a sensemaker needs to find information in an electronic environment, such as online archives. Within this context, the study examines the sensemaker's task of constructing a narrative understanding of information by constructing queries using an electronic dataset, searching for documents (evidence) and reviewing the results to decide on individual document relevance (document triage). Due to the extensive increase in the volume of information in electronic environments, this process has become challenging and may cause difficulties in finding meaning and identifying connections within information.

Stories provide a natural analytic account of sensemaking tasks and, as MacIntyre (1981) observes, people make sense of their lives only through the stories of which they find themselves a part. Bruner (2003) argues that stories are central to the human experience in general and in the sensemaking process in particular. Bruner (2003) opines that stories are what we use to interpret and understand the world and our experiences. In complex sensemaking tasks, such as intelligence analysis, sensemakers tend to communicate facts and events by marshalling them into a scheme, such as a story, as in the schema step in the notional model of sensemaking (Pirolli & Card, 2005).

The creation, augmentation and use of representations are central to the process of sensemaking, whether internally with a mental model, or externally by creating maps or tables, for example. When solving complex sensemaking problems, people tend to represent information externally, in order to make sense of it. It has been suggested that sensemaking is achieved by means of the manipulation of these created representations.Previous research (e.g. that of Cox and Brna, 2015; Zhang, 1997; Kirsh, 2010; Larkin & Simon, 1987) has emphasised the role of external representations in aiding cognition in general. It has been shown that the role of external representations is not limited to improving memory recall, but that they can also help in sharing memories, facilitating problem-solving, reasoning and decision-making. It has been suggested that external representations change the way people infer information (Stenning & Oberlander, 1995) and minimise the required effort for perceptual inference (Larkin & Simon, 1987).

An approach that stresses the role of external representations in cognition is distributed cognition. Hutchins (1995) argues that, when studying cognition "in the wild", it should be viewed as a non-individual phenomenon that does not only occur internally in the mind, but as a process that is embodied across artefacts.

In the context of sensemaking, some of the sensemaking models explicitly recognise and point to the frequent significance of external representations during sensemaking. In their notional model of sensemaking, Pirolli and Card (2005) emphasise the centrality of representation to the "schematize" stage of the sensemaking process, when the analyst structures the collected information into a representation designed to guide the analysis process. According to Pirolli and Card (2005), the process of sensemaking is not limited to the gathering of information; instead, it is accomplished through the manipulation of a created representation by means of which sensemakers can build insight, create further knowledge, or take action.

In their learning loop complex model, Russell et al. (1993) claim that, during the sensemaking process, sensemakers engage in three activities: the generation loop, the representational shift loop and the data coverage loop. Sensemakers establish the process of sensemaking by searching for a good representation within the generation loop. The generated representation is then filled by data in the data coverage loop. The representation may shift and change in the representational shift loop, when the sensemaker may find data that does not fit into the first generated representation.

Besides the theoretical works that emphasise the significance of external representations to the process of sensemaking, some qualitative empirical studies have been conducted to investigate the phenomenon. Such studies help in answering questions, including:

- What strategies do people follow to create external representations?
- How do sensemakers use external representations and what type of external representations do they create?
- How do sensemakers use external representations in a collaborative setting?
- How do sensemakers utilise external representations created by others?

Some empirical research confirms that the use of external representation helps sensemaking in different ways, e.g. in finding missing episodes and gaps in a narrative; building hypotheses; constructing an understanding of new concepts; and gaining higher-order thinking skills (Attfield & Blandford, 2011; Yi, Kang, Stasko, & Jacko, 2008; Çakan Akkaş, Sönmez & Kabataş Memiş, 2018). However, some studies highlight that the use of some of types of external representations is associated with challenges and difficulties, particularly in the sensemaking problem, pointing out that they may actually hinder the process (Tversky, 2010; Niebuhr & Pinkwart, 2012; Kang, Kane & Kiesler 2014; Sharma, 2010).

A range of software has been developed to support the creation of different types of external representations during different sensemaking tasks, for example narrative representation (Bhangaonkar, Chu & Quek 2016), hierarchical structure (Ryder & Anderson, 2010), freeform environment (Brade, Sehl & Groh 2016), concept maps (Jonassen, 2003) and argument representations (Uren, Shum, Bachler & Li 2006).

Although a number of theories, studies and tools concerning sensemaking explicitly recognise and point to the frequent significance of external representations during sensemaking, this has not been addressed in depth. Such studies are often qualitative and exploratory in nature. The qualitative studies have been useful for describing processes and allowing the creation of models that point to phenomena of interest. However, a reliable quantitative and experimental paradigm is needed to understand the relationships between variables of interest; particularly in understanding the way in which different kinds of tools may affect outcomes in electronic environments. Gaining a better understanding of this process will assist in designing tools to enhance sensemaking.

1.1 Research problem

Creating a representation of a domain of interest – whether stored internally as a mental model, or externally (such as by using maps or tables) – is central to sensemaking, There is an assumption that external representations help sensemaking. Although a number of theories of sensemaking explicitly recognise the frequent significance of external representations during sensemaking (e.g. those of Russell et al., 1993; Pirolli & Card, 2005), they do not address this in depth. Gaining a better understanding of this process will assist in designing tools that enhance sensemaking. Although these models and empirical studies do reveal a good deal about the information behaviour involved in sensemaking and underlying cognition and they do offer exploratory characterisations that identify some key phenomena of sensemaking, there is a need for studies that measure things around these phenomena as a natural development.

Moreover, while some of the existing research emphasises the importance of creating external representations in the process of sensemaking, some studies (Mandel, Karvetski & Dhami 2018) show that some type of external representations may, in fact, not help the process. Some researchers recommend the use of a particular type of representation to a particular type of problem. In addition, tools that are assumed helpful in supporting the creation of external representations have been evaluated, based on their ease of use and their effect on the process of sensemaking. Therefore, it is worth asking the question as to whether sensemaking would actually help in the sensemaking process and whether there is a paradigm that can be used for testing if external representations are suited to the problem.

This thesis addresses these issues by investigating the effects of the use of external representations quantitatively. The purpose of this thesis is to apply quantitative measurements to form a better understanding of what occurs in the sensemaking process when using external representations (Figure 1.1). Such a focus seems particularly significant where external representations are supported by electronic environments and are designed by interaction designers.

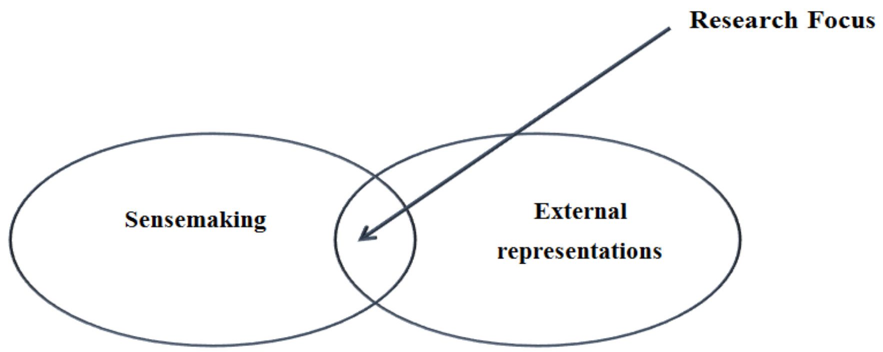


Figure 1.1: Research focus: How does external representation in the notion of sensemaking alter the process and how can these changes be quantitatively measured?

Figure 1.2 presents a paradigm that has been designed to approach the research problem. This paradigm shows the iterative process that participants are expected to follow when given a particular task. On recognising an information need, the participant would construct a query and then conduct a search. They would then review (triage) the results (documents), selecting those they consider relevant. Creating user-generated representations involved the additional step of using the selected documents to create/modify an external representation (user-generated representation). The paradigm was designed, so that quantitative measures could be taken of its subtasks, such as query and user-generated representation and level of structuring within user-generated external representation.

The paradigm design was used in controlled experiments with two conditions: under one condition, the paradigm was applied in the user-generated representation stage (Figure 1.2) and under the other condition, it was applied without the user-generated representation condition (Figure 1.3).

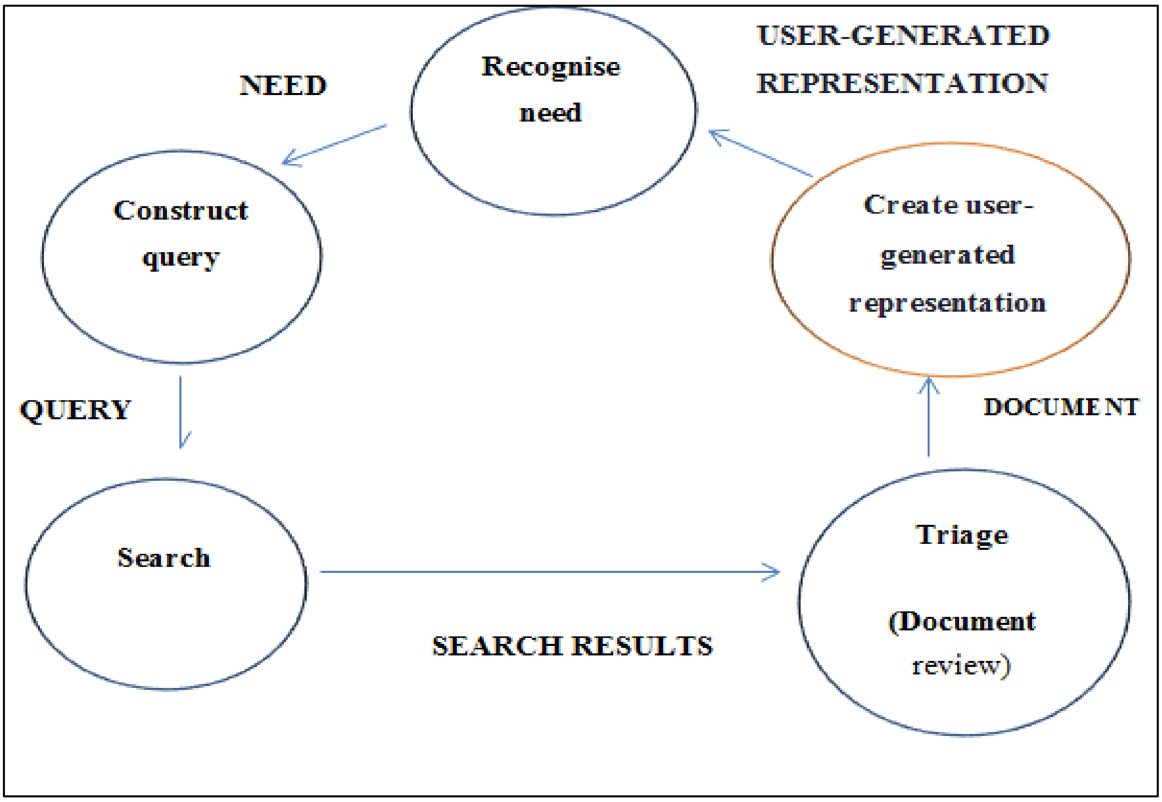


Figure 1.2: Process model showing what participants were predicted to do, based on the paradigm design under the user-generated representation condition

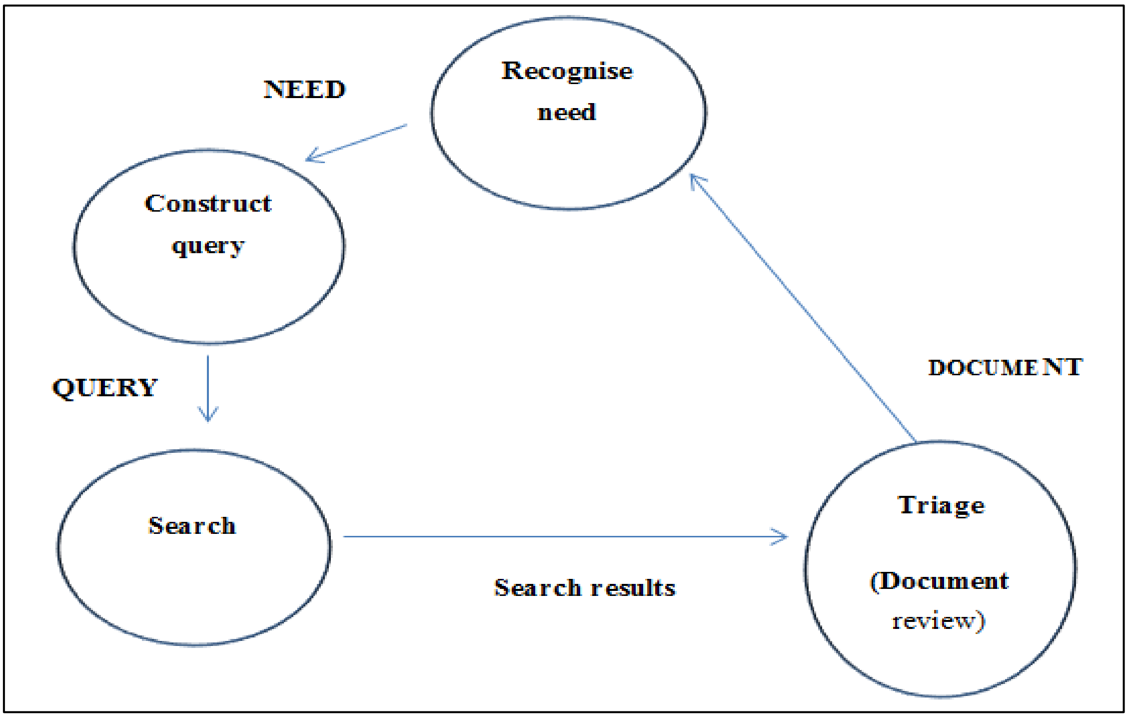


Figure 1.3: Process model showing what participants were predicted to do, based on the paradigm design under the non-representation condition

1.2 Research questions and hypotheses

1.2.1 Research questions

The overall aim of this research was to investigate how the structuring of thinking in user-generated external representations affected sensemaking and how that effect could be measured quantitatively.

In order to achieve the research aim, the following three research question and sub-questions were identified:

RQ1: *How does the creation of user-generated external representations measurably affect the sensemaking process?*

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

RQ1.2: *What is the relationship between the creation of user-generated external representations and query construction?*

RQ1.3: *What is the relationship between the creation of user-generated external representations and perceived uncertainty?*

The sub-questions for RQ1 were approached in the following two ways:

- The first way involved an experimental manipulation of the independent variable user-generated representation. The designed paradigm (illustrated by Figures 1.2 and 1.3) was used to collect the data. The dependent variables (perceived sensemaking, keyword novelty and perceived uncertainty) were then compared across the two conditions (user-generated representation and non- representation).
- The second way concerned the relation between the level of structuring user-generated external representation and some of the sensemaking sub-tasks and final products. The correlations within the user-generated representation condition were measured between perceived sensemaking, keyword novelty and perceived uncertainty, in order to define a new variable called *structuredness*, which refers to the amount of structuring within external representations.

1.2.2 Hypotheses

The following hypotheses were developed and tested in the course of the research:

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

H_2: Creating user-generated external representations during sensemaking helps to increase keyword novelty.

H_3: Structuredness correlates with perceived sensemaking.

H_4: Structuredness correlates with keyword novelty.

H_5: Creating user-generated external representations during sensemaking helps to reduce the level of perceived uncertainty.

H_6: Structuredness correlates inversely with perceived uncertainty.

Table 1.1 outlines the relationship between the research questions and the hypotheses.

Table 1.1: Relationship between research questions and hypotheses

Research questions	Related hypotheses
RQ1.1	H_1, H_3
RQ1.2	H_2, H_4
RQ1.3	H_5, H_6

1.3 Aims, approaches, and methods

To complete this thesis, four studies were conducted. The first study (presented in Chapter 3) and the fourth study (presented in Chapter 5) were controlled experiments. The aim of the second study was to develop and validate a metric of structuredness in the external representations created by users during sensemaking tasks (presented in Chapter 4). The aim of the third study (presented in Chapter 4) was to validate a questionnaire developed to measure levels of perceived sensemaking. The aims, approaches, methods and the results involved in each of the four studies are outlined in the following sections.

1.3.1 Study 1: The effect of user-generated external representations on perceived sensemaking and construction of query

1.3.1.1 Aims and objectives

Study 1 (reported in Chapter 3), which was a combination of a confirmatory and an exploratory study, aimed at investigating the effects of using representations to externalise thinking during the sensemaking process. The study particularly aimed at investigating the quantitative measurement of the changes that occurred when externalising thinking in some of the sub-tasks in sensemaking (keyword constructing) and the final products (levels of participants' perceived sensemaking at the end of a given sensemaking task).

The main objective of the study was to establish a paradigm for measuring sensemaking, which was addressed by meeting the following objectives:

- To measure quantitatively the effect of the creation of user-generated external representations on perceived sensemaking by testing H_1;
- To investigate the effect of the creation of user-generated external representations on query construction.

1.3.1.2 Approaches and methods

The study followed a controlled experiment and a repeated measure design, with a single independent variable (user-generated representation) with two levels (user-generated representation vs. non-representation). The independent variable was perceived sensemaking. Participants performed sensemaking tasks under two conditions – user-generated representation and non-representation. Under the user-generated representation condition, the paradigm in Figure 1.2 was applied, where participants were asked to externalise their thinking in user-generated representations, while performing a sensemaking task by using Microsoft OneNote. Under the non-representation condition, the paradigm in Figure 1.3 was applied and under this condition, participants saved files that they judged as relevant in a folder, without creating any representations.

The confirmatory investigation part of the study was conducted to address a hypothesis, while the exploratory investigation part was conducted to explore what would happen in some subtasks of sensemaking when externalising thinking in user-generated representations during the process.

Data were collected by using a questionnaire (see Appendix A.3) that was developed to measure perceived sensemaking, based on models and definitions that covered different features of sensemaking. To meet the second objective of the study, data were collected by using BB Flashback screen-recording software.

The collected data were analysed by means of different statistical tests. – the Cronbach's alpha test was used to measure the internal consistency of the questionnaire and Wilcoxon signed-rank was conducted to compare participants' perceived sensemaking across conditions. A qualitative analysis was also conducted to analyse the participants' activities related to query constructions.

1.3.1.3 Results

The result of the Cronbach's alpha test showed that the questionnaire was reliable. The results also showed that perceived sensemaking was higher when participants externalised their thinking in user-generated representations (under the user-generated representation condition). The analysis of the screen recording study showed some evidence of the effect of using external representations in the process of developing keyword searches. These results led to the development of H_2, which strongly suggested an increase in developing new search terms when externalising thinking in user-generated representations during sensemaking.

Although the study had some limitations, it helped to answer part of the first research question (RQ1.1) and to develop a new hypothesis H_2. The external representations created by participants during this study were analysed (presented in Chapter 4), which led to the development of a metric to measure their level of structuring and to develop further hypotheses.

1.3.2 Study 2: Measuring structuredness

1.3.2.1 Aims and objectives

The motivation for Study 2, which is reported in Chapter 4, was based on the results of the analysis of the types of external representations created by participants during the exploratory study in Chapter 3 and reported in Chapter 4. The results show variations in the types and complexity of the created external representations. Therefore, I hypothesised that it is not only creating user-generated representation that may affect sensemaking: the level of structuring within representation "structuredness" may also have an effect. Accordingly, the objectives of Study 2 were to:

- Develop a quantitative metric to measure the levels of structuring "structuredness" in user-generated external representations during individual sensemaking tasks; and
- Validate the developed metric.

1.3.2.2 Approach and methods

The development of the metric was based on an approach that was introduced by Okoro (2014) and Okoro and Attfield (2016). The approach is based on the assumption that, similar to linguistic analysis, when people create external representations during sensemaking tasks, there are production rules of visual language that users implicitly generate and then follow when creating representations. These visual representations can be described in terms of parse trees (syntax trees) consisting of entities embodied within other entities.

According to the metric, representations can be analysed as a series of embedded relations (e.g. timeline relation and themed grouping relation), where each relation connects a set of lower-level elements in a way that conveys relational meaning. More details on this are provided in Chapter 5.

The developed metric was evaluated in a study by comparing people's intuition of what structuredness is to the levels of structuredness calculated by the developed metric. Participants were asked to rank samples of representations with different level of structuredness by assigning a number from one to five to each sample.

The correlation between the structuredness of the levels, as measured by mean ranks assigned by participants and measured by the metric value, was calculated to depict the association between both variables accurately.

1.3.2.3 Results

The results of the study demonstrated that the developed metric was a valid measurement of the level of structuredness. The study contributed to answering RQ1 by developing a quantitative measurement of the level of structuring structuredness within user-generated external representations. This study helped to develop the hypotheses $H_{3,}$ $H_{4,}$ and $H_{6.}$ Further, Study 2 contributes to existing research on the effects of external representations in sensemaking by developing a metric for measuring the structuredness of external representations created by users during sensemaking.

1.3.3 Study 3: Measuring perceived sensemaking

1.3.3.1 Aims and objectives

This study, which is reported in Chapter 4, was conducted to:

- Produce a more general version of the questionnaire developed in Chapter 3 to measure levels of perceived sensemaking that can be used in any future studies about sensemaking; and

- Validate the new version of the questionnaire.

The new version of the questionnaire, which was developed based on rewording some of the statements in the previous version, is presented in Chapter 3.

1.3.3.2 Approach and methods

To meet the second aim of validating the new version of the questionnaire, data were collected from participants after they had performed one of the following sensemaking tasks:

- Reading a paper (academic article);
- Attending a lecture;
- Attending a seminar;
- Attending a workshop;
- Participating in a lab study; and
- Submitting course work.

Principle component analysis (PCA) and Cronbach's alpha were used to validate the instrument for measuring sensemaking.

1.3.3.3 Results

The results of the study showed that the developed questionnaire was a valid and reliable instrument to measure what is believed to be sensemaking, because the development of the questionnaire was based on definitions and theories of sensemaking. This study contributed to answering RQ1 by developing an instrument to measure perceived sensemaking.

1.3.4 Study 4: The effect of user-generated external representations in perceived sensemaking, perceived uncertainty, and keyword novelty

1.3.4.1 Aim

Study 4 (reported in Chapter 5) was conducted to replicate the findings of the first exploratory study and to expand on the findings by testing additional hypotheses H_5 and H_6. In this study, the scope was increased to include the notion of uncertainty.

Previous researchers (e.g. Kuhlthau, 1993b) reported a reduction in the level of uncertainty over the period of performing extended information seeking. It was also expected that, over the same period, the level of sensemaking of some domains would increase. Both sensemaking and uncertainty have been investigated separately in information seeking research. Uncertainty is viewed as important to the information seeking process (Belkin, 1980; Kuhlthau, 1993b), while sensemaking is important as a positive outcome of the information seeking journey (Dervin, 1998, 1992).

Part of the motivation for relating these two (i.e. uncertainty and sensemaking) in the current study was the idea that they are more or less equivalent constructs, viewed from a different perspective. However, these two concepts have rarely been studied in relation to each other. Therefore, investigating the concept of uncertainty appeared to be important.

1.3.4.2 Approach and methods

The study followed the same paradigm design (Figures 1.2 and 1.3) used in the first study reported in Chapter 3. The study, which followed a repeated measure design, involved a controlled experiment, with a single independent variable (user-generated representation) with two levels (user-generated representation and non-representation). Some amendments were made to overcome the limitations of the exploratory study. (Details of the amendments are presented in Chapter 5). The independent variable involved in the study was creating user-generated representation and non-representation.

The dependent variables were as follows:

- Perceived sensemaking;
- Keyword novelty; and

- Perceived uncertainty.

1.3.4.3 Results

The results of the study showed external representations having an effect on the process of sensemaking. Under the user-generated representation condition, participants reported lower levels of perceived uncertainty, higher levels of perceived sensemaking and they generated more new novel keywords. The results also showed no correlation between structuredness and keyword novelty, perceived uncertainty, and perceived sensemaking. The study contributed to answering RQ1 by testing sets of the developed hypotheses.

1.4 Contribution

This research makes the following contributions to the field of HCI and existing research in sensemaking in the electronic environment:

1. It presents a paradigm to study the process of sensemaking through its subtasks (e.g. quality of the query: Figure 1.2.). All the results presented in Chapters 3, 4 and 5 contribute to framing this contribution.
2. It presents a reliable instrument to measure perceived sensemaking (Chapters 3 and 4).
3. It presents a reliable metric to measure structuredness (Chapter 4).
4. It offers empirical findings (Chapter 5) clarifying the effects of externalising thinking in user-generated representations on key variables in the sensemaking process, specifically:
   - Perceived sensemaking;
   - Keyword novelty; and
   - Perceived uncertainty.
5. It offers empirical findings (Chapter 5) clarifying the relationship between key variables during sensemaking processes, specifically:
   - Structuredness;
   - Perceived sensemaking;
   - Keyword novelty; and
   - Perceived uncertainty.

6. By adding an explanation of the effect of user-generated representations on some of the sensemaking process subtasks (keyword novelty), it presents a theoretical contribution extending the existing model of sensemaking.

The studies, research sub-questions and contributions involved in this research are illustrated in Figure 1.4.

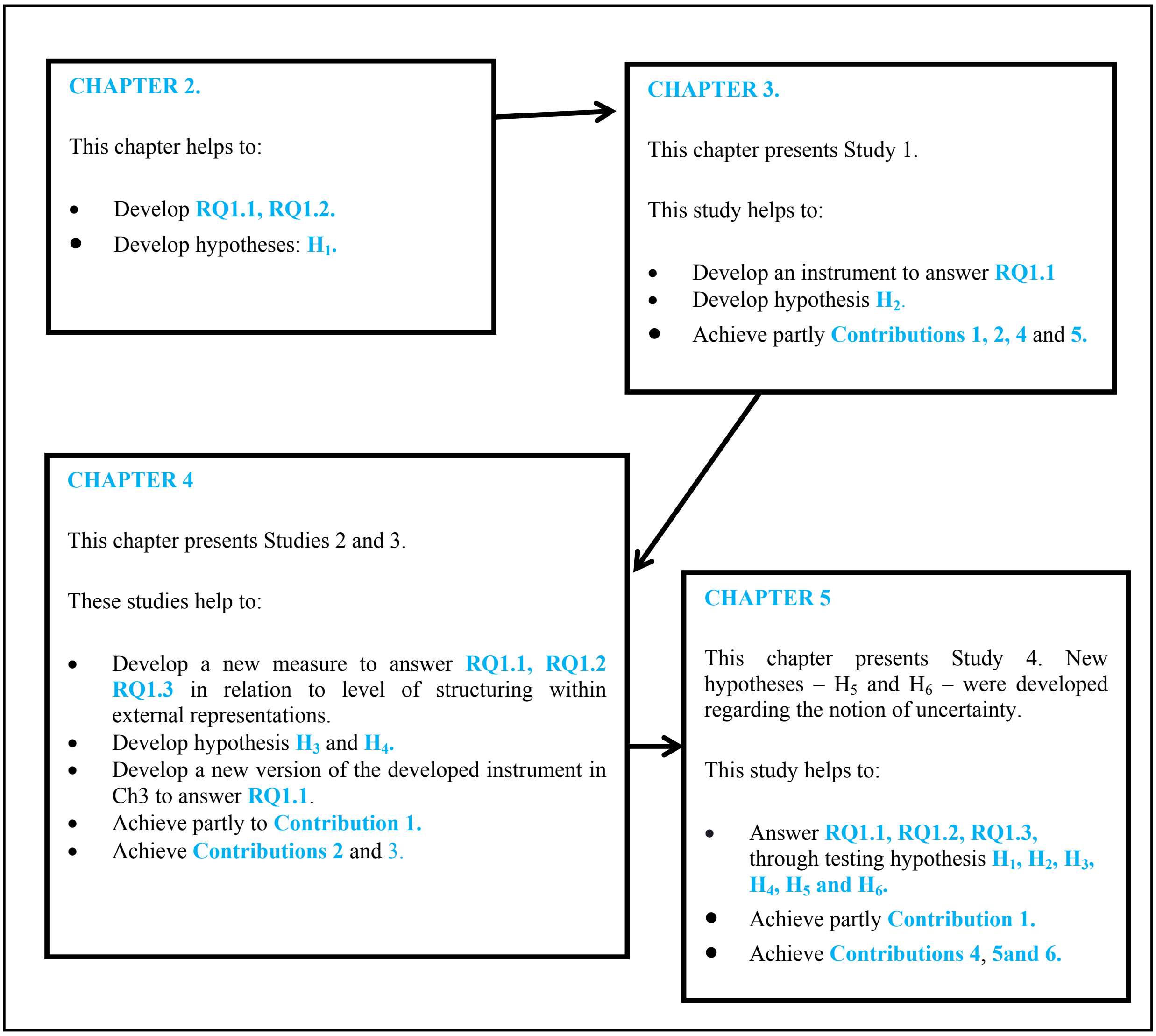


Figure 1.4: The development, answering and achievement of the research questions, hypotheses and contributions

1.5 Thesis structure

This thesis is structured in the following chapters:

Chapter 2: Literature Review

Chapter 2 presents an overview of the literature on sensemaking, a brief review of information seeking as a part of the sensemaking process and a brief review of the role of external representations for cognition in general. The chapter also reviews the literature on the role of using external representations in sensemaking, as well as the tools that support the use of external representations during sensemaking.

Chapter 3: The Effect of User-Generated External Representations on Perceived Sensemaking and Construction of Query

This chapter reports on the first study conducted to investigate the effects of external representations during individual sensemaking tasks. It presents the motivation for the study, the data collection and analysis methods, the results and the limitations of the study. It contributes to answering RQ1 by answering RQ1.1 and by testing hypothesis H_1, and presenting the development of H_2. Finally, the chapter presents the partial achievement of applying the designed paradigm in Figure 1.2 and helps to establish the design of an instrument of measuring perceived sensemaking.

Chapter 4: Development of Measures for Structuredness and Perceived Sensemaking

Chapter 4 reports on the development of the following quantitative measures:

- A metric to measure structuredness; and
- A new version of the questionnaire developed and used in Chapter 3 to measure levels of perceived sensemaking.

It also presents two evaluation studies of each of the measures. The chapter starts by reporting on the analysis of the type of representations created by participants in the exploratory study in Chapter 3, after which it covers the development of a metric to measure the level of structuredness. It also reports on a validation study of the developed metric. The second part of this chapter presents the development of a new version of the questionnaire designed to measure the levels of perceived sensemaking in Chapter 3. It reports on a validation study of the new version of the questionnaire, as well as on the study design, analysis and results.

The studies in this chapter contribute to answering RQ1 and offer developed measures that help to answers the following sub-questions: RQ1.1, RQ1.2, and RQ1.3. The studies in this chapter make it possible to achieve Contributions 2 and 3.

Chapter 5: The Effect of user-generated external representations on Perceived Sensemaking, Perceived Uncertainty and Keyword Novelty

This chapter reports on a study to replicate the findings of the first exploratory study, presented in Chapter 3, and to expand on the findings by testing additional hypotheses. It presents the motivation for the study and the methods used to collect and analyse the data. It also presents the results of testing of the following hypotheses: H_1, H_2, H_3, H_4, H_5 and H_6. This chapter contributes by answering the following sub-questions: R1.1, RQ1.3 and RQ1.3. Finally, it helps to achieve Contributions 1, 4, 5 and 6. By applying the designed paradigm in Figure 1.2, the study provides empirical results of the effect of externalising thinking in user-generated representations in the sensemaking process.

Chapter 6: Discussion and Conclusion

This chapter presents a further discussion on the thesis in terms of the research questions and hypotheses and provides the conclusions of the study.

CHAPTER 2: LITERATURE REVIEW

The main interest of this thesis is to reach an understanding of the effects of using external representations in the sensemaking process when conducting information searches in the electronic environment. Therefore, this chapter presents a review of the following topics: the process of sensemaking; the process of information seeking as an essential part of sensemaking in an electronic environment; and the effects of information users' external representations on cognition in general and on the sensemaking process in particular. This chapter also presents some of the tools that support the creation of external representations during sensemaking tasks.

The literature review is divided into the following three main sections:

- Section 2.1: The sensemaking process (Defining sensemaking and reviewing the significant models of sensemaking);
- Section 2.2: The process of information seeking (Presenting the significant information seeking models related to the context of this thesis, which focuses on sensemaking in information seeking in the electronic environment; and
- Section 2.3 (External representations), which rests on the following four pillars:
  - A review of the studies that investigate the role of users' external representations in cognition in general;
  - A review of the studies that investigate the role of creating and using external representations in the sensemaking process. Because the review only covers studies that investigate the representations that users create to externalise their thinking, studies of visual analytics, which involve the automated representations of data created by models, are not included;
  - The tools designed to support users in externalising their thinking while performing sensemaking tasks; and
  - Narrative representations, which essentially refer to the type of representation that are created when people are constructing a story in the process of sensemaking.
- Section 2.6 presents a chapter summary of the literature review, as well as the development of hypotheses, based on the reviewed literature.

2.1 Sensemaking

Although the concept of sensemaking has been investigated in different disciplines, such as human computer interaction (Russell et al., 1993), Library and Information Science (Dervin, 1998, 1992), organisational studies (Weick, 1995; Weick, Sutcliffe & Obstfeld 2005) and naturalistic decision-making (Klein, Moon & Hoffman 2006a), there is an extent of agreement in defining the construct of sensemaking.

Weick (1995, p. 4) provides a simple definition of *sensemaking* by describing it as follows: “the concept of sensemaking is well named because literally, it means the making of sense”. Klein, Phillips, Rall & Peluso (2007, p. 114), on the other hand, define *sensemaking* as the “deliberate effort to understand events”, whereas Pirolli and Russell (2011) define *sensemaking* as the process that includes all behaviours involved in the gathering and organising of information to gain profound understanding. During the process of sensemaking, sensemakers engage in a number of activities, such as searching for information; placing information in a structured scheme; and using the scheme to gain understanding, which, in turn, either builds the sensemaker’s understanding or leads to an action (Pirolli & Card, 2005).

From a cognitive point of view, Klein, Moon & Hoffman (2006a) define *sensemaking* as the process of comprehension. However, contrary to the common meaning of comprehension in Psychology, which refers to understanding specific stimuli, sensemaking refers to the comprehension of complex events. In this way, Attfield and Blandford (2009) define *sensemaking* as the process of building an understanding when facing complex situations. Klein, Moon & Hoffman (2006a) expand the definition of sensemaking to include “a motivated, continuous effort to understand connections (which can be among people, places and events) in order to anticipate their trajectories and act effectively”.

Some sources in the literature suggest that, in order to make sense of a domain, sensemakers create or use representations that provide meaning to the data at hand. For instance, Starbuck and Milliken (1988) opine that, in order to make sense of stimuli, they are put into a framework that helps sensemakers to perform processes such as explaining, understanding, attributing, extrapolating and predicting. Klein et al. (2007) and Klein, Moon & Hoffman (2006b) describe *sensemaking* as a process of framing and reframing, where the frame is used to filter the data or, in turn, use the data to update the frame. The frame is a metaphor for the representation that people construct in their minds and use to comprehend the world. In this way, the frame refers to the way in which we look at something, which determines what count as expectations and surprises for us (Blandford & Attfield, 2010).

Similarly, Pirolli and Card (2005) observe that the process of sensemaking is not limited to the collection of information. – It is accomplished through the manipulation of a created representation by means of which sensemakers can build insight, create further knowledge, or take action. The representation can be created internally as a mental model (in analysts' minds) or externally, for instance, by drawing a map, creating a timeline and using tables. Attfield, Fields and Baber (2018) define *sensemaking* as a quest for consistency between descriptions of a domain or a situation at different levels of abstractions, e.g. the consistency between a theory about a situation and the information that is collected and observed about this situation.

Sensemaking starts when inconsistent and surprising events are noticed, which, in turn, triggers the need to find explanations (Louis, 1980). Weick (1988) considers ambiguity and confusion as the two stimuli for sensemaking in organisations, as people react to both circumstances by engaging in the process of sensemaking: "Sensemaking is about contextual rationality. It is built out of vague questions, muddy answers, and negotiated agreements that attempt to reduce confusion" (Weick, 1988). Dervin (1983, 1998) states that sensemaking starts when a gap, which is a confusion emerging from a particular situation, is faced and explored at a given moment across space and time. In order to overcome the confusion, people need to bridge this gap, which is made possible by the use of available information sources.

2.2 Models of sensemaking

Different models of sensemaking have been developed in different disciplines, with each model explaining the sensemaking process in a different context and by using different language. The most significant models of sensemaking are explained in the following sections.

2.2.1 Dervin's sensemaking methodology

When Brenda Dervin explored the concept of sensemaking in the subject field of Information Science 1983, she introduced a methodological framework that suggests a range of assumptions about people and their sensemaking processes. The framework emphasises the importance of understanding sensemaking from the sensemaker's perspective, rather than that of an observer. It centres on the user by considering what is real to them and what is understood in their own terms. Dervin (1998) suggests that, instead of studying individuals' information needs and information use, based on characteristics that are static across space, such as their demographic and their personality, it is important to consider that people move through two dimensions – time and space – and, as they move through their context, their situation changes.

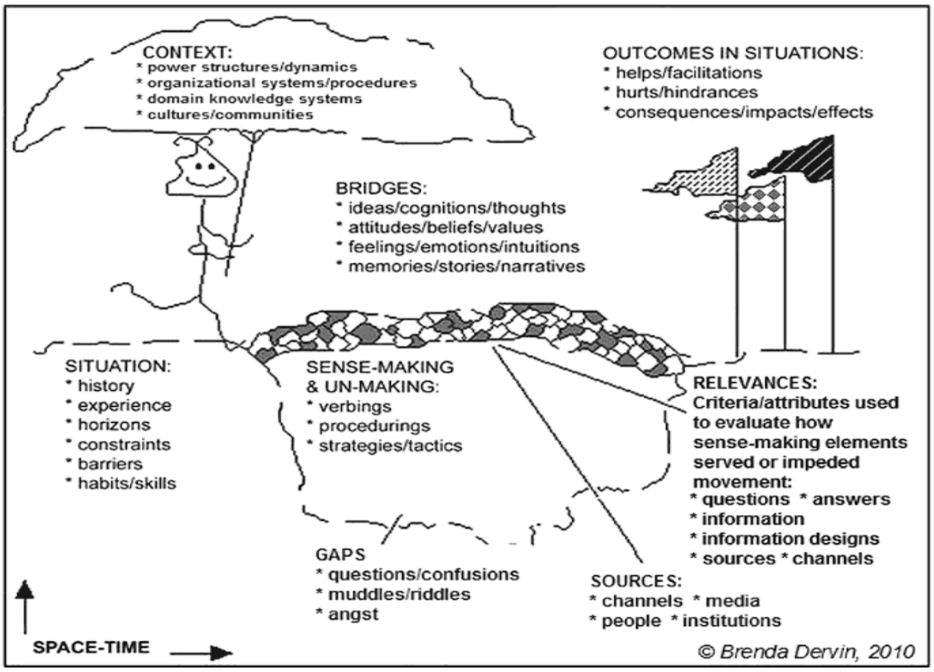


Figure 2.1: The gap-bridging metaphor of sensemaking
(Source: Dervin & Foreman-Wernet, 2013)

As illustrated in Figure 2.1, the focus areas in Dervin's methodology are gap, situation and use. The situation, which refers to the context in which sensemaking occurs, includes different factors, such as the individual's experience, history, domain knowledge and culture. A gap is a confusion that emerges from a particular situation, or a question that an individual faces and explores at a given moment across space and time. These gaps inhibit people from moving forward to the outcome of a situation and, in order to overcome the gaps, people need to bridge them. People use available sources, such as media channels, which they evaluate according to specific criteria, to bridge the gap. Apart from the available sources, people also utilise their cognition (ideas, thoughts and beliefs), as well as their emotions and feelings to bridge the gap. In this way, information can be seen as a personal construct that is based on a particular situation. The outcome of the process – i.e. the information use – can be either helpful or hurtful to the individual.

Dervin designed sets of questions related to gap, situation and use as the three concepts in her methodology. These questions, which can be used in Micro-Moment Time-Line Interviews to understand the way in which people make sense of a situation within a particular context, include:

Understanding situations:

- What happened?
- What stood in the way?

Understanding gaps:

- What were your big questions?
- What were you trying to unconfused, figure out, learn about?

Understanding use:

- What conclusions/ideas did you come to?
- What emotions/feelings did you come to?

2.2.2 Learning loop complex model

Russell et al. (1993) presented the learning loop complex model, which emphasises the crucial role of the "searching for representation" phase in the sensemaking process. The development of the model was based on the results of a case study of designers designing a training course of laser printers. In order to reduce the training time, the designers' main task was to combine different training courses of laser printers into one course that unified all their concepts. In the case study, the designers used a tool for knowledge structuring in which they could include and arrange the new course training information. Therefore, the model focused on the role of external representation. Russell et al. (1993) established that, before producing the final training course, designers were involved in a learning loop complex, where they engaged in a repeated process of developing and changing the representation.

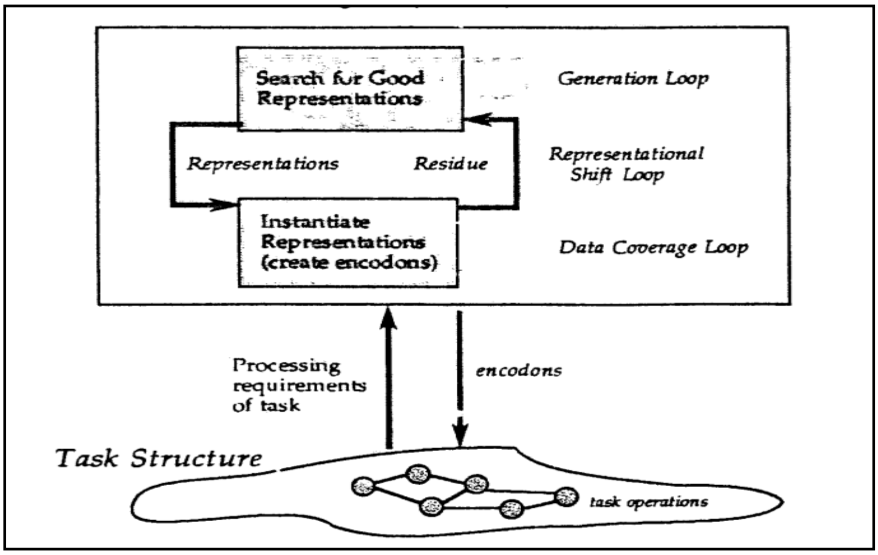


Figure 2.2: The learning loop complex model
(Source: Russell et al., 1993)

Based on the results of the case study, Russell et al. (1993) developed the learning complex model (Figure 2.2), which claims that, during the sensemaking process, sensemakers engage in three activities: the generation loop, the representational shift loop and the data coverage loop. Sensemakers establish the process of sensemaking by searching for a good representation in the generation loop, after which the generated representation is filled by data in the data coverage loop. However, the representation may be shifted and changed in the representational shift loop, when the sensemaker finds a mismatch between the data and representations. When such a mismatch is identified, the representations can be expanded to accommodate additional information. On the other hand, when information does not fit the identified categories, the initial categories can be split or expanded. The model provides a rich description of the sensemaking process as a process of schematisation. However, sensemaking is a broader process that includes other activities.

2.2.3 Notional model of sensemaking

The notional model of sensemaking, which was designed by Pirolli and Card (2005), is based on a cognitive task analysis of intelligence analysts. In the model, (see Figure 2.3), sensemaking is described as an iterative process that involves two main loops: a foraging loop and a sensemaking loop. The flow of data representation is displayed in boxes and the flow of the process in circles. During the foraging loop, analysts are engaged in processes related to information gathering, such as "search and filter" and "read and extract".

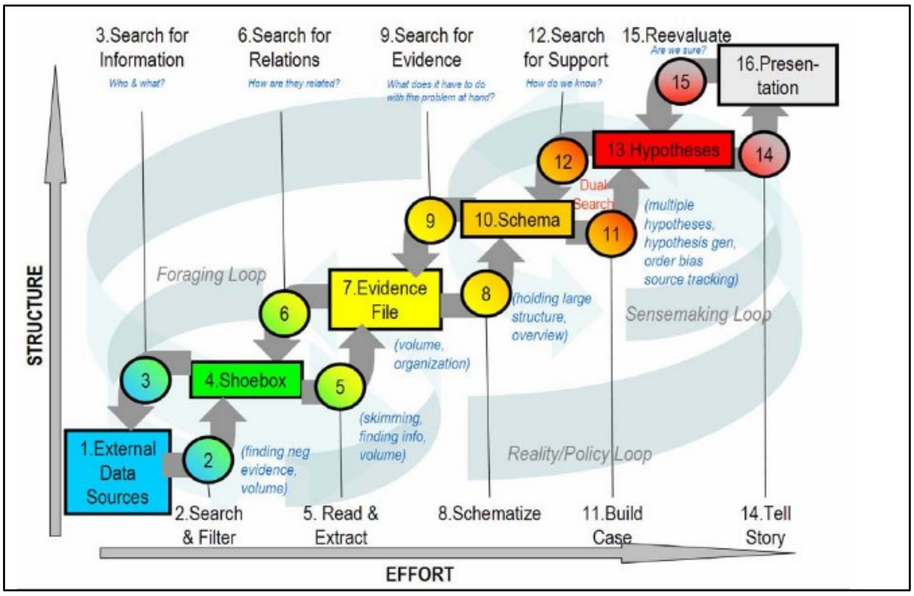


Figure 2.3: Pirolli and Card's notional model of intelligence analysis
(Source: Pirolli & Card, 2005)

In the sensemaking loop, analysts engage in processes related to gaining insight into the collected information, such as "schematise" and "build a case and tell a story". The "external data sources" box represents raw data, which is a large set of evidence, whereas the "shoebox" refers to a part of the raw data selected after being filtered, based on its relevance. Snippets from the “shoebox” are then saved in the “evidence file”. “Schema” involves re-organising of evidence, so that analysts can draw conclusions about a case. Information is then temporarily represented as “hypotheses” with supporting arguments. “Presentation” is the final report (representation) to be produced. The process can be performed either bottom-up or top-down.

In the notional model proposed by Pirolli and Card (2005), the process of sensemaking is not limited to the collection of information: it is accomplished through the manipulation of a created representation by means of which sensemakers can build insight, create further knowledge, or take an action. The representation can be created internally as a mental model (in analysts’ minds) or externally, e.g. by drawing a map, creating a timeline and using tables.

The notional model of sensemaking is used by other researchers to support different purposes, e.g. as a framework for the evaluation of the tools that support sensemaking (Yang-Turner, Lau & Dimitrova, 2012).

2.2.4 Data frame theory of sensemaking

Similar to the notional model of sensemaking, representation is central to the process of sensemaking in the data-frame theory, although the data frame theory is concerned with mental representations.

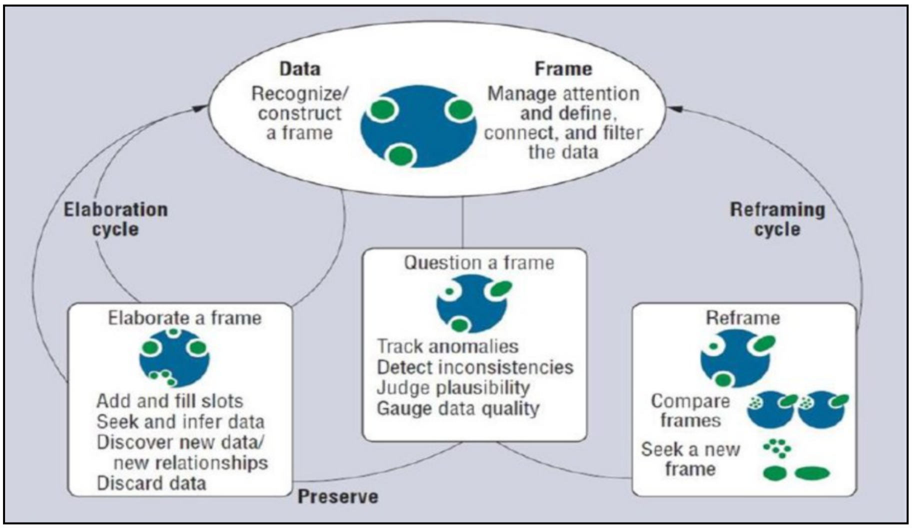


Figure 2.4: The data frame theory of sensemaking
(Source: Klein et al., 2007)

In their data frame model, Klein et al. (2007) describe *sensemaking* as an interactive process between two entities: data and frame, where data is the obtained or found information and the frame is the explanatory structure that defines the relations between this information. The data can be organised within the frame in different ways, such as spatial relations (maps), causal relations (stories), in chronological order (stories), or as jobs (scripts). The frame helps to identify elements within a situation; explain the importance of these elements; determine the relationship between the elements; and it acts as a filter to decide which elements are relevant to a situation and which are not.

During the process of sensemaking, people fit new situations (data) into a representation (frame), in order to make sense of them. The frame is used later to define what is considered as relevant data to the situation. However, finding new data may lead the sensemaker to discard the frame and search for a frame that can be anchored in the new data.

The interaction between the data and the frame can take the following different forms:

- Connect data and a frame: identify an initial frame to explain and interpret a situation;
- Elaborating the frame: the frame may extend and elaborate as people progress in learning about the situations;
- Questioning the frame, which occurs as a response to unexpected data: people may find new data that does fit into the frame, without the reason being apparent to them, whether it is due to the incorrect frame or the newly discovered data being inaccurate; and
- Preserving the frame: people preserve the frame by finding explanations or by rejecting data that does fit within the frame.

To make a better judgement in some situations, people compare multiple frames with each approach occurring differently and, at the end of the process, they choose the more adequate frame. Similarities may occur between these frames, but data that fits into one frame does not fit in a competitive frame. When data that is more adequate is found, the existing frame may also be replaced with a new frame. Frame searching/seeking may occur when people deliberately search for a frame to structure new data that does make sense, or when none of the available frames match the data. Attfield and Baber (2017) suggest that the frame is a combination of a generic frame and a situation-specific frame, with the generic frame referring to sensemakers' background knowledge and the situation-specific frame referring to sensemakers' interpretation of a current situation.

The model shares similarities with the learning loop complex model of Russell et al. (1993), in that both models emphasise the centrality of representations to the process of sensemaking. In addition, both models explain the interplay between the data and the created representations by means of which the created representation is used to determine the elicited data and the newly discovered data may result in changing the representations.

2.2.5 Weick's formulation of sensemaking

In an attempt to explain and define the concept of organisational sensemaking, Weick (1995) established a formulation of sensemaking by developing the following seven essential properties:

- Grounded in identity construction, suggesting that the understanding of what is occurring around us is a result of, and a process grounded on the way in which we define ourselves;
- Retrospective, which includes retrospection of previous experience;
- Enactive sensible environment: sensemakers are not isolated from their environment and, therefore, when they take specific actions, they enact or create their own environment;
- Social: sensemaking occurs in organisations through social communications; exchange of ideas and conversations; and the implied, imagined and actual presence of others directly impacts on organisational sense;
- Ongoing: people are always in the middle of things that are continuously changing, and, because people's perception and understanding also change, sensemaking has no start or endpoint;
- Focused on and created by extracted cues: people tend to attend to and extract specific environmental elements that often form the basic materials of the organisational sensemaking process; and
- Driven by plausibility rather than accuracy: the establishment of meaning is based on plausible explanations, as opposed to accurate or scientific discoveries.

2.3 Information seeking

In order to make sense of a situation, people perform different sensemaking activities and information seeking is a central activity to the process: "Sensemaking often involves gathering information, gaining an understanding of the information and then using the understanding to finish a task" (Sharma, 2006, p. 1). Information foraging has been considered an important phase in sensemaking (Pirolli & Card, 2005).

Kuhlthau (1991, p. 361) describes the information seeking process as the "users' constructive activity of finding meaning from information, in order to extend his or her state of knowledge on a particular problem or topic". Users seek information from their point of view, which suits their current state of knowledge of a topic. Hence, the final product of the information seeking process is not always the same for all users (Kuhlthau, 1991; Dervin, 1983).

In an electronic environment, the process of information seeking consists of an iterative series of activities that involve information need identification, query construction, and search results evaluation (Salton, 1989; Marchionini, 1992).

Figure 2.5 illustrates a standard model of Broder (2002), which summaries the key activities of the information seeking process in an electronic environment.

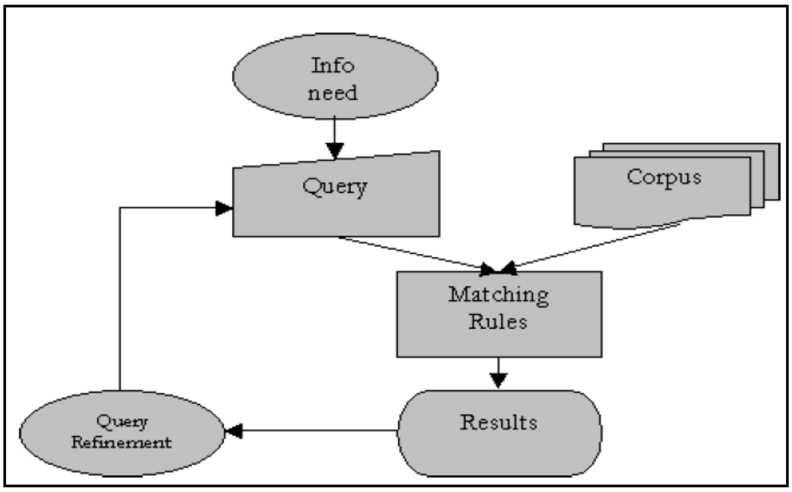


Figure 2.5: The classic model for inforamtion retrevial
(Source: Broder, 2002)

As illustrated in Figure 2.5, the information seeking process starts by recognising and identifying the information need. *Information need* refers to the amount of missing information that stimulates and leads to users performing the information search (Wissbrock, 2004). Users then communicate their information need to the system as a query. When searching for information in an electronic environment, formulating and using a keyword is an initial step. Users form their information needs as search terms – a construct that is referred to as a *query* (Marchionini& White, 2007). Wissbrock (2004) demonstrates three situations that users may experience in terms of their information need: the possibility that users may not know their exact information need; users may find it challenging to articulate their information need; and the user's information need may change during the search process.

The quality of the constructed query may be affected by the status of the users' information need. Failing to express an information need, e.g. when information seekers use poor search terms, may hinder users' progress in the search process (Savolainen, 2015). Some of the previous research investigated the way in which users formulate a search terms in relation to different variables, such as users' background knowledge, age and their skills in using information retrieval systems (Vakkari, Pennanen & Serola 2003; Sanchiz, Chin, Chevalier, Fu, Amadieu & He 2017).

Vakkari (2001) investigated the changes in students' search term creation throughout the proposal writing process. He explains the results in the light of the information seeking model by Kuhlthau (1993b) and the psychological notion that the progress in people's understanding of a topic helps them to differentiate its concepts. Vakkari (2001) observed research participants creating general search queries in the early stages of the search process. Based on this finding, Vakkari (2001) opines that, if participants are not familiar with the topic, their level of uncertainty is high, their understanding of the task is vague, and their mental models of tasks are less differentiated, However, as they progress in the search process, participants create specific search terms. Vakkari (2001) suggests that, as the search process progresses, participants become more familiar with the topic and their mental models become more differentiated.

In their research, Sanchiz et al. (2017) found that, when participants had more background knowledge of a topic, they did not rely on the problem statements provided to them by the researcher; instead, they created new search terms.

Once participants submitt the search query to the system, the system produces search results. The presented search results go through two evaluation phases to determine their relevance: the decision of relevance of the system (determined by underlying algorithms) and the human decision of relevance. The system's judgement of relevance is performed before the results are presented to the user. For example, the algorithm bases its evaluation on criteria such as the frequency of the used keyword search in the document. The human judgement of relevance occurs after the results have been produced.

The user's initial relevance judgment of the search results is known as the *documents triage process*. The term "triage," which is primarily used in a medical context, refers to the process when the "triage nurse" decides the patient's sequence of treatments, based on the degree of emergency of their case. The information seeking community adopted the term to refer to the essential step in the information seeking process, when people evaluate the results of an information search to decide what to consider as relevant to their information needs. This assessment step may occur at any stage – whether initial or advanced – of the information seeking process (Loizides & Buchanan, 2009). In the document triage process, the judgement of relevance can be performed in less than one minute (Buchanan & Loizides, 2007). Cool, Belkin, Frieder & Kantor (1993) reported six features of a text against which the information seekers examine a paper to determine its relevance.

Kuhlthau (1993a,) suggests that, as the search process progresses, users' judgment of relevance changes form searching for "relevance" to searching for "pertinence". According to Kuhlthau (1993a, p. 39), "relevance information has some bearing upon the research topic and is considered useful in a search for information", while "pertinence is a determination that information has a more decisive and significant relationship to a topic than relevance and is related to a personal information need".

Tang and Solomon (1998) conducted a case study of a student searching for documents and judging their relevance while writing a term paper. The research, which was based on the analysis of think-aloud protocol data, found changes in the student's dynamics of judging relevance of documents as the search progressed and the student read more documents. For instance, the student's self-confidence increased in terms of what to consider as a relevant document.

In a study involving eleven students searching for documents to write proposals for their Master's dissertations, Vakkari and Hakala (2000) found a relation between the criteria of relevance and the user's progression in the search process stages. The results of the study showed that, as the students progressed in the search process and their understanding of the topic increased, their ability to distinguish relevant sources also increased.

In the course of research into the informaton-seeking process, a number of models have been proposed. These models are outlined in the following sections.

2.3.1 Marchionini's information seeking process model

Marchionini (1992) proposes a model that summarises the essential stages in the information seeking process. (See Figure 2.6).

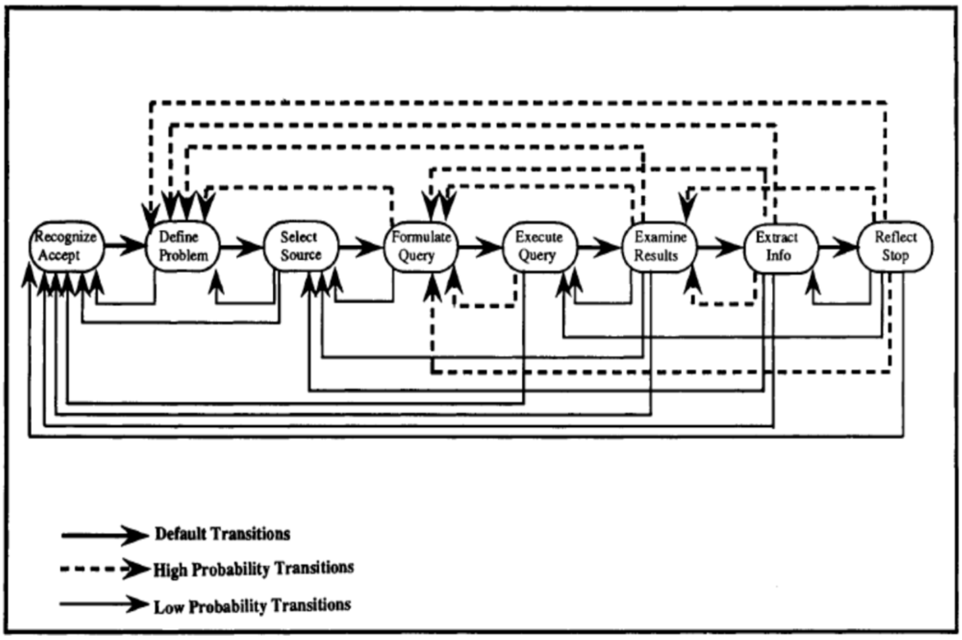


Figure 2.6: The information seeking process model proposed by Marchionini
(Source: Marchionini, 1997)

As illustrated in Figure 2.6, the following stages are involved in the information seeking process: recognise/accept; define the problem; select the source; formulate a query; execute a query; examine results; extract information; and reflect/stop.

- Recognise/accept knowledge gap:
  The first stage refers to the process of information seekers recognising and acknowledging gaps in their knowledge.

- Define the problem:
  As the second stage, defining the problem involves the process of narrowing down the problem. This can be achieved by different means, such as having expectations about what the problem may look like or what it may involve.

- Select source:
  Selecting the source is the process of deciding from where to obtain the information. The source may be a specific search engine or a journal.

- Formulate query:
  This stage refers to the process of constructing a query, based on the information seeker's understanding of the task to be submitted to the search engine. This process may be limited by the features of the search system being used.

- Examine result/s:
  This is the process of judging the relevance of the search results in terms of the information task.

- Extract information:
  This stage, which occurs once the information has been judged as relevant, involves extracting the information to use it in solving the problem.

- Reflect/stop:
  As the final stage, the set of relevant information is evaluated, in order to decide whether a new query needs to be formulated to retrieve more information.

2.3.2 Kuhlthau's model of the information search process

The information search process has been investigated as part of a set of broader task goals, as in the model proposed by Kuhlthau (illustrated in Figure 2.7).

Tasks	Initiation	Selection	Exploration	Formulation	Collection	Presentation
Feelings (affective)	Uncertainty	Optimism	Confusion, Frustration, Doubt	Clarity	Sense of Direction, Confidence	Satisfaction or Disappointment
Thoughts (cognitive)		Vague →		→ Focussed	→ Increased Interest →	
Actions (physical)	Seeking relevant information, exploring →				→ Seeking pertinent information, documenting	

Figure 2.7: The information seeking process
(Source: Kuhlthau, 1993b)

According to Kuhlthau (1993b), the information seeking process incorporates a comprehensive range of human thoughts and feelings and, as a result, emotions become involved in various stages of the process.

In the beginning, the user's awareness of a lack of knowledge or understanding generates the emotion of apprehension. With apprehension and anxiety, feelings of uncertainty also emerge and acquire a central position in the information seeking process. The second stage of the process involves the identification and selection of the topic to be investigated to gain specific knowledge. A delay in selection intensifies anxiety and apprehension, which, in turn, increases the level of uncertainty. The third stage involves an exploration of the knowledge, which is the most challenging stage for users, in that it involves feelings of confusion and uncertainty. Two forms of uncertainty are involved in this stage. – The first is related to the subject of knowledge, while the second relates to the effectiveness of the methods used for gaining the knowledge. The fourth stage is formulation, which involves a metamorphosis of the user's emotions. Clarity of focus is achieved and the increase in knowledge on the subject generates confidence, with the rise of which uncertainty diminishes. The sixth stage involves a presentation when the task of searching has been completed and the problem has been resolved. In this stage, the user experiences emotions of satisfaction and confidence (Kuhlthau, 1993b).

In the perspective of Kuhlthau (1993b), the overall information seeking process involves the generation and de-generation of a range of emotions at different stages of the process, such as anxiety, apprehension and confusion, excitement to explore new knowledge, confidence, happiness and disappointment. With the involvement of different emotions, the level of uncertainty is also influenced at every stage. Kuhlthau (1993b) observes that uncertainty is a cognitive state that leads to the generation of emotions of confusion, frustration and loss of confidence among users.

2.3.3 Wilson's problem-solving model

Wilson (1999) proposes the problem-solving model (Figure 2.8), which also emphasises the significance of uncertainty in the information seeking process. The model illustrates why people engage in information seeking.

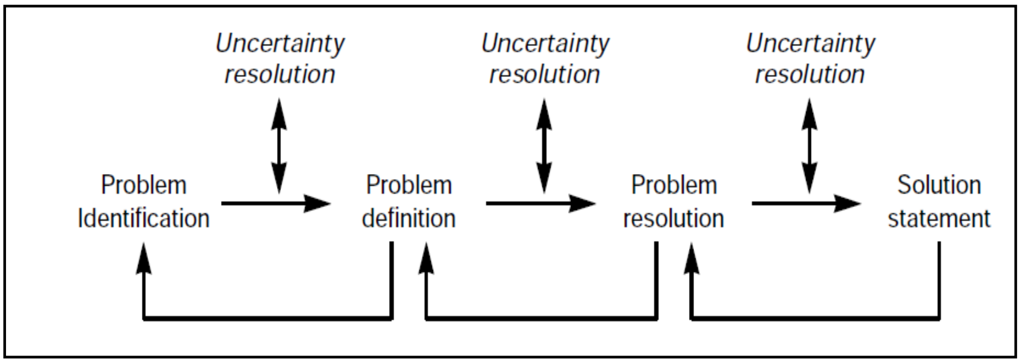


Figure 2.8: The problem-solving model of information seeking
(Source: Wilson, 1999)

According to Wilson's model, the goal of an individual during problem-solving is to solve a problem and to progress from being uncertain to certain – a process that can be achieved in the following four stages: problem identification, problem definition, problem resolution, and solution statement. In the first stage, problem identification, a person aims at determining the nature of the problem. The problem definition stage involves formulating specific terms for the problem. In the problem resolution stage, when an individual has a clear definition of the problem, they seek to find ways to solve it. Having solved the problem, the final stage is to present a statement of the problem solution.

The model considers that information seeking can occur at each of these stages. To move forward from one stage to the next, the level of uncertainty has to be reduced. In other words, when users discover new information and they are not able to resolve the problem at one of the stages, their level of uncertainty increases and they move back to the previous stage.

Regardless of whether research in information retrieval takes the concept of uncertainty into account, it is always a factor hindering information seeking and retrieval (Wilson, 1999).

2.4 External representations

This section focuses on the effect of external representations in sensemaking, as it is central to the argument presented in this thesis. The section starts with a brief review of the effect of external representations in general, after which a review of the studies and tools that investigate and support the effects of external representations in sensemaking are reviewed. Finally, external narrative representations are explored.

2.4.1 Significance of external representations to cognition

According to Zhang and Norman (1994, p.89) *external representations* can be "physical symbols, objects, or dimensions (e.g. written symbols, beads of abacuses, dimensions of a graph, etc.) and as external rules, constraints, or relations embedded in physical configurations (e.g. spatial relations of written digits, visual and spatial layouts of diagrams, physical constraints in abacuses, etc.)". The importance of external representations has been widely emphasised by previous researchers in the context of cognition. Some researchers argue that representations aid cognition differently, based on how these representations visually encode information.

For example, Larkin and Simon (1987) compared the effect of two different types of information representations (linear and diagrammatic representations) on the process of problem-solving in Mathematics and Physics. Linear representation involves translating a problem into a simple natural language, whereas diagrammatic representation provides a representation of a problem based on location relationships. The researchers measured the difference between the two representations by evaluating the performance of a computational model after applying both representations to it. The results of the study confirmed the hypothesis that different types of representations affect performance in different ways. The two representations resulted in differences in both searching for elements and pattern recognition. It was established that linear representations only helped in search elements, while diagrammatic representations helped in both search and pattern recognition. Although the study conducted by Larkin and Simon (1987) did not investigate the effect of the user's generated representations, it does shed light on the possibility that it could also be true for the user's generated representations.

Similarly, Stenning & Oberlander (1995) suggest that graphical elements within external representations shape the type of inferences drawn from them. Based on that, the researchers concluded that the use of diagrams is valuable in constraining the inferences that can be made of a particular problem. Information provided by the representations limits inferences, which results in more correct solutions. Therefore, coupling the graphical representations with the problems they represent may lead to more sufficient inferences.

Moreover, some researchers add that it is the form of the external representations – and not the amount of information they hold – that makes the difference when solving a problem. Larkin and Simon (1987) claim that it is the computational properties of diagrammatic representations – such as localisation, where related information is located in one group – that minimise the required effort for perceptual inference.

Similarly, Zhang and Norman (1994) compared the use of Roman numbers and Arabic numerals in solving the same multiplication tasks. They established that, although the representations had a similar structure, the decimal system made the use of Arabic numerals easier, compared to that of the Roman numbers.

Based on a review of the literature on cognitive science, which examined the role of external representation, Scaife and Rogers (1996) propose an approach for the explanation of cognitive processing. They suggest three essential aspects of external cognition, which can be used to explain the cognitive processing and that make external representations valuable. The researchers argue that the use of external representations may help to reduce computational offloading; may improve the structural properties that enhance the informational processing mechanisms; and may constrain the permissible inferences to solve a problem. Scaife and Rogers (1996) suggest that such aspects of external representation can be used as a guide in the design and selection of visual representations to solve a particular problem.

Other researchers attempted to understand the role of external representation by explaining its relation to the internal representation (mental models). Although their study focused on the use of external representations in problem-solving, Larkin and Simon (1987) suggest a possible relationship between the diagrammatic representation and some cognitive aspects, but they limit their emphasis to mental imagery. They argue that, similar to diagrammatic representations, mental imagery has localisation characteristics that promote perceptual inferences.

In a series of empirical studies, using isomorphs of the Tower of Hanoi problem, Zhang and Norman (1994) also focused on the interaction between external and internal representations. Their findings summarise the importance of external representation in terms of three key attributes: it promotes memory aids; it provides clues of how to solve a problem (affordance) without explicit interpretation; and it anchors and constrains the cognitive behaviour by its graphical structure. The results also suggest that, compared to internal representations, external representations are capable of changing the nature of the problem they represent in a way that makes solving the problem easier.

Another approach that stresses the role of external representations to cognition is distributed cognition. The construct of distributed cognition refers to the exploration of the cognitive processes beyond the known capacity of human internal memory to incorporate the environment, artefacts, social interactions, as well as culture. Norman (1993) claims that, when performing daily tasks, information distributed in the world is as fundamental as information in the mind.

Unlike traditional approaches, which view cognition as a confined process that occurs in the mind only, distributed cognition views it as a process that is shared across objects. The distributed cognition approach is generally considered as having been developed by Hutchins, who studied cognition from an anthropological perspective. Hutchins (1995) argues that, when studying cognition "in the wild", it should be viewed as a non-individual phenomenon that does not only occur internally in the mind, but also as a process that is embodied across artefacts.

Hutchin used the distributed cognition theory in different examples to illustrate how distributed cognition functions beyond an individual's mind by encompassing people's coordination and their utilisation of materials and resources. For instance, Hutchin (1995) used the distributed cognition theory to explain the coordination and cooperation between the crew members and the different structures in the system of an aeroplane, indicating that the cockpit system and the pilots' memory cannot work in isolation, as they complement each other. Remarkably, an aeroplane has many devices that cooperate and coordinate to make a flight effective. For example, the speed bug is one of the systems in an aeroplane that forms part of the memory functional unit. According to Hutchin (1995), distributed cognition is socially disseminated in the cockpit: the system allows the cockpit to accommodate two pilots, who work closely with each other for complementation purpose, such as reading speeds at various intervals, reading the altitude of the flight, as well as notifying the crew of their locations.

Kirsh (2010, 2009) explains the different ways in which external representation enhances cognitive power. One of the significant benefits of externalisation is the ability to share the structure as an object of thought. Kirsh (2010, 2009) also posits that external representation results in the reorganisation of pieces to simplify complex relations. Regardless of the complexity of the structure or problem, physical representation remains relatively stable. This interpretation informs Kirsh's argument on physical persistence and independence as another advantage of external representation over the internal mental processes. It implies that information remains independent of the authors, thereby improving consistency and exposing unanticipated consequences (Kirsh, 2010).

In terms of the importance of the role of external representation in improving cognitive power, Kirsch further emphasises reformulation and explicitness. He demonstrates that, unlike the internal representations, external representation provides a more straightforward approach to complex problems, which improves the individual's ability to manage vast amounts of information. Kirsch also points out the role of external encoding, which allows for the manipulation of the elements of thought, thereby making it more valuable. Other benefits of external representation, such as enhancing a person's ability to interact with multiple representations and to promote construction and tools, form part of the way in which Kirsh advances the arguments for external representations. He concludes that the efficiency associated with external representation results from an individual's ability to control the internal interaction processes.

Wright, Fields and Harrison (1996, 2000) propose an analytical framework to analyse human computer interaction, based on the literature on distributed cognition (DC). The framework, which is known as the "resources model", centres on two main concepts: the characterisation of information structures or resources, and the way in which these resources can be used to inform action – i.e. "interaction strategies". The proposed model focuses on external representations that help users to achieve a task and not external representation created by the user to construct an understanding. For instance, instead of having the tasks in the user's mind, it can be represented on interfaces in different abstract information structures, such as plans, goals, possibilities, history, action-effect relations and states.

The main argument of the model developed by Wright, Fields and Harrison is that, when evaluating and designing interactive interface systems, the relationship between devices, representations and actions should be considered. Effective interaction strategies can be achieved by using a specific structure of resources. On the other hand, a particular structure of resources constrains the types of interaction strategies that can be applied on them (Wright, Fields & Harrison 1996, 2000). For example, allowing the user to create a plan structure (write a list) without the ability to perform the right interactions strategies, such as crossing the completed tasks in the plan structure, will eliminate the usefulness of the interface and, in complicated information structures, it results in errors. A framework that considers the role of distributed cognition can provide a better analysis framework for different complex activities than the traditional approach in human-computer interaction in which the human role – e.g. visualising and interacting with information – is central to the process (Liu, Nersessian & Stasko, 2008).

2.4.2 External representations and sensemaking

In the sensemaking process, external representations can either be created manually, e.g. by taking notes, or with the help of automated visualisation systems, such as visual analytics tools.

Rooney, Attfield, Wong and Choudhury (2014) make the same distinction between user-generated representations, or what they referred to as "user-structured spaces" which allow the user to manipulate entities in a free-form space and define relationships between them, and "system-structured spaces", which concern discovering the relation between entities through the help of some computational model. The user-structured spaces are tools used for externalising users thinking, such as capturing interpretations and ideas. Such a process is beyond what can be discovered computationally form the data.

Thomas and Cook (2005, p. 4) define *visual analytics* as "the science of analytical reasoning facilitated by interactive visual interfaces". The core of visual analytics is to assist users in discovering hidden patterns in the data (Nguyen, 2017) by integrating interactive visualisation and automated analysis of the datasets (Keim, Andrienko, Fekete, Görg, Kohlhammer & Melançon, 2008). Keim, Kohlhammer, Mansmann & Ellis (2010) developed a process model for visual analytics according to which the visual analytics process is a loop of interaction between users, data, visualisation and automatic models aimed at leading to new insight. The use and development of visual analytics systems have been widely investigated. For instance, some of the previous research (e.g. that of Munzner, 2014) provides a descriptive account of visual channels and the different interaction techniques that can be applied when designing visual analytics tools (e.g. Dix & Ellis, 1998; Kosara, Hauser & Gresh, 2003; Keim, 2004; Wilkinson, 2005).

The scope of this thesis is limited to the effects of representations created manually by individual sensemakers to externalise their thinking in the process of sensemaking, such as users taking notes or creating timelines, maps, or tables to represent their thinking. Therefore, visual analytics literature that focuses on the "system-structured spaces" only was not regarded as relevant and such literature was not included in this thesis.

The sensemaking process consists of different activities, such as data extraction and the creation of representations. Putting information into a structure is important to the sensemaking process. The significant role of creating representations has been emphasised in previous sensemaking models, such as the notional model of sensemaking, the learning loop complex theory and the data-frame theory of sensemaking.

In the learning loop complex theory, *sensemaking* is defined as "the process of searching for a representation and encoding data in that representation to answer task-specific questions" (Russell et al. 1993, p. 1). In this theory, sensemakers search the data to build an initial representation, in order to make sense of the domain. The initial structure is used to select the data that fits into it. New data that does not fit into the frame may result in shifting and changing the frame. Russell et al. (1993) ran a series of studies of people using external representation in different contexts, including a laser printer training course, an algebra course for high school students and intelligent analysis. They found that part of the significant role of external representations centres on the ability of changing and shifting the created representations, which helps to reduce the cost of information processing.

External representations are also central to the notional model of sensemaking of Pirolli and Card (2005). The model shows that, in a stage called "Schematize", the analyst uses the data from the "Evidence File", in order to structure a representation to aid the analysis process. Pirolli and Card (2005) suggest that, at this stage of the intelligent analysis, sensemakers can be supported with computer-based tools that enable them, for example, to organise event chronology or to sort events into themes to create sub-stories.

Zhang and Soergel (2009) propose an analytical framework that links the iterative process of sensemaking and activities with conceptual changes. As part of the approach to develop the information seeking and sensemaking model from the synthesis of existing research works, the researchers focus on theories and models from different areas, such as sensemaking models and cognition and learning theories. Although the creation of the new model is the primary outcome of the study, it also demonstrates the importance of external representation as an assistant tool in understanding vast amounts of information. The framework encompasses three main factors that can be considered when examining the sensemaking process of the users. These factors are the sensemaking activities, such as creating external representations; the conceptual changes; and the cognitive mechanisms. Zhang and Soergel (2009) suggest that the early stage of sensemaking is mainly affected by two sub-loops in which sensemakers engage: the structure loop and the data loop. The outcome of the sensemaking process involves the sensemaker changing the conceptual structure by means of accretion, tuning, or restructuring, which are processes that Zhang and Soergel adopted from other learning models. Zhang and Soergel (2009) argue that people perform sensemaking activities, including the creation of an external structure, based on the status of their current knowledge of a domain of interest.

Besides the theoretical works, which emphasise the importance of external representations in the sensemaking process, some researchers have conducted qualitative empirical studies into the different aspects related to the phenomenon. These qualitative studies include the type of representations people create during sensemaking tasks, strategies and approaches they follow, and the way in which the use of external representations helps or hinders the process of sensemaking.

Previous research shows that sensemakers use different sources to create external representations when performing sensemaking tasks. For example, Qu & Furnas (2005) conducted a study in which participants took notes and created outlines while conducting an online search. Based on a qualitative analysis of interviews and an analysis of the created representations (notes and outlines), the researchers established that participants used the following two types of resources when creating representations:

- The information they encounter during the search session from a resource or part of a representation that has been created by others; and
- Their prior knowledge.

Qu & Furnas (2005) observe that these results point to a close connection between external representation creation and information seeking, in that part of the created representations are driven from the collected information in the search process.

Likewise, Zhang and Soergel (2009) conducted a qualitative user study in which participants searched for information and externalised their thinking while performing various tasks in news writing and business analysis by using concept maps software and OneNote software. Zhang and Soergel (2009) found that participants adopted different strategies to create the external representations, based on their background knowledge, inferred from instructions provided in the task brief; followed a data-driven approach; and utilised information from representations created by others.

In a study involving intelligence analysts being required to visualise connections among facts and events within external evidence, Chin, Kuchar and Wolf (2009) established that analysts relied on their background knowledge most of the time. For instance, analysts, who created geosocial representations, reported that they relied on their knowledge of crimes usually being committed by people living in the neighbourhood where the crime took place. Therefore, they focused on externally representing connections and information about people in the area near the crime scene.

Baber, Conway, Attfield, Rooney, Kodagoda and Walker (2015) and Baber, Attfield, Conway, Rooney and Kodagoda (2016) indicate that experience forms the way in which sensemakers build, utilise and share representations. Baber et al. (2015, 2016) compared experienced military analysts to novices performing the same intelligent analysis task. The study revealed a number of differences between experienced and non-experienced analysts. For instance, inexperienced participants spent less time in editing the representations; they used the representations to help them to discover the data, such as finding links between people and places. They elaborated on the created representations at the end of the task, when they chose the more accurate explanations of what they discussed during the analysis to explain the created representations. Apart from the fact that they used the representations to discover patterns within the data, experienced participants used the representations to build a hypothesis, which was presented to their audience and investigated further during the session. In other words, they followed an abductive approach in their analysis. Experienced participants were being observed grouping around the created representations several times during the analysis to prepare for presenting their representations. In this process, they were elaborating and questioning the representations by discussing issues, such the plausibility of the story and the sufficiency of the supportive data.

Baber et al. (2016) suggest that, when designing tools to support sensemaking, the way in which these presentations are used, should be considered – a tool that proves to be successful in extracting data may not be useful for constructing hypotheses. Certain types of representations have been found to be preferred and more helpful in making sense of a particular domain. For instance, tools that help in providing an overview of the data give users a clear picture of what they have already covered in their search and identify topics that require more investigation, while detecting patterns, such as relationships that help users to build hypotheses (Yi et al., 2008).

In a study that involved participants creating a representation to track the changes of people and places over times, Kessell and Tversky (2008) established that participants preferred to represent information of people, places and time in tabular format.

Participants used rows to represent places and columns to represented times, while using coloured dots or lines to fill in the cells of information about people. The results of this study also indicate that most participants preferred the use of dots over lines, as they found using lines complicated and confusing, unless they represent a temporal meaning. These results are confirmed by Tversky (2010), who suggests that the use of external representations carrying multiple meanings, such as lines and arrows, may result in confusion.

In a study that involved the observation of lawyers during an e-discovery investigation, Attfield and Blandford (2011) found that, among the different representations, chronological representations created by means of spreadsheets were widely used by lawyers. The researchers suggest that, since e-discovery investigations are centred on building a narrative from the evidence, chronologies enable lawyers to track missing episodes and gaps in the narrative.

Chin, Kuchar and Wolf (2009) investigated the use and creation of external representations in the context of intelligent analysis. They reported that, during the first stage of the analysis, when the analysts had to collect evidence and judge its relevance, participants created simple external representations of the retrieved documents manually, e.g. by drawing graphs, to indicate the relation among evidence, organising evidence into groups, or by ordering them in spreadsheets, based on their relevance. Once the relevant documents had been retrieved and organised, participants created more complex external representations to find patterns, facts and information from the collected evidence, such as timelines of events. In some cases, participants created more than one graph, each with relationships among different facts, such as graphs containing information on people and topics and others containing terrorists and topics. Some participants also supported the graphs with chronological representations.

Passmore, Attfield, Kodagoda, Groenewald and Wong (2015) recommend externalising thinking in a thematic form during the early stages of sensemaking, when sensemakers are confused and uncertain about the data. Externalising thinking, in the form of argument and narrative, is recommended at the advance levels of the sensemaking process, when sensemakers' thinking is more focused and specific.

Abraham, Petre and Sharp (2007) investigated the process of sensemaking and interacting with complex tasks when using online information sources. Participants, who used an online search engine to make sense of a new topic, were provided with Microsoft Notepad, Microsoft Word and pen and paper to create external representations while performing the task. The analysis of audio and video recordings that were collected during the study showed participants using the provided tools to create two types of representations: conceptual representations, such as creating connections between concepts, and planning representations of what to do next, such as adding titles and sections of the information requiring further investigation to Microsoft Notepad. The researchers suggested that, when following data-driven strategies, participants used external representations as a planning strategy when they were drawing on their background knowledge, while they were creating a conceptual external representation.

In their think-aloud study, Haider, Seidler, Pohl, Kodagoda, Adderley, and Wong (2017) indicated cognitive strategies that intelligent analysts follow when making sense of a domain. The researchers illustrate how each strategy can be supported as follows:

- Obtaining an overview through the identification of trends and changes within the data;
- Obtaining new knowledge by identifying patters and connections in the data;
- Elaborating and developing new understanding by finding similarities and differences and grouping data based on those; and
- Increasing certainty by eliminating non-relevant data.

In their research, Zhang and Soergel (2009) found that participants externalised their thinking in different ways to serve different purposes, even when they used the same tool that constrained external representations into a specific type (concept maps). Some participants used concept maps to create a simple external representation to help them to draw an overview and a bigger picture of the story within the task, while others used concept maps as a conceptual account to find connections and to construct a story to build deeper understanding. Zhang and Soergel (2009) suggest that these variations in representation types result from the differences among individuals in terms of their experience in creating external representations by using such tools, as well as the differences in their thinking style. Therefore, external representation tools should be flexible and easy to use, in order to improve the outcomes of task performance and to support the different users' purposes.

The foregoing studies reveal the positive effect of external representations in the process of sensemaking. However, other studies suggest that external representations may result in limitations and may actually hinder the sensemaking process. For example, Russell, Jeffries and Irani (2008) report on the results of two studies of the way in which people use sensemaking tools when performing simple sensemaking tasks by using Google Notebook to take notes while browsing on the Internet and using a spreadsheet to collect and arrange data. The results of the analysis of 163 notebook samples showed that, although this tool is designed to support sensemaking, people used it to save information without performing any sensemaking activities, such as restructuring and reorganising of the saved information. The results of the analysis of 22 random spreadsheet samples showed participants performing some sensemaking activities and restructuring the information. Russell, Jeffries and Irani (2008) ascribe this to the complex design of Notebook, which does not match the task it is supposed to support. Therefore, the use of sensemaking tools with complex features and a high level of representational structure in a simple sensemaking task does not assist the sensemaking process. In fact, it may hinder it.

Chin, Kuchar and Wolf (2009) conducted a study that required intelligence analysts to perform a mock investigation of terror attacks, while allowing them to use the tools they would usually have used in intelligence analysis. These participants did not use any advanced tools; instead, they created manual representations by using pen and paper, or they used simple tools, such as Microsoft PowerPoint and spreadsheets. Similarly, Mandel, Karvetski and Dhami (2018) found that some structured analytic techniques − in this case, analysis of competing hypotheses − failed to improve the quality of judgment of alternative hypotheses in intelligence analysis tasks.

The benefits of creating multiple external representations during sensemaking have been emphasised in some of the previous literature, such as using tools that allow users to externalise their thinking in multiple visual views, e.g. in timelines and themed grouping views.

Attfield and Blandford (2011) found that, when lawyers performed an e-discovery task, they created multiple structures at different stages of the process. This helped them to draw two kinds of focusing: data focusing, when they reviewed the evidence in light of the investigated legal case to determine its relevance, and issue focusing, when they reviewed the case in light of new evidence.

Zhang and Soergel (2016) conducted a qualitative investigation into the process patterns and conceptual changes in knowledge representations during sensemaking. Some participants reported on using two tools at the same time – concept maps and OneNote – when creating representations of the domain as being useful in aiding them to recognise their existing gaps knowledge. Kirsh (2009) states that interacting with multiple representations may lead to explorations that may not be attainable when using one type of representation. In a collaborative intelligent analysis task, Baber et al. (2015, 2016) established that participants created multiple representations, as the process of intelligent analysis is not straightforward and involves multiple explorations.

Similarly, Selvaraj, Attfield, Passmore and Wong (2016) report on an interview study of police analysts working on crime data, indicating that the creation of multiple representations at the different stages of the investigation process enabled them to discover gaps and to conduct further research. It also helped them to construct a narrative of what had occurred. The result of the study indicates analysts breaking down the investigation process into think-steps and using multiple representations. During the preparation phase, when analysts were dealing with new cases, they put the information of the new cases into context by creating concept maps representing entities involved in similar cases occurring in the past. During this phase, the analyst also represented information from the current case, such as time and location in tables. In the analysis phase, they constructed representations from the preparation step in the form of Excel spreadsheets, Word documents, or charts. The police analysts made sense of the crime data by iteratively querying information resources and by using the resulting information to construct elaborate link charts and timelines for the generation and testing of hypotheses.

Padilla, Methven, Robb and Chantler (2017) investigated the way in which people organise information when using concept maps. In the study, each participant created a concept map of a list of ideas provided by the researchers. Follow-up interviews showed that participants, who created concept maps with more than one relation, such as narratives representations and themed grouping representations of ideas, were confident to recall information and to explain their representations to others. On the other hand, participants, who created only a narrative representation, reported their concept maps as being challenging to understand by others, although they felt that the representations helped to make sense of the domain. The study also shows that participants, who created single block representations in which all ideas linked with a single connection, found it challenging to recall information or to explain their representations to others.

However, Rau et al. (2017) suggest that using multiple representations is insufficient, unless it is combined with connection-making support that sensemakers can use to make sense of the content of the representations, while, at the same time, improve fluency during the whole process, in that sensemakers can make rapid and effortless connections between the multiple representations. Similarly, Zhang and Soergel (2009) suggest that using different tools to create multiple representations is only useful when there is integration between these tools. They found that, when provided with two tools in the performance of sensemaking tasks, some participants used only one tool, as they found that the use of two tools might result in repetitions of the information.

The effects of using external representations created by other sensemakers and their impact on the process of sensemaking have been investigated by some scholars (Sharma 2010). They have established that the use of external representations provided by another sensemaker may result in some benefits, such as reducing confirmation bias.

In a controlled experiment, Sharma (2011) examined the impact of the use of external representation (notes and outlines) with different levels of articulation, prepared by previous participants, who worked on the same topics. The representations differed in terms of their "maturity" and – measured by the amount of time it took the previous participants to produce them – it could be concluded that, the more time the user spends on creating a representation, the higher the maturity level of the representations. Sharma (2011) established that notes and outlines produced at the beginning of the sensemaking task are less useful and articulated than those produced towards the end of the process are. Participants in the control experiment were divided into two groups: one group was provided with a representation that was produced by others within the first ten minutes of the sensemaking process, while the other group was provided with a representation that was produced by others after 50 minutes of the sensemaking tasks. The results show mature representations being rated better than less mature ones. The results also show that the mature representations (produced within 50 minutes) were more helpful to participants and were used by participants more during the sensemaking process. However, participants relied on them and performed smaller numbers of sensemaking activists, such as structuring.

Fisher, Counts and Kittur (2012) conducted a study in which they examined the use of external representations created by others during sensemaking. The study consisted of two stages. In the first stage, a group of participants created representations while planning a trip. During the second stage, new groups of participants performed the same task by using the representations created by participants in the first stage, each under a different condition. A group of participants was asked to use and add more structure to representations created by only one user in the first stage of the study, while another group of participants was asked to use and add more structure to representations that were created iteratively by multiple users in the first stage. The results, based on self-rating, showed that participates who used the iterated external representations created by multiple previous users, reported less cognitive effort to perform the task and a higher quality in sensemaking as represented by the representations they produced. However, the time that people spent was similar under the three conditions. The study also showed that participants, who used representations created by one user, preferred to search for information themselves, before using any information form such representations.

Although such studies show the benefits of external representations or what Fisher, Counts and Kittur (2012) refer to as *distributed sensemaking*, such representations may result in some challenges. Kang, Kane and Kiesler (2014) conducted two experiments to analyse participants' performance in solving a complex task involving a serial killer. The experiments had two conditions: in one condition, participants externalised and shared their thinking with other participants, while, under the other condition, participants did not share their representations with others. The researchers also examined the impact of the information quality provided by an analyst to another under both conditions. The results showed that participants, who used collaboration tools, performed better than those who did not. However, the performance of participants, who used collaboration tools and received irrelevant or inaccurate information, was lower than that of those who did not use any tools. Kang, Kane and Kiesler (2014) determined that participants perceived inaccurate information provided by their colleague positively when they received it via collaboration tools with advanced features. In this way, sharing notes via such tools may misguide the users and lower their performance. Kang, Kane and Kiesler (2014) claim that, although tools designed to assess organisation and summarise information to overcome the challenges of information sharing may prove helpful, their importance depends on the accuracy of the information provided by a team member. For instance, the meaning held by the representations may be vague, or they may be an elaboration of the representations originally created (Qu & Hansen 2008; Jaasma, Van Dijk, Frens and Hummels, 2017).

In some sources, external representations were found to be helpful in collaborative settings in which a group of sensemakers work collectively to make sense of a domain and to create external representations to achieve a shared understanding. Jaasma et al. (2017) conducted a study in the context of multi-stakeholder collaboration in which participants used an interactive tool to make sense of a public issue. The study concluded that the final representations created by participants were not fixed narratives of the domain; they were representative of the conversations occurring among participants during the sessions. In other words, representations were used as scaffolds to start conversations between group members and they made conflicting interests among the participants debatable, as they were explicitly presented (Jaasma et al., 2017).

Garreau, Mouricou and Grimand (2015) also found that, in collaborative sensemaking of practitioners working in shopping centres, representation construction helped them to persuade one another with their points of views. The researchers also found that participants used the representations to brainstorm ideas. The findings of the study showed that practitioners' discussions fell behind in general ideas when they did not use representation.

Similarly, Baber et al. (2015, 2016) conducted a study in which participants, who were provided with tools such as whiteboards, notepads, pens and paper, performed collaborative intelligent analysis tasks. The findings showed that the participants created basic representations that were mostly used for discussions.

Faily, Lyle, Paul, Atzeni, Blomme, Desruelle and Bangalore (2012) investigated the use of concept maps in collaborative sensemaking in the context of software engineering and improving requirement quality. The researchers asked a group of developers to update the requirements specifications of a particular program (software). The developers first met and agreed on general ideas, after which they worked individually, with each of them developing a concept map. Participants met again and gathered all the concept maps into one diagram. The results showed that the ability to move and link concepts helped the developers to become more confident to make value judgments and justify them. Participants reported that the more the concepts were added over time in the shared concept map, the less complicated the task became. However, the use of external representations in collaborative sensemaking may result in some issues. The three results of the study indicate that combining the concepts maps into one shared concept map was cognitively challenging and time-consuming, as most of the time was spent on dissections. Therefore, to minimise effort and time, some participants eliminated concepts that were essential requirements, thereby loosing significant concepts. De Vries and Masclet (2013) indicate that the creation of basic representations in collaborative sensemaking that cover general concepts only may lead to losing important information, while the results of complex representations may be confusing.

In a study that involved students creating shared arguments by using an online tool, Niebuhr and Pinkwart (2012) found that students felt lost and confused as time progressed and argument maps became more complex. Qu and & Hansen (2008) recommend sensemakers sharing and discussing external representations during the sensemaking – not at the end of the process – in order to perform better in collaborative sensemaking.

Other researchers interpreted sensemaking as a form of distributed cognition (Hutchins, 1995), referring to the process as *distributed sensemaking*. Accordingly, the unit of analysis for understanding and explaining sensemaking is extended beyond cognition “in the head” to incorporate representations supported by external artefacts and interactions with these during the sensemaking process, as well as distribution across social groups where applicable. Explaining the role of external representations played an essential role in these studies. Understanding how external representations, created and developed from a distributed cognition viewpoint, is essential in the design of better visualisation tools (Liu, Nersessian & Stasko, 2008).

An example of these studies is the work of Attfield et al. (2015) and Wheat, Attfield and Fields (2016), which was part of broader study into distributed sensemaking. The researchers observed and interviewed intelligence analysts in a military context. In an initial analysis, Attfield et al. (2015) suggested that the characteristics of the entire distributed sensemaking system were influenced by the characteristics of the arrangement and layout of the external representations that were used and the way in which users can interact with them. For instance, they found that, by externalising some information in printed tables and through certain properties of representations, such as the ability to eliminate some information and annotation, the analysts were able to make a judgement and track the eliminated and considered possibilities or hypotheses.

In a further analysis, Wheat, Attfield and Fields (2016) found that the analysts performed the analysis process as sub-tasks. In the performance of each sub-task, the analysts developed an understanding by using information within their external representations. When they moved to the next sub-task, their inference was shaped by the understanding they had developed while performing the previous sub-task. The combination of these insights helped them to develop a more coherent understanding at the end of the task. Wheat, Attfield and Fields (2016) also suggest that the following three characterisations of the representations should be considered to use external representations effectively:

- Physical features, which refer to the way the representations shape and materialise, so that the users can perform physical action on them, e.g. in a table that enable users to read information row-by-row;
- Semantic features, which relate to the meanings encoded within the artefacts provided for the task; and
- Pragmatic structuring, which refers to the meanings the participant ascribes to the representation while performing the task.

Attfield, Fields and Baber (2018) presented a framework for analysing sensemaking as distributed cognition. The framework elaborates on the data frame theory of sensemaking of Klein et al. (2007) by linking it to three types of resources –knowledge and beliefs; values and goals; and action. Knowledge and beliefs are concerned with the way things are; values and goals are concerned with the way things are desired to be; and action provides the means for redressing the gap. These resources can be distributed across multiple cognitive systems, such as people and external representations of a domain.

Some researchers have developed approaches to analyse and describe external representations created by sensemakers while performing sensemaking tasks. Such approaches may lead to interesting findings when investigating the relation between of type of representations and other variables.

For instance, Walny, Huron and Carpendale (2015) found a link between the type of external representations and the type of inferences driven from them. In their study, they asked participants to use pen and paper to draw sketches to describe a provided dataset. At the end of the task, participants explained their understanding of the dataset in written reports. The researchers then developed a way to analyse the types of sketches by describing the information within sketches. Based on their approach, sketches can be placed on a scale ranging from numeric to abstract. Numeric sketches occur when numerical or statistical information can be extracted from the sketches, such as bar charts, while abstract sketches occur when descriptive information, such as network graphs, can be extracted from them. Walny, Huron and Carpendale (2015) found that participants' written reports varied from reports capturing individual statements to describe the data to reports with a coherent statement that involved hypothesis building. The researchers also established an association between the way people sketch data and their understating of that dataset in the written reports: the more abstract the sketch, the more analytical they were, with analytical reports including hypothesis building.

Okoro (2014) and Okoro and Attfield (2016) developed an approach to analyse external representations created by users during investigative sensemaking. Their approach is based on the creation of an *ad hoc* visual language of graphical meanings, which they then aim to apply consistently. These visual languages incorporate visual embedding and can be described by using simple production rules, allowing representations to be characterised as a hierarchical parse tree (syntax tree). These parse trees (syntax trees) consist of entities that are embodied within other entities. This approach was adopted in this thesis, in order to analyse the external representations created by participants in the first (Chapter 4) and the fourth exploratory study (Chapter 5). More details about this approach are presented in Chapter 3.

Çakan Akkas, Sönmez and Kabataş Memiş (2018) opine that, when users apply sensemaking tools, such as argument maps, they gain higher-order thinking skills, as they explicitly represent their thoughts, which enables them to evaluate, criticise and correct them.

2.4.3 Tools that support sensemaking

Munzner (2014) opines that computer-based visualisation tools help users to perform tasks more effectively. A variety of tools has been developed to support the role and potentials of user-generated external representations in the process of sensemaking. Some of these tools have been developed to help sensemaking in a particular domain, e.g. tools that have been developed for intelligent analysis.

Some of the developed sensemaking tools impose a certain type of structure on users when externalising their thinking, in that they have to think of the task as an argument or a narrative. These types of tools emphasise one of the advantages of using external representations by means of leveraging the power of different approaches, such as leveraging the power of narrative. Other tools adopt a freeform workspace in which users can externalise their thinking in any way that helps them to make sense of a particular domain.

The following sections present examples of some of the tools that support user-generated representations – not visual analytics tools, where the visualisation is automated by models and algorithms.

2.4.3.1 ClaiMapper

ClaiMapper (Figure 2.9) is a sensemaking system developed by Uren, Shum, Bachler and Li (2006) to support researchers' sensemaking in performing scholarly tasks. The system allows users to build an argument and explain the relation of a document to other parts of the collected literature. Users can add objects into their created claim networks, including claims, concepts and data represented by nodes.

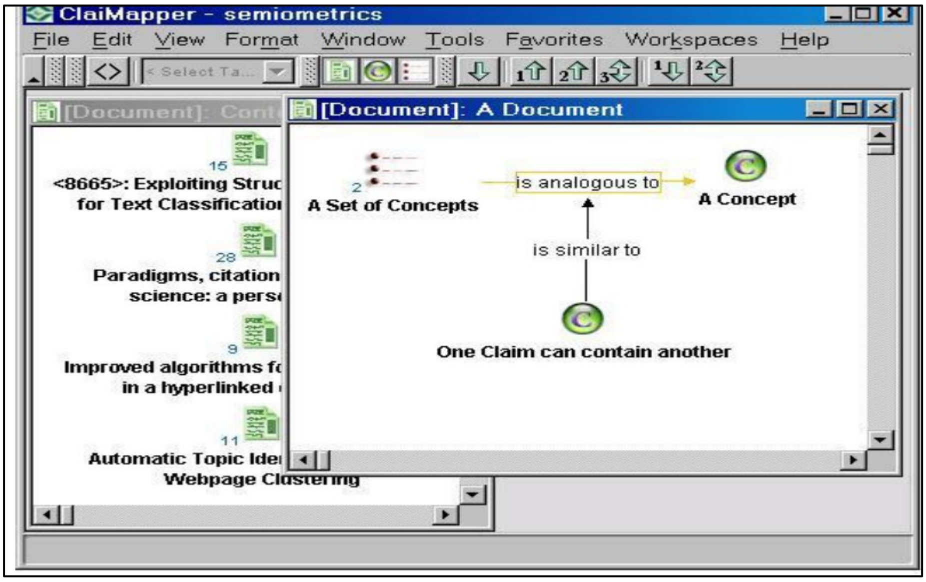


Figure 2.9: Screenshot of ClaiMapper showing concepts linked to one another by means of claims (Source: Uren et al., 2005)

One of the main features of the tool is the ability to create connections between the added objects by finding a connection between the information, which is key to sensemaking (Klein et al. 2006). Connections can be created by adding discourse relations provided by the system, such as: "is similar to" to express the similarity, or "is evidence" to support an argument. The tool also allows users to organise concepts in any other type of representations that they find helpful in externalising their thinking.

2.4.3.2 Sandbox

Sandbox (Figure 2.10) is another example of a basic computer-based sensemaking tool that supports both user-generated representations and automated analytical visualisations. The tool offers an evidence marshalling space, where analysts can visually externalise their thinking when working with complex data (Wright, Schroh, Proulox, Skaburskis & Cort 2006).

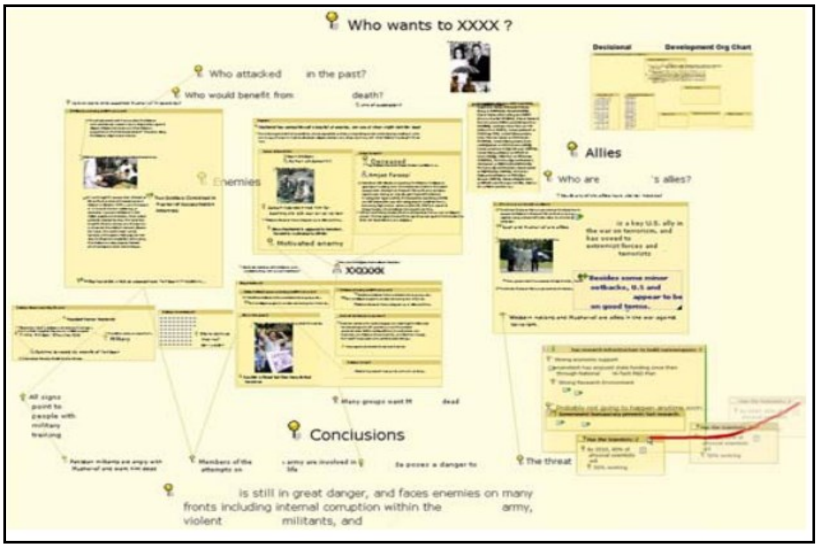


Figure 2.10: Screenshot from Sandbox showing competing hypotheses each supported by evidence (Source: Wright et al., 2006)

Analysts can easily drag evidence, references and notes to Sandbox. Notes are the analysts' hypotheses or their brainstormed ideas, whereas evidence refers to files, images, snippets and documents. The tool allows analysts to create links between the added entities and to organise and group them, based on themes and patterns.

Wright et al. (2006) suggest that Sandbox could enhance the performance and the quality of the analysis processes, in that it provides flexible environments and multiple task views, where analysts can work on more than one task simultaneously. According to the results of a usability and utility questionnaire reported by four analysts in an evaluation lab-based study, the tool enables analysts to perform analytical tasks to produce analyses of better quality in less time.

2.4.3.3 Polestar

Pioch and Everett (2006) developed Polestar (Figure 2.11), which is a visual analytic tool for intelligence analysts.

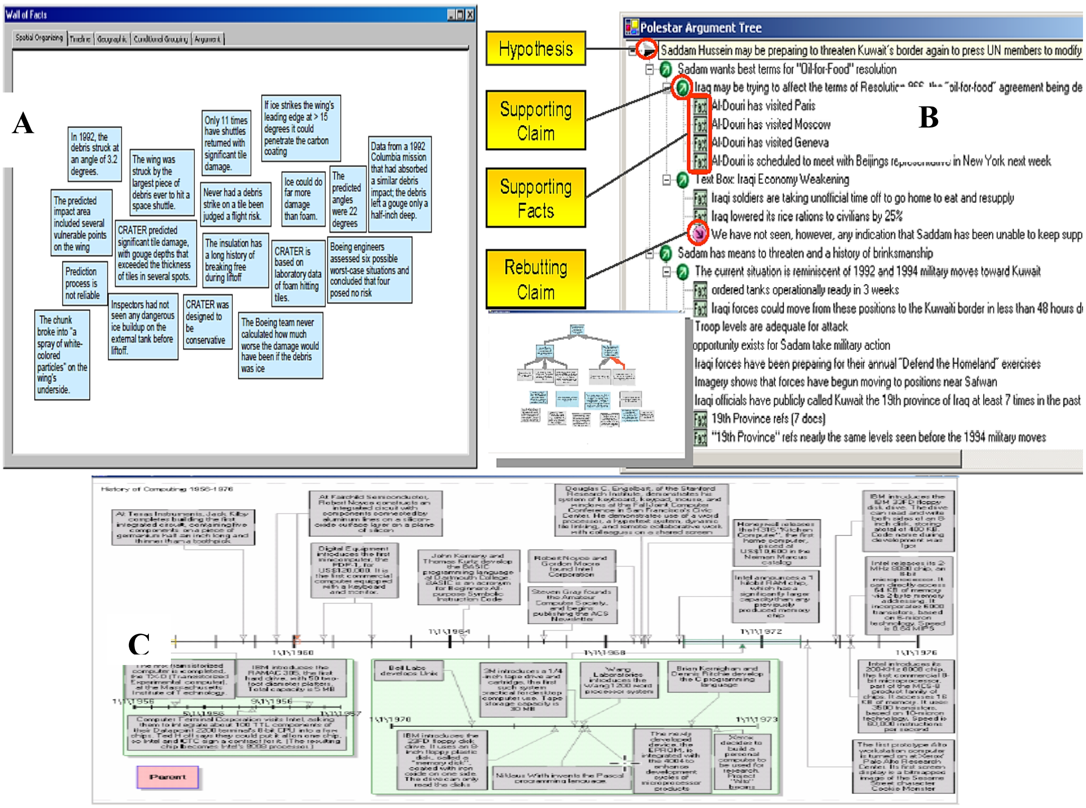


Figure 2.11: (a) The "wall of facts", where analysts can organise information spatially and create clusters; (b) The argument view where analysts can create arguments via a tree structure that consists of facts, claims and sub-claims and linked to documents; (c) The 'timeline view' where analysts can organise information chronologically (Source: Pioch & Everett, 2006)

Similar to Sandbox, the tool provides users with automated visualisations, as well as a manual visualisation space, where they can externalise their thinking in the following three ways:

- Freeform workspace (Figure 2.11a), where the analyst can drag and drop evidence into the workspace and manipulate and organise it in a way that helps their sensemaking, such as arranging documents in clusters based on their similarities;
- Argument view (Figure 2.11b), where the analysts can formulate hypotheses in argument structuring and organise evidence in a tree-like structure that consists of facts and claims and sub-claims, each supported by evidence form the dataset; and
- Timeline view (Figure 2.11c), where the analyst can track changes over time by arranging evidence into chronological order.

2.4.3.4 ScratchPad

Due to the enormous volume of the information on the World Wide Web (WWW), users need to perform multiple search sessions to build an understanding of a domain, which makes it difficult for them to track the context of the search (Krishnamurthy, Pham, Santos & Freire 2016). Gotz (2007) argues that tools designed to support sensemaking during an online search should enable users to organise the collected information to discover new insight.

Based on this argument and some observations of a user study on the analyst's use of pen and paper to take notes during sensemaking (Gotz, Zhou & Wen 2006), Gotz developed ScratchPad (Figure 2.12) – a tool to facilitate sensemaking tasks with features such as saving, arranging and displaying the collected information.

Figure 2.12: Screenshot of ScratchPad
(Source: Gotz, 2007)

ScratchPad provides users with a feature called "snapshotting" to save and manipulate the collected data, by allowing them to drag information they found while searching on the web and drop it into the workspace on the ScratchPad tool.

Any saved information – whether it is URL links, images or a fragment of a text – is represented graphically in the workspace as boxes. Users can manipulate the stored information by adding links between information they regard as relevant. This link un-link property was added to the tool to assist the sensemaking process through the discovery of relations between bits of information. Moreover, users can take notes and create representations from scratch, without using sources form the web.

2.4.3.5 CiteSense

Zhang, Qu, Giles and Song (2008) developed a tool to support users in building an understanding of the collected information in literature review tasks. Zhang et al. (2008) suggest that an integrated environment that supports the different tasks of information seeking and sensemaking can be of more assistance to users conducting a literature review in the research process. Based on this approach, the researchers built a prototype system known as CiteSense.

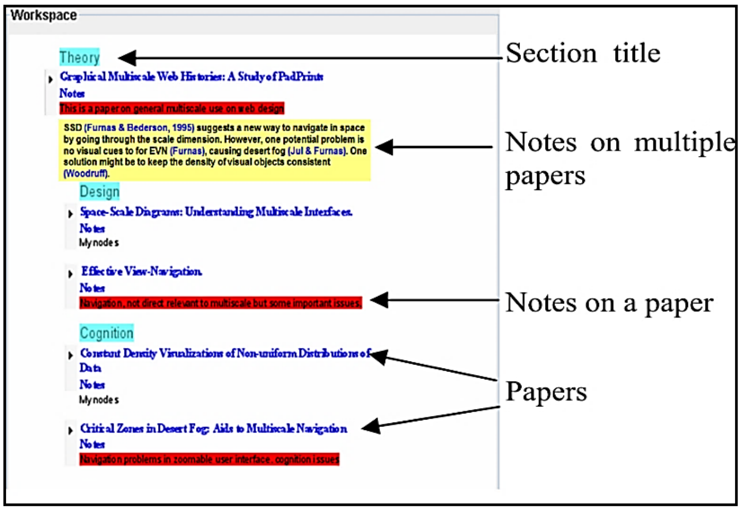


Figure 2.13: Screenshot showing notes and information collected by a user using CiteSense (Source: Zhang et al., 2008)

CiteSense provides users with features such as searching, filtering, citing and structuring knowledge. Similar to Sandbox, CiteSense integrates two visualisation views where users can externalise their thinking: a model-based visualisations view and a manual visualisations view. In the manual view, users can manipulate the collected information in a freeform working space. Information can be easily dragged and dropped into the working space, after which users can structure and organise information in a way that helps them to make sense of the domain. For example, users can spatially group information they regard as relevant close to each other to indicate that it belongs to the same cluster. The tool also allows users to take notes and write summaries of the collected papers. The added notes are highlighted, so that users can easily track paper annotations.

The notes can also be used to indicate relationships between papers. Zhang et al. (2008) suggest that the created notes and summaries grow as the task progresses, which may, at the end of the task, turn into a literature review report.

The prototype of the working space on the system was evaluated by seven graduate students and lecturers. They indicated that the flexibility of organising information helped to enhance the techniques of collecting and managing the literature. This allows users to represent their knowledge subjectively, which is vital in visualisation tools supporting the process of literature review writing, as researches approach the same topic with different aims and motivations (Faisal, Attfield & Blandford 2006).

2.4.3.6 Aruvi

Shrinivasan and Van Wijk (2008), who emphasise the importance of user-generated representations in an information visualisation framework, developed a system to support sensemaking in analytical reasoning processes. The researchers argue that, during analytical reasoning, analysts should be provided with tools that present data in three different views: a visual view of the data by using an interactive visualisation tool; a visual view of the process navigation; and a visual view of the analyst's knowledge.

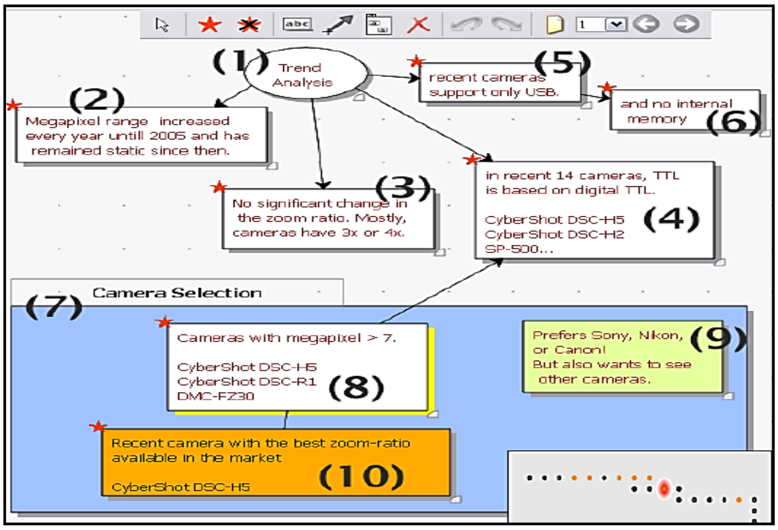


Figure 2.14: Screenshot of the knowledge view in Aruvi system
(Source: Shrinivasan & Van Wijk, 2008)

Their framework is also based on having a synchronocity between automated visualisations created by computational algorithms and the representations created manually by analysts. Analysts can externalise their thinking by taking notes of findings. Each added note is represented individually, either in a rectangle or an elliptical shape. Once created, they can be grouped into categories to build hypotheses and causal reasoning by using directed arrows to support or attack an argument.

The two researchers evaluated the usefulness of the approach in a user study by using the prototype Aruvi that had been developed for this purpose. The results of interviews show that the knowledge view plays an important role in the analysis process, as it helps users in gaining knowledge of data in the automated visualisation view. In a series of experiments in which students solved scientific problems, Trafton and Trickett (2001) found that note-taking not only helps students to recall what they have learned, but also to make sense of the information, while enhancing their problem-solving strategies.

2.4.3.7 StoryTree

Bhangaonkar, Chu and Quek (2016) proposed StoryTree (Figure 2.15) as a web-based system that promotes narrative thinking to support the process of writing an academic literature review.

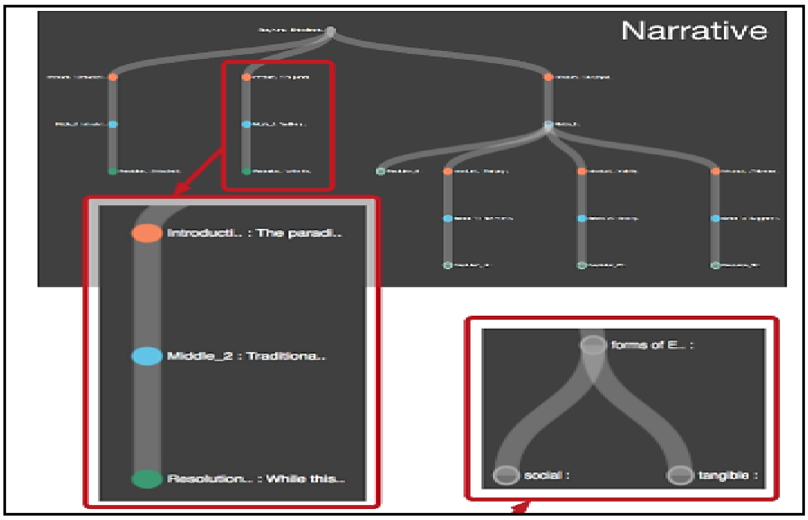


Figure 2.15: Screenshot of a narrative created by StoryTree tool (Source: Bhangaonkar, Chu & Quek, 2016)

By using the tool, users can create an external narrative in a tree-like representation. The tree representations are built by adding text fragments represented as nodes from the documents they regard as relevant.

Once the user has added a node to the tree, the system considers it as the beginning of a story and, in this way, narrative thinking is imposed on researchers. Hence, two nodes are automatically added, with one node the middle of the story and the following node representing the end of the story. Users can add information to these two nodes by being allowed to add new nodes. Bhangaonkar, Chu and Quek (2016) compared StoryTree to the traditional hierarchical structure provided by another tool by asking students to use both tools to produce a literature review report on a particular topic. The analysis of the produced reports showed that StoryTree does help the students to write reports with higher quality.

2.4.3.8 Coalesce

Coalesce (Figure 2.16), developed by Ryder and Anderson (2010), is another tool that supports sensemaking in the performance of individual web-based tasks. The tool consists of three main areas: a search area, where users can search for information on the web; a reading area to display the found materials, so that users can read the content; and a representation construction area called SenseMap to help users with the creation of external representations during sensemaking tasks.

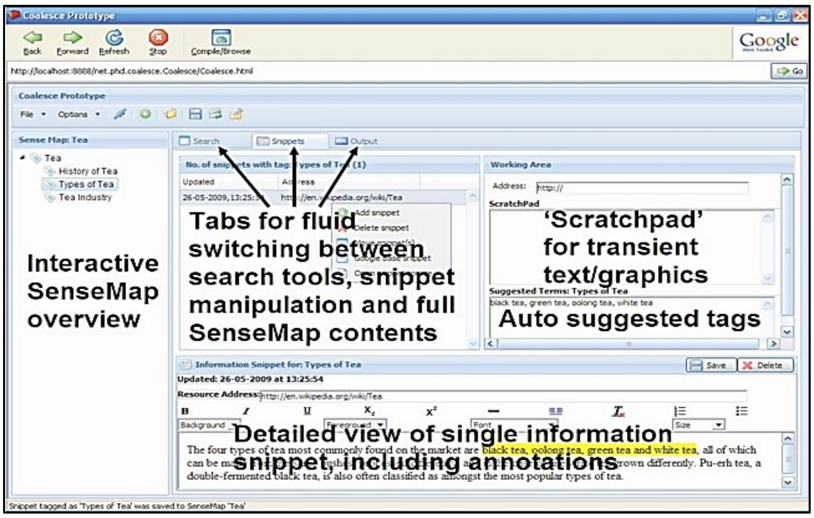


Figure 2.16: Screen hot of the SenseMap view in Coalesce system
(Source: Ryder & Anderson, 2009)

In SenseMap, users can generate a hierarchical structure of selected concepts that they have found in their searches. This type of structure was integrated into the tool to help users keep track of the relations between concepts in the search session. The evaluation of the tool, which was conducted by means of a user interface satisfaction survey, showed that the Coalesce prototype provides better support for sensemaking compared to Microsoft Word, which does not integrate searching, organising and sorting.

Concept maps are one of the external representation types that have been used to support the process of sensemaking. Part of the importance of concept maps stems from the assumption that they are explicit representations reflecting the user's mental model of a domain and that changes in the concept maps during the progress of the creation process change the user's mental model (Novak & Canas, 2006; Krishnamurthy et al., 2016).

2.4.3.9 INVISQUE

INVISQUE (Figure 2.17) is a tool that enables users to organise their knowledge to make sense in information searches. It allows users to manipulate search results in an interactive visual environment. Search results in INVISQUE are represented as physical index cards and, to make sense of the results, users can group the index card into themes. Unlike traditional search systems, which present the results in a one-dimensional list, the index cards in INVISQUE can be ordered in two dimensions determined by the user.

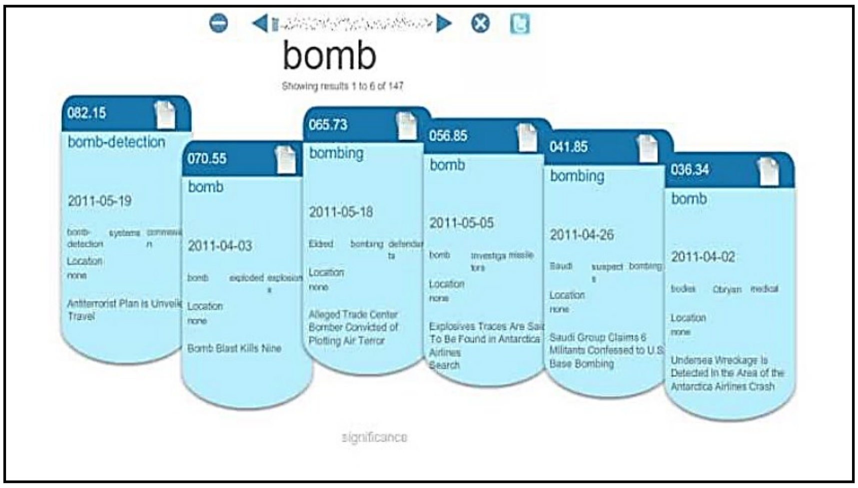


Figure 2.17: Screen shot of INVISQUE system
(Source: Wong et al., 2011)

INVISQUE also introduces the concept of an infinite workspace, where users can see the search results of unlimited search sessions in the same visual view (Wong, Chen, Kodagoda, Rooney & Xu, 2011). Choudhury, Brierley, Rooney, Xu, Chen, Wong & Atwell (2011) used the tool to solve one of the VAST challenges, where the task was to search in a data set of thousands of news articles to investigate a terror attack. Choudhury et al. (2011) found that the visual display of the search results sped up the investigation process and helped them to get a sense of what happened regarding the terror attack at an early stage of the process.

Kodagoda (2012) conducted an evaluation study to compare INVISQUE to a traditional web interface. She examined the impact of the functionality provided by INVISQUE on users' levels of literacy. The results demonstrated that the tool helps users with low literacy levels to spend less time when searching for online information and to reduce the number of pages they read. Kodagoda (2012) regards the decrease in both time and the number of pages as a positive result, because this allows users to spend more time on the other part of the search process.

Hearst and Degler (2013) suggest a number of design requirements that should be considered when designing tools to support saving and organising search results, particularly during the documents triage process. The researchers suggest that users should be provided with the following properties:

- The ability to create groups by tagging documents of interest in the search results while searching and to name and rename the created groups;
- A default template to create groups to save time, e.g. having boxes with the same size and fixed spatial order;
- A guideline of where and how to move and add objects within groups, e.g. a gird; and
- Multiple views of the query search box, the search results view and the documents organising view, all presented at the same time.

2.4.3.10 Prototype of Hearst and Degler

The design requirements by Hearst and Degler (2013) are actually close to a recommendation for designing less freeform tools to save the user time and effort. Hearst and Degler developed a prototype that covers most of these requirements and compared the prototypes to a traditional system displaying search results in a list view. They asked participants to rate the usability systems subjectively on a scale of 1 to 7.

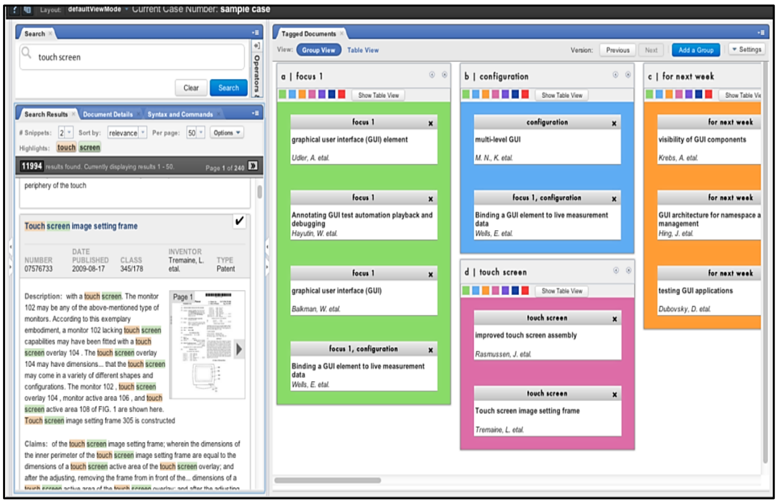


Figure 2.18: Screen shot of prototype developed by Hearst and Degler
(Source: Hearst & Degler, 2013)

Although the results show participants giving high rates for the prototype compared to the traditional system, the researchers may need to compare their prototype to tools that provide freeform document organisation.

2.4.3.11 SketchViz

Some of the developed sensemaking tools follow a simple approach by replacing pen and paper with electronic sketching. Such infinite freeform workspace allows seeing different viewpoints of the task at hand (Linder et al., 2015). An example of the freeform tools are tools that promote sketching, such as SketchViz (Figure 2.19), which was introduced by Brade, Sehl & Groh (2016) as a computer-based alternative to pen and paper in the thinking process.

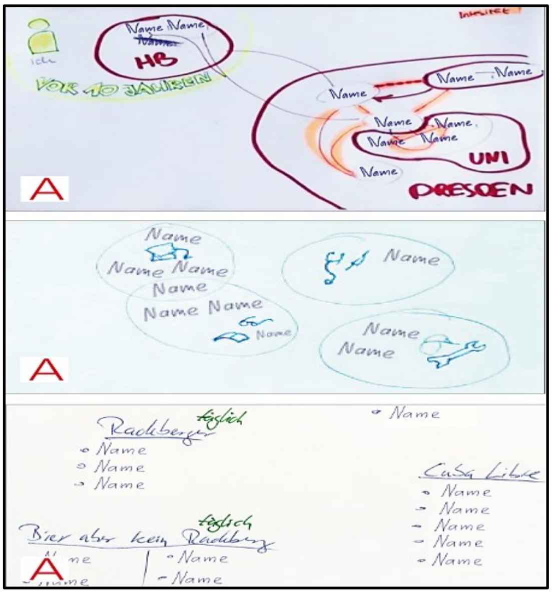


Figure 2.19: Screenshot of representations created by using SketchViz tool
(Source: Brade, Sehl & Groh, 2016)

SketchViz targets sensemaking in the early stage, when the created representations are changeable. It provides users with the ability to sketch representations, as if they were using pen and paper; the ability to use handwriting and line drawing (or other shapes such as circles) between objects to represent relations; and the ability to change the colours of elements in the sketched representations.

The aim was not only to simulate pen and paper usage, but also to overcome some of its limitations. For example, users can easily edit the representations by manipulating the size and position and deleting parts. The tool also enables users to see the big picture of the sketch they have generated, in that they can zoom in and out on objects. An evaluation showed that, among the different features offered by the tool, users appreciate the ability to revise sketches. The shift in the created representations was found as one of the important phases in the sensemaking process.

2.4.3.12 Jigsaw

Jigsaw (Stasko, Görg & Liu, 2008; Görg, Liu & Stasko 2013) is another visual analytic tool that considers the role of externalising users' thinking, apart from providing automated visualisation of the data. The tool aims at supporting the process of analysing and making sense of a set of documents. To support users in externalising their thinking, the tool offers a view tool called TABLET.

As illustrated in Figure 2.20, the view tool is a freeform workspace, where users can build hypotheses by adding entities (documents, people or places) to the workspace; moving the added entities; organising the entities; adding links between related entities; and taking notes.

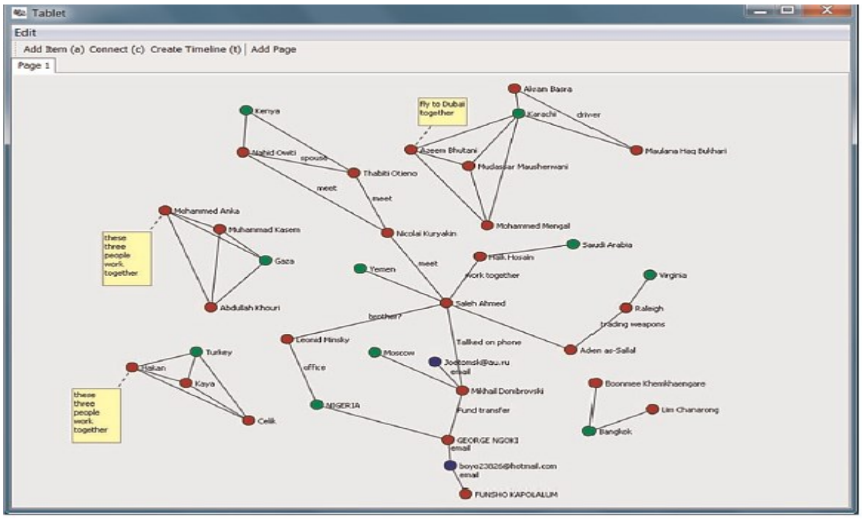


Figure 2.20: Screenshot of a social network in the TABLET view of Jigsaw, with red nodes representing people and green nodes representing place. The connection can be made between people or between places and people. The view also allows users to add notes
(Source: Görg, Liu & Stasko, 2013)

The view tool also provides users with a feature for the manual creation of a timeline of the added entities (Figure 2.21).

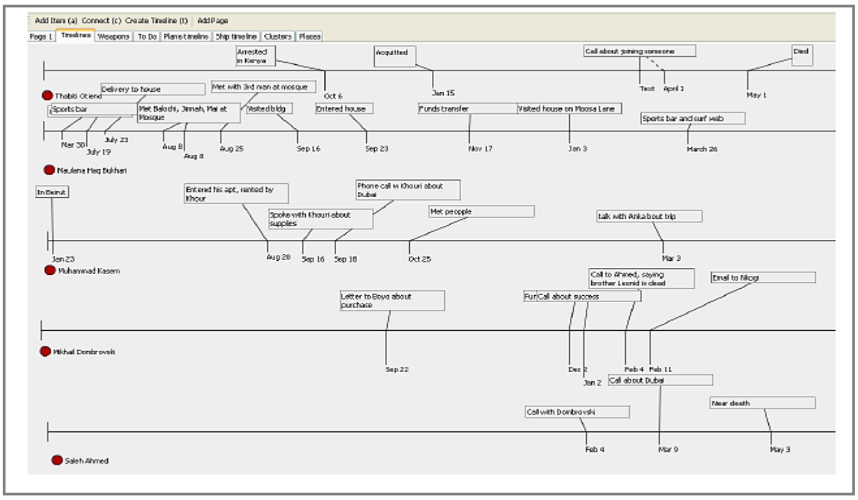


Figure 2.21: Screenshot of timelines in the TABLET view of Jigsaw, with each timeline representing the chronological order of the activities of a person
(Source: Liu, Nersessian & Stasko, 2008)

2.4.3.13 CISpaces

CISpaces is another example a sensemaking tool that supports users in externalising their thinking by focusing on supporting the collaboration between analysts (Toniolo et al., 2015; Cerutti, Norman & Toniolo, 2018). It provides analysts with two properties to create and share representations: AGENT-BASED, which provides support with automated analysis methods, and WORKBOX, which supports the manual creation of external representations. The WORKBOX window is a workspace where analysts can collaboratively add information that they have collected, e.g. from a dataset or an intelligence report, and where they can develop hypotheses and claims. Boxes represent information, hypotheses and claims. Analysis can create links between boxes to support or attack the additional information, hypotheses and claims (see Figure 2.22). The tool also allows analysts to take notes and to add more information to describe links between boxes.

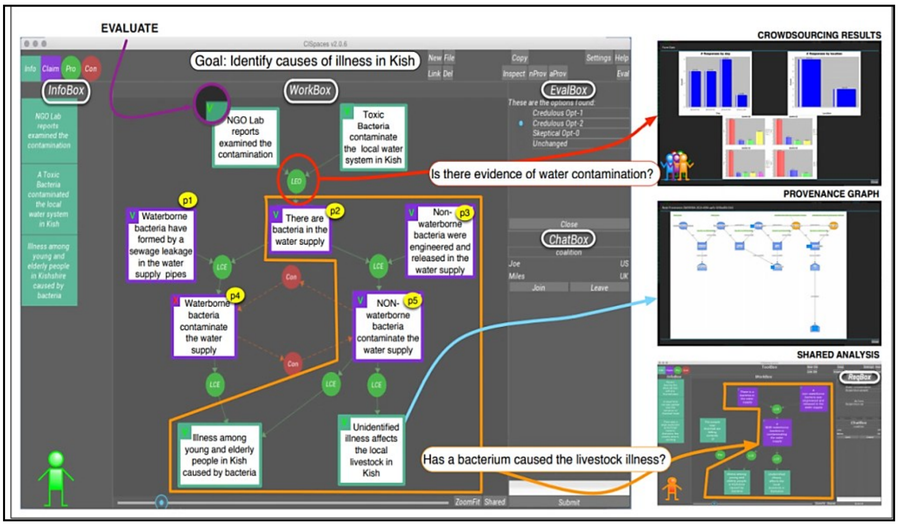


Figure 2.22: Screenshot of CISpaces
(Source: Toniolo et al., 2015)

2.4.3.14 Microsoft OneNote

One of the main features of Microsoft OneNote (Figure 2.23) is the ability to take notes. By using the tool, users can take notes in different simple ways, such as clicking and typing anywhere in the workspace; and adding notes from external resources, such as a PDF document or a website, by copying and pasting the selected fragment of texts into the workspace. The added notes can be moved, organised, highlighted and resized (Microsoft, 2020).

Microsoft OneNote also provides users with the ability to add different elements, such as documents, images and audio and video recordings and/or notes to the workspace. Moreover, users can insert web-based resources via links and can also insert different shapes to the added elements, e.g. lines and rectangles, by using the draw tap. Another advantage of Microsoft OneNote is that users can organise the added elements – such as notes, files and drawings – in a freeform workspace in any way that help them to perform the task at hand.

Previous research has shown that, during sensemaking tasks, sensemakers tend to create different types of external representations to serve different purposes. For instance, in the research conducted by Attfield and Blandford (2011), creating chronological representations was preferred when the task centred on building a narrative, in that it helped to track missing episodes and gaps in the narrative. Externalising thinking in a thematic form has been suggested as being more helpful during the early stages of sensemaking, as sensemakers are confused and uncertain about the data. On the other hand, creating an argument and narrative form of representations is more helpful when sensemakers' thinking is focused and more specific (Passmore, Attfield, Kodagoda, Groenewald & Wong, 2015). Moreover, during sensemaking, sensemakers make deliberate efforts to understand connections (which can be among people, places and events), in order to anticipate their trajectories and act effectively (Klein, Moon & Hoffman, 2006a, p. 71).

The flexibility of organising notes and documents in a freeform space in Microsoft OneNote, as well as the other mentioned features of Microsoft OneNote can empower users when creating external representations during sensemaking. Therefore, Microsoft OneNote was chosen as a tool to create external representations in this research

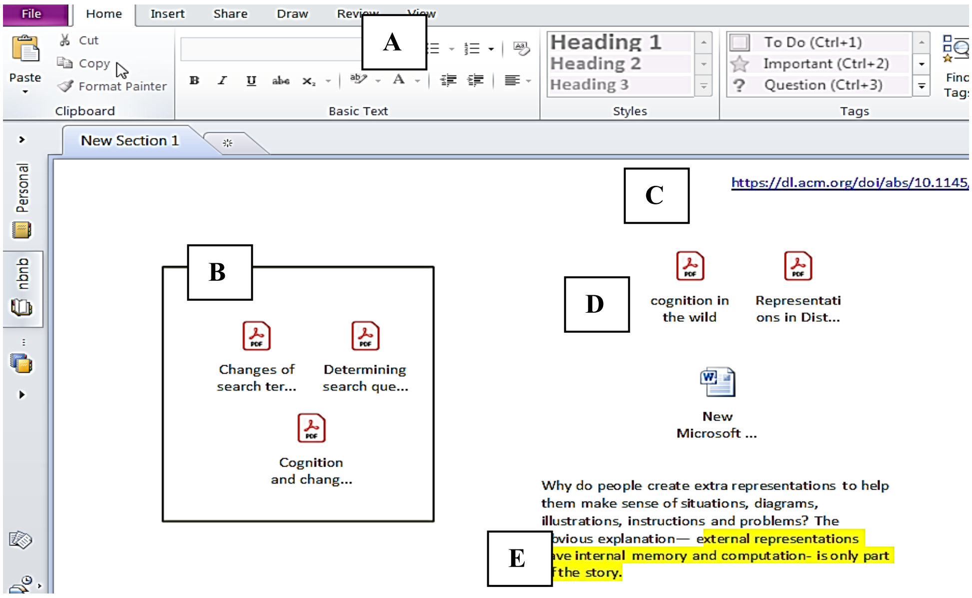


Figure 2.23: Screenshot of Microsoft OneNote. (A) Toolbar (B) A cluster of PDF documents created by drawing a rectangle around documents (C) A link added to the workspace (D) A set of documents with different format added to the workspace (E) A note added to the workspace where part of it has been highlighted

2.4.4 Narrative external representations

Information can be represented externally in a variety of ways, for instance, based on relationships (networks), based on location (spatial), based on specific sequence (timeline), based on rank order (hierarchical), based on argument building (argumentation structures), or based on some classification (faceted) (Faisal, Attfield & Blandford 2009). This thesis focuses on the narrative form of the user's externalised thinking, when the individual sensemaker's task is to create an external representation to build a narrative-based understanding of a domain.

A *narrative* can generally be defined as a series of events that are chronologically linked. Tobin (2007) suggests that narratives always consist of events organised in the sequence of beginning, middle and end. Pontis and Blandford (2016) distinguish between sensemaking tasks as narrative sensemaking and structure sensemaking. Narrative sensemaking occurs when sensemakers build a chain of events to construct a narrative that helps them to make sense of a situation.

Stories provide a natural analytic account of sensemaking tasks. According to MacIntyre (1981), people make sense of their lives only through the stories of which they find themselves a part. Bruner (2003) argues that stories are central to the human experience in general and in the sensemaking process in particular. As Bruner (2003) points out, stories are what we use to interpret and understand the world and our experiences.

In complex sensemaking tasks, such as intelligent analysis, sensemakers tend to communicate facts and events by marshalling them into a scheme, such as a story, as in the schema step in the notional model of sensemaking (Pirolli & Card, 2005). Similarly, the anchored narrative theory (ANT) by Wagenaar, Van Koppen & Crombag (1993) emphasises the role of the narrative when making decisions in complex situations. According to the ANT, legal decisions should have a basis in stories that can be anchored in common sense generalisation. The quality of the stories presented by the parties firstly have to be determined by the judge as the prosecution and defence, after which the anchoring of the stories is examined by means of common sense generalisations that can be strictly true by consideration. Those stories that will be compiled in terms of their quality and the extent to which they are anchored to general common sense will ensure that the anchoring process can be performed internally (the content of the story) or externally (evidence) (Bex & Verheij, 2012). Besides the emphasis on the role of story in reasoning with evidence in ANT, it is essential to consider that it is not an entirely story-based theory. The way that stories are embedded in common sense generalisations contains argumentative elements and, therefore, it is a hybrid theory that combines two type types of relationships – narrative and argumentative (Bex, Van Koppen, Prakken & Verheij, 2010).

Similar to the ANT, the story model by Pennington and Hastie (1991) emphasises the role of narrative in the mind of the juror during the legal decision-making process. Pennington and Hastie (1991) observe that the trial juror builds a narrative account of a case by construing stories from common knowledge and the available evidence. The researchers build the story model on the results of a series of studies. In one of the studies, 26 participants were shown a film of a realistic murder trial and, at the end of the film, they were asked to play the juror role and give a verdict description. The results of interviews confirmed that they reached their verdicts by construing stories of what had happened.

In one of the empirical studies that Pennington and Hastie (1991) conducted to investigate their claim of state jurors' decisions being made through constructing stories, they provided 130 participants with evidence of a first-degree murder story. The order of the prosecution and the defence evidence were manipulated under four conditions, e.g. in one condition, prosecution evidence was presented to participants in story from, while defence evidence was presented in the form of witness testimony. The results showed that 78% of the participants, who were presented with prosecution evidence in story sequence and the defence evidence in witness testimony, chose guilty, while 31% of participants, who were presented with the defence evidence in story sequence and the prosecution evidence in witness sequence, chose guilty. Pennington and Hastie (1991) concluded that verdict participants' decisions were highly affected by the coherence of the story and determined by the sequence in which the evidence was presented.

The role of the narrative is considered as vital in e-discovery tasks (Chapin, Attfield & Okoro, 2013). Furthermore, on the part of computer technology, there are compelling arguments that build the e-discovery cases around the anchored narrative theory that would further lead to an improvement in the performance of e-discovery tools (Chapin, Attfield & Okoro, 2013). Predictive coding practitioners using the understanding of machines can enhance the process of predictive coding by combining it with narrative thinking as a tool that uses an understanding of a real-life context (Chapin, Attfield & Okoro, 2013). There are compelling arguments that combine predictive coding techniques with machine learning by using an anchored narrative theory that would further improve the performance of e-discovery tools (Chapin, Attfield & Okoro, 2013).

The power of narrative has been leveraged in previous research to support different purposes, for example:

- Narrative as a tool to make sense and interpret data (e.g. Chapin, Attfield & Okoro, 2013);
- Narrative construction based on data analysis (e.g. Haggerty, Haggerty & Taylor, 2014);
- Narrative and storytelling as a means of communication (e.g. Segel & Heer, 2010); and
- Narrative as a tool of systems evaluation (e.g. Hedman & Borell, 2005).

External representations of narrative can take different forms, such as organising story episodes into themes and clustering or creating a timeline of events. Ordering events in chronological sequence is a vital element of any story, in that it supports an essential structure of narratives – namely how events flow and evolve over time. The concept of time flow varies in the literature, depending on the domain and context. An example of this type of temporal-based system is an approach to visualise news stories, proposed by Fisher, Hoff, Robertson and Hurst (2008). They developed Narratives, which is a system that aims at providing users with the association between news stories and comments about these stories in blogs over time by using a simple timeline graph.

Similarly, in Jigsaw (Figures 2.19 and 2.20), Stasko, Görg and Liu (2008) leverage the concept of changing time to allow analysts to engage in a legal or journalistic investigation to build a coherent understanding of a set of documents, in order to assist them in formulating a hypothesis. The time-based visualisation in Jigsaw, displaying the document collections in a horizontal timeline, is one of the multiple views that the system provides. The aim is to help users to build a single hypothesis and to test the hypothesis against the available information, while performing a writing task.

Haggerty, Haggerty and Taylor (2014) propose a novel narrative-based approach that utilises network diagrams and tag clouds to create what they call a "network narrative". The tool automatically visualises a combination of both the social network and the content (discourse) between actors within a vast amount of emails to help forensic investigators track the evolving narratives within the evidence. They apply textual analysis to visualise the content of the emails, after which the result of the textual analysis is displayed as cloud words.

Stories play an important role in the way that we make sense of complex situations. Laurel, Bates, Don and Strickland (1991) suggest that computer interfaces would be more effective if they were organised as a narrative, as this would be responsive to the human mode of understanding. The focus of this thesis lies in external representations that individual users create to construct a narrative-based understanding of a domain.

2.5 Gaps in the literature

In the foregoing sections, various definitions and models of sensemaking have been presented. Sensemaking has been described as a process of constructing an understanding. Sensemaking starts when facing surprising events, ambiguous and/or complex situations and discovering gaps in our knowledge of a particular domain (Attfield & Blandford 2009; Klein et al. 2006; Louis, 1980; Dervin, 1983; 1998). Sensemakers then perform continues and deliberate effort that involves structuring (Pirolli & Card, 2005) and finding connections (Klein, Moon & Hoffman, 2006b) to build an understanding of the complex situation (Attfield & Blandford, 2009; Klein, Moon & Hoffman, 2006a).

Representation is central to the process of sensemaking whether internally, with a mental model, or externally, by creating maps or tables. When solving complex problems, people represent information externally, in order to make sense of it. It has been suggested that sensemaking is achieved by manipulating these created representations. In electronic environments, sensemaking frequently involves a complex interplay of information foraging and information structuring, as well as reflection and hypothesising, based on the created structures (Pirolli & Card, 2005).

Although some of the existing research emphasises the importance of creating external representations to the process of sensemaking, some studies (e.g. that of Mandel, Karvetski & Dhami, 2018) show that external representations may actually hinder the process. Whether external representations assist or hinder the sensemaking process, it is important to understand how users think in external representations, because it will assist in the design of tools that enhance sensemaking.

Additionally, most studies of sensemaking are qualitative and exploratory in nature, e.g. based on interviews and observations. Only a few studies attempt to measure sensemaking quantitatively, such as the study by Duffy, Baber and Stanton (2013), where the researchers compared collaborative sensemaking performance of two different social system organisations in a hierarchical network organisation and an edge network organisation by means of quantitative metrics to measure variables such as information sharing, network structure and utility of information.

Moreover, tools that were designed to support the creation of external representations were mostly evaluated based on their ease of use –not their objective effect on the process of sensemaking.

Finding accurate metrics to evaluate tools that support sensemaking remains challenging (Scholtz, 2008). Sensemaking has been measured subjectively in qualitative studies by means of data collection techniques such as interviews or writing summaries, as in the study conducted by Wilson and Wilson (2013). Adopting a qualitative approach is beneficial when investigators are not certain of what to measure and, therefore, it has been mostly applied at the early stages of the research process. However, difficulties emerge when an investigator attempts to perform a comparison, as the results of qualitative studies are not suitable for comparison. As numerical data allows the investigator to discover patterns in data, regardless of the natural differences between people (Ravasio, Guttormsen-Schar & Tscherte 2004), the comparison of numeric data is probably the most reliable way to assess the efficacy of tools.

Although models of sensemaking and qualitative empirical studies have revealed a great deal about the information behaviour involved in sensemaking and underlying cognition and they offer exploratory characterisations that have identified some key phenomena of sensemaking, there is a need for studies that measure the key elements in these phenomena as natural development. Therefore, it worth to ask the question as to whether sensemaking would help at all and whether there is a paradigm that can be used for testing whether external representations are suited to the problem.

These gaps in the literature were approached in this PhD, based on the idea that sensemaking is an iterative process and not a final product. As a process, sensemaking consists of sub-stacks, which makes it possible to measure how the use of external representations changes these sub-tasks.

2.6 Research Question 1: RQ 1

The review of the literature in this chapter has resulted in the development of the following research question (RQ1):

RQ1: *How does the creation of user-generated external representations measurably affect the sensemaking process?*

The aim for this PhD is to develop associated quantitative measures that can be applied to the sub-tasks in the sensemaking process by using the paradigm design (Figure 1.2) that brings the notion of external representations to the process of sensemaking.

2.6.1 Sub-research Question 1: RQ 1.1

The first sub-research question (RQ1.1) is:

RQ1.1: What is the relationship between the creation of user-generated external representations and perceived sensemaking?

The following hypothesis was developed to answer RQ1.1:

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

This hypothesis was tested through a questionnaire that was developed based on operationalising the concept of sensemaking within an instrument (reported in Chapter 3). This hypothesis was tested again in Chapter 5 by using a new version of the developed questionnaire. The results are reported in Chapter 4.

This sub-question associates the thesis with a quantitative instrument to measure the participants' perceived level of sensemaking. Sensemaking frequently provides a context for the use of technologies for information seeking and exploration (such as information retrieval, information extraction, data mining, data visualisation, etc.), as well as the tools for visually structuring and reflecting on the information. For example, Selvaraj et al. (2016) report on a study of police analysts, who made sense of crime data by iteratively querying information resources and using the resulting information to construct elaborate link charts and timelines for the generation and testing of hypotheses. Operationalising the concept of sensemaking within measuring instruments can make a meaningful contribution to the design of such tools. It also helps to investigate whether the use of external representations assists or hinders the process of sensemaking through manipulating the variable user-generated external representations in controlled experiments by using the designed paradigm in Figure 1.2.

2.6.2 Sub-research Question 2: RQ 1.2

RQ1.2: What is the relationship between the creation of user-generated external representations and query construction?

This sub-question relates to finding a quantitative measurement to investigate how the creation of user-generated external representations alters the process of sensemaking by measuring the effect on some of its sub-tasks – in this case, the process of constructing a query.

Constructing a query is an essential step when searching for information in an electronic environment. At this point in the literature review, it is not yet clear how to measure the effect of externalised users' thinking in user-generated representations on query construction quantitatively. However, the analysis of the queries created by participants during the exploratory study reported in Chapter 3 shows some evidence that, when participants create user-generated external representations, they develop new search terms. This finding resulted in the development of new hypotheses, which were tested in Chapter5.

2.7 Chapter summary

The literature review presented in this chapter covers several areas related to the research, including the following: a definition and models of sensemaking and information seeking; the role of external representations in cognition, externally generated representations in the context of sensemaking; existing tools supporting users in externalising their thinking during sensemaking, as well as a review of the importance of narrative representations. The review in this chapter has resulted in the development of RQ1 and some related sub-questions and hypotheses, which are investigated in the next chapters.

CHAPTER 3: THE EFFECT OF USER-GENERATED EXTERNAL REPRESENTATIONS ON PERCEIVED SENSEMAKING AND CONSTRUCTION OF QUERY

This chapter reports on the first study that was conducted during this doctoral research. Apart from covering the methods used in data collection and analysis, it also discusses the results and the limitations of the study. The first part of this chapter reports on the development of an instrument to measure perceived sensemaking. The second part reports on an experiment that was conducted to investigate the effect of externalising thinking in user-generated representations on sensemaking. It presents the quantitative and qualitative analysis of the collected data. The quantitative analysis was undertaken to test a hypothesis regarding the effect of using external representations in sensemaking, while the qualitative analysis was conducted to explore the effect of externalised thinking in user-generated representations on query constructing.

The remainder of this chapter is structured as follows:

- Section 3.1 presents the motivation;
- Section 3.2 presents research aims and questions;
- Section 3.3 presents the development of an instrument to measure perceived sensemaking;
- Sections 3.4 presents an outline of the method used in this study, which includes a description of the experimental design, the participants, procedures, and data analysis;
- Section 3.5 presents the results;
- Section 3.6 presents the discussion of the results;
- Section 3.7 summarises the study limitations; and
- Section 3.8 summarises the chapter.

The content of this chapter is an extended version of two papers – Alsufiani et al. (2017) and Alsufiani and Attfield (2018).

3.1 Motivation

Although the significant role of external representation in the process of sensemaking has been highlighted by many previous studies (e.g. Klein et al., 2006; Pirolli and Card, 2005; Russell et al., 1993), little is known about exactly how external representations alter the process of sensemaking. Studies of sensemaking are often qualitative and exploratory in nature. Such studies do reveal a good deal about the information behaviour involved in sensemaking and underlying cognition and they offer exploratory characterisations that have made it possible to identify some key phenomena of sensemaking. However, there is a need for studies that measure things around these phenomena as a natural development.

In addition, besides the studies that emphasise the effect of external representations in sensemaking, some studies (e.g. that of Mandel, Karvetski & Dhami2018) show that some type of external representations may, in fact, not help the process, and it has been recommend being use a particular type of representations to a particular type of problem.

Therefore, it is worth to asking the question as to whether external representations would help or hinder the process of sensemaking, and whether there is a paradigm that can be used for testing whether external representations are suited to the problem. Gaining a better understanding of this process will assist in designing tools that enhance sensemaking. Such questions can be answered through a quantitative and experimental paradigm to gain a reliable understanding of the relationships between variables of interest and in particular how different kinds of tools may impact on outcomes in an electronic environment.

The study in this chapter addresses these issues by establishing an experimental paradigm for measuring sensemaking. The designed paradigm (Figures 1.2 and 1.3 in Chapter 1) represents sensemaking as an iterative process that consists of sub-tasks. It also brings the notion of external representations into the sensemaking process. Creating user-generated external representations in the paradigm is part of the sensemaking iterative process and the effects of user-generated external representations on cognition may well propagate around that process and be detectable in different parts in ways that have not been previously explored. The manipulation of the use and non-use of user-generated external representations has been assumed to enable the measuring of changes that externalising thinking causes on some sub-tasks of sensemaking (keyword novelty) and some of the final products (perceived sensemaking).

The study followed a combination of confirmatory and exploratory approaches to investigate the effect of externalising thinking in user-generated representations in an individual sensemaking task, which involves searching for information in an electronic environment. The study followed a controlled experimental design. The confirmatory was conducted to address a hypothesis, while the exploratory investigation was conducted to explore what would happen in some subtasks of sensemaking when thinking was externalised in user-generated representations during the process.

During the study, participants were asked to perform a mock investigation by using a collection of documents. The task involved constructing queries by using a data set, searching for documents, and reviewing the results to decide on individual document relevance (known as a *document triage*).

3.2 Research aim and research questions

The main objective of the study was to establish a paradigm for measuring sensemaking, which was achieved by addressing a number of sub-objectives, which were to:

- Measure the effect of user-generated external representations on perceived sensemaking quantitatively; and
- Investigate the effect of user-generated external representations on query construction.

This study helped in answering the following research question:

RQ1: *How does the creation of user-generated external representations measurably affect the sensemaking process?*

More specifically, this study focused on answering the following sub-questions RQ1.1 and RQ1.2.

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

Research sub-question RQ1.1 was answered thorough an experimental manipulation of the use and non-use of external representations by testing the following hypothesis:

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

RQ1.2*: What is the relationship between the creation of user-generated external representations and query construction?*

Research sub-question RQ1.2 was answered through a qualitative analysis of participants' activities relating to query construction when they used and did not use external representations.

3.3 An instrument to measure perceived sensemaking

Most studies of sensemaking are qualitative and exploratory in nature, e.g. based on interviews, observations or the analysis of written summaries, as in the study conducted by Wilson and Wilson (2013). Moreover, tools that have been designed to support the creation of external representations are mostly evaluated based on their ease of use – not their objective effect on the process of sensemaking.

Only a few studies attempt to measure sensemaking quantitatively, such as the study by Duffy, Baber and Stanton (2013), where the researchers compared collaborative sensemaking performance of two different social system organisations a hierarchical network organisation and an edge network organisation by means of quantitative metrics to measure variables such as information sharing, network structure and utility of information.

Qualitative approaches are beneficial when investigators are not certain of what to measure and, therefore, it has been mostly applied at the early stages of the research process. However, difficulties emerge when an investigator attempts to perform a comparison, as the results of qualitative studies are not suitable for comparison. Developing an instrument to measure perceived sensemaking provides a quantitative way to investigate the phenomenon and evaluate tools that support sensemaking.

This section explains the first version of a questionnaire (Appendix A.3) that was developed and used to answer RQ1.1 as follows:

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

The questionnaire was used to answer RQ1.1 by testing the following hypothesis:

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

Models and definitions that cover different features of sensemaking, which are elaborated below, were operationalised to develop the questionnaire. It was primarily developed to measure sensemaking, while concurrently each subscale measured a different feature of sensemaking. Each theory or definition was represented by a subscale in the questionnaire. These subscales were comprehension and gaining insight; drawing on prior knowledge; linking and finding connections gap-discovering and bridging; structuring and reducing confusion; and ambiguity. A single question directly addressed sensemaking: *To what extent do you think conducting the given task under this condition helped you to make sense of the available information*. All other questions were phrased in such a way as to address the various theories of sensemaking within their corresponding subscales.

The questionnaire started off with a root question, effectively foregrounding the key verb in each item. The questionnaire was divided into six subscales, with each item scored on a visual analogue scale (VAS), ranging from 1 (to a small extent) to 11 (to a large extent).

One of the advantages of using VAS is that the scales are simple for participants to complete, if they are provided with clear instructions (Ahearn, 1997), and result in useful self-reported information. Using a VAS also allows for variations in responses, which should improve data quality (Klimek et al., 2017). Among all the different types of VAS, the 11-step scale is the most commonly used (Hjermstad et al., 2011), as it results in high internal consistency and good convergent and discriminant correlation of the underlying measured factors (Watson, Clark & Tellegen, 1988).

The following six sub-scales were used in the questionnaire:

1. **Sensemaking as a process of gaining insight**

   In certain literature, the phenomenon of sensemaking is associated with cognitive processes, such as comprehension and the process of gaining insight. For example, Pirolli and Card (2005) define *sensemaking* as the process of collecting information, developing a representation (schema) of the collected information, utilising the developed representation to build insight, and using the gained insight to generate the final product, which can either be knowledge or a specific action.

They summarised the definition in a formula as follows, with insight presented as one of its main stages:

Information → Schema → Insight → Product

2. Sensemaking as a process of understanding connections

Sensemaking has also been described as “a motivated, continuous effort to understand connections (which can be among people, places and events) in order to anticipate their trajectories and act effectively” (Klein, Moon & Hoffman, 2006a, p. 71). This has become one of the most widely adopted approaches. Assessing the process of finding relationships among entities within large amounts of data proves its usefulness in supporting sensemaking, as it is part of the sensemaking process mechanism. A typical example of systems that integrate such a technique and have proven effective in guiding sensemakers is Jigsaw. The system allows the analyst to visualise relationships between entities, which can be people, places, dates or organisations (Stasko, Görg & Liu, 2008).

3. Sensemaking as a process of drawing on prior knowledge

It has been found that, in some cases sensemakers draw on their background to make sense of a situation during the sensemaking process (Qu and Furnas, 2005; Chin, Kuchar & Wolf, 2009; Zhang & Soergel, 2009). According to the data frame theory of sensemaking (Klein et al., 2007), sensemaking is a process of fitting data into a frame and fitting a frame around data. The entire frame can be an internal representation of a situation to make sense of data, which can be the sensemakers’ background knowledge. For instance, in some cases when police investigators are faced with a robbery, they build part of their understanding of criminal behaviour and the evidence they may find on their prior knowledge of similar cases. Attfield and Baber (2017, p. 27) describe the use of prior knowledge during sensemaking as “general “understandings” that a sensemaker can bring to situations to help them make sense of them. For example, for a doctor, this may include a set of medical conditions and their features, or a theory about possible situation. Rummelhart (1980, p. 34) describes the frame as “a data structure for representing generic concepts stored in memory”. Rummelhart (1980) gives an example of a schema in the concept of buying. When buying a new product, people make sense of the process by drawing on their prior knowledge of the concept; they have a generic internal representation of the association between entities such as purchaser, money, seller, and merchandise.

4. Sensemaking as a process of gap discovering and bridging

Sensemaking is also defined as the process of gap defining and gap-bridging as the user moves within time and space (Dervin 1992, 1998). Using travel through time and space as a metaphor for sensemaking, a gap in knowledge is seen as preventing the user from moving forward in time or space in a given situation. To complete the sensemaking process, these gaps have to be identified and bridged. Gaps could be defined by history, experience, or the past and present horizons. Bridging these gaps requires the use of mechanisms such as cognition, beliefs, emotions, or narratives, considering that such wide-ranging conceptualisations of sensemaking allows for greater complexity, nuance and responsiveness to a variety of users and sensemaking tasks.

5. Sensemaking as a process of structuring

Sensemaking is further defined as "the process of searching for a representation and encoding data in that representation to answer task-specific questions" (Russell et al., 1993, p.269). Creating representations to filter and understand data may be central to the sensemaking process. During the process, people create representations (whether internally or externally) to aid their interaction with data. This guides their decision-making as to what to include and exclude from the data (Faisal, Attfield & Blandford, 2009). Klein et al. (2007) further describe sensemaking as the process of framing and reframing, where the frame is used to filter the data or the data to update the frame. The process of structuring can occur internally, as illustrated in the data-frame model, or externally, as in the notional model of sensemaking by Pirolli and Card (2005). In the latter model, schematisation appears as an essential stage within the process of sensemaking, where *schematisation* refers to the external artefacts created by the analyst, e.g. a visual representation such as a map or a table.

6. Sensemaking as a process for reducing confusion and ambiguity

Weick (1988) relates sensemaking to "contextual rationality" and sees it as being built from vague questions, muddy answers and negotiated agreements that attempt to reduce confusion. Wieck (1988) considers ambiguity and uncertainty as two stimuli for sensemaking within organisations, where people react to stimuli by engaging in a process of sensemaking. Uncertainty and ambiguity are differentiated in terms of the reasons for people reacting to each. When people are faced with ambiguity, sensemaking occurs due to plurality of interpretation. In uncertainty, on the other hand, sensemaking occurs as reaction to a lack of knowledge. Therefore, people follow different strategies to make sense in each case. In this study, part of Wieck's definition was adopted, namely that "sensemaking is the attempt to reduce confusion" (Wieck, 1993, p. 636), whether this confusion is uncertainty or ambiguity. It is argued that, as sensemaking is the continued effort to reduce confusion, increasing the level of sensemaking means decreasing the level of both uncertainty and ambiguity.

Table 3.1 details the sub-questions included in the instrument following the root question *(To what extent do you think conducting the given task under this condition helped you to perform the following process successfully?)* and the name given to their corresponding subscales.

Table 3.1: Items within each sub-scale

Sub-scale	Items
Gaining insight	Q1: Construct understanding from the available information
	Q2: Gain insight from the available information
	Q3: Make sense of the available information
Finding connections	Q9: Understand connections between people
	Q10: Understand connections between places
	Q11: Understand connections between events
Drawing on prior knowledge	Q5: Draw a link between the story you read about and similar previous stories
	Q4: Draw a link between the conflict you read about and similar previous stories
Gap discovering and bridging	Q12: Discover where the gaps in your information about the given task
	Q13: Bridge gaps in your information about the given task
Structuring	Q7: Find a structure in the information
	Q8:Find a way to organise the information
	Q6: Develop a coherent representation of the information
Reducing confusion	Q14: Reduce confusion
	Q15: Reduce ambiguity

3.4 Method

This section presents an account of the experimental design, the participants, as well as the data collection and data analysis procedures.

3.4.1 Experiment design

The study utilised a controlled experimental approach, which included a single independent variable (user-generated representation) with two levels (user-generated representation vs. non-representation). Participants either created external representations of the documents by using OneNote software (user-generated representation condition), or they simply put the documents into a folder (non-representation condition). Therefore, a single independent variable (user-generated representation) was involved, with two levels (user-generated representation vs. non- representation). The dependent variable was the participant's level of comprehension, measured by a questionnaire.

In this doctoral research, external representations refer to the process of creating user-generated external representation by using Microsoft OneNote. Therefore, other types of external representation (externalising thinking) creations were not controlled. That to say, creating search terms that are externalising thinking were not controlled, and participants were allowed to create search terms under both conditions. Moreover, both conditions involved some types of "passive structuring", which refers to the process of having the information structured by tools used in the experiments setup and not created by participants, e.g. documents in the search results are presented externally as a list of documents.

To summarise: in this doctoral research, external representations under the user-generated representation condition refers to the process of externalising thinking through user-generated representations by using a tool – in this case Microsoft OneNote – while performing a task to make sense of a domain. While non-representation under the non-representation condition, on the other hand, refers to the process of saving documents that were judged as relevant in a folder.

The experiment, which was based on a given scenario, involved an information-gathering task in preparation for writing a news story. The time for the task was fixed to a maximum of one hour for each session for each participant, who performed two tasks in two sessions individually.

Due to the long session times (two hours per participant for two tasks each under different conditions – i.e. user-generated representation condition and non-representation condition – only a small number of participants were expected to take part in the study. Therefore, a repeated measure design was followed. Apart from requiring a small number of participants, such a design provides the benefit of reducing individual differences (Shaughnessy, Zechmeister & Zechmeister, 2011). However, the repeated measure design does have some disadvantages, such as order effect. In order to eliminate this issue, participants were divided into four groups (A, B, C and D) and assigned randomly, as illustrated in Table 3.2. For instance, the first session for a participant, who was assigned to Group A, was to perform the crisis in Syria task under the user-generated representation condition, while the second session involved performing the task about the Ukraine crisis under the non-representation condition.

Table 3.2: Groups to which participants were assigned to avoid order effects

Group	Condition 1	Scenario 1	Condition 2	Scenario 2
A	User-generated representation	Syria	Non-representation	Ukraine
B	User-generated representation	Ukraine	Non-representation	Syria
C	Non-representation	Syria	User-generated representation	Ukraine
D	Non-representation	Ukraine	User-generated representation	Syria

3.4.2 Measures and materials

3.4.2.1 Software used

The following software was used in the data collection process:

- Microsoft OneNote was used to structure the documents participants judged as relevant to the given task during the search (user-generated representation condition) as a way of externalising participants' thinking while performing the given sensemaking tasks. This allowed them to create different types of representations in a free-form workspace by using different drawing features, such as lines linking added files and circles or rectangles around added files they considered related. It also allowed note-taking, drawing different shapes and lines, as well as highlighting.
- Windows Explorer was used as a search engine.
- BB Flashback software was used to record the screens to answer the second research question.

3.4.2.2 Dataset

The datasets used in the study were collected from many different news sources. Each file had a title, date and content, which included a news story. The stories in the dataset ranged from key events (e.g. *Isis rebels declare "Islamic state" in Iraq and Syria*), to daily news stories (e.g. *Whole generation of Syrian children could be lost, says UN*). They also included “noise” data, telling stories unrelated to the crises in the tasks (e.g. *What to eat in Aleppo Syria: a food and drink guide*). The documents for each task were saved in a separate folder and Windows Explorer was used to display and search during the task.

3.4.2.3 Tasks

As the design of the study had two levels for the single independent variable (user-generated external representations vs. non-representations), the participants performed two different tasks in one session, each task under different conditions. In both, they were asked to find the key political events that led to a certain crisis since the conflict started until 2016. One task was about the war in Syria, while the other was about war in Ukraine. The two tasks are summarised below.

Task 1:

The Syrian government, Russia and the US have reached agreement on preparations for the Syrian government to step down. The government and some rebels have been accused of causing the civil war in Syria. Syria has been at war since the March 2011 uprising. Your task as a journalist is to gather the information in preparation for writing a news story that sums up the key events that have occurred in Syria and led to the conflict.

Task 2

The Ukrainian government have reached an agreement between the Ukraine army and the pro-Russian rebels. Ukraine has been at war since the 2013 uprising. Your task as a journalist is to gather information in preparation for writing a news story that sums up the key events that have occurred in Ukraine and led to the conflict.

3.4.3 Participants

In total, 13 participants were recruited from the Science and Technology Department at Middlesex University. The participants were postgraduate students (four female and nine male). An invitation to take part in the study was issued by email, with help from the Research Degrees Administration department. A Middlesex University catering voucher valued at £22 was awarded to each participant for their time and effort.

3.4.4 Experiment setup

Participants were provided with three screens. Under the user-generated representation condition, the screens were used as follows: the first screen was used to display the dataset and the search tool within Windows Explorer; the second was used as an area to read the selected documents; and the third was to display Microsoft OneNote, where participants could create the external representations. The same setup was used under the non-representation condition, but instead of displaying Microsoft OneNote, the third screen displayed an empty folder where participants could save relevant documents.

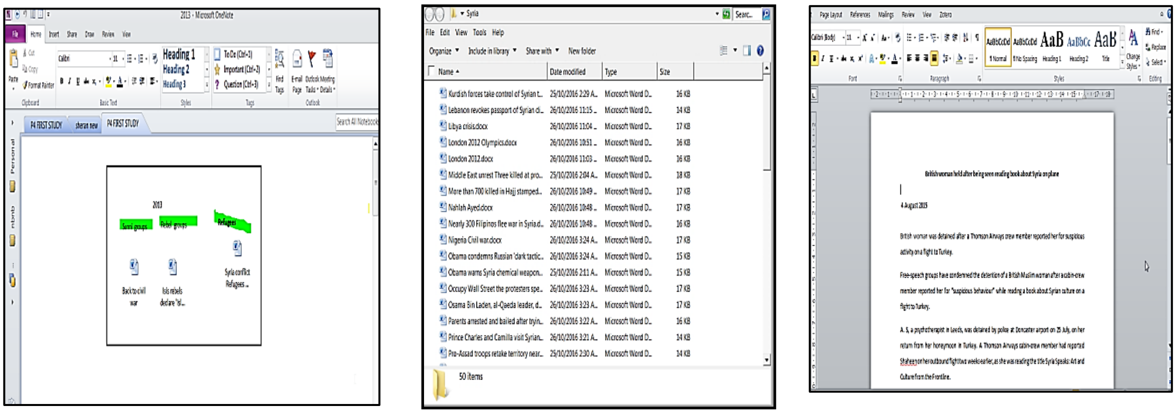


Figure 3.1: The setup for the experiment, from left to right: screen to display Microsoft OneNote under the user-generated representation condition and displays a folder where participants can save relevant documents under the non-representation condition; screen to display the search engine Windows Explorer; and screen used as an area to read the selected documents

3.4.5 Procedure

The experiment consisted of an information-gathering task in preparation for writing a news story, based on information given in a scenario. The following procedures were followed:

- Participants were asked to read and sign an informed consent form.
- At the beginning of the user-generated representation condition, participants were given a brief tutorial on the use of OneNote.
- Participants were provided with a set of files (as representative of online archives) and each file consisted of a newspaper article recounting part of what occurred in the given scenario.

- Windows Explorer was used as a search engine.
- The participants were required to perform a mock investigation for which they first needed to read the scenarios and conduct a search for documents, reviewing the results to decide on individual document relevance (in other words, document triage).

As the experiment had a single independent variable (user-generated representation) with two levels (user-generated representation vs. non-representation), the participants performed this data-gathering as part of the experiment under the following two conditions:

- In one condition, they were asked to structure the documents they judged relevant to the given task during their search by using OneNote software (user-generated representation condition) as a way of externalising their thinking while performing the provided sensemaking tasks. This allowed them to create different types of representations in a free-form workspace, using different drawing features, such as lines linking added files and circles or rectangles around added files they considered related. It also allowed note-taking, drawing different shapes and lines, as well as highlighting.
- Under the other condition, they were asked to simply copy and paste the documents they judged relevant to the given task into a folder (non-representation condition). Participants were encouraged to verbalise their thoughts while performing the task.

Participants were also asked to complete questionnaires at the end of each task to report their perceived sensemaking.

3.4.6 Ethics

Ethical approval was granted from the School of Science and Technology at Middlesex University to conduct this study. Participants were asked not to divulge any confidential information and they were advised that they were free to withdraw themselves and their data from the study at any point. Detailed consent forms and further information about the study were provided to all participants (see Appendices A.1 and A.2).

Data was collected by means of a questionnaire to answer the first research question and test the first hypothesis in this study, namely:

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking*?

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

A quantitative approach was adopted for this analysis, because it is deemed adequate in controlled experiments when data is collected by using a close-ended questionnaire (Newman & Benz, 1998). IBM Statistical Package for Social Sciences (SPSS) Statistics 24 software was used to perform the test.

Firstly, scores were assigned from 1 (to a small extent) to 11 (to a large extent) for each vertical line of the VAS. For instance, when a participant answered the first question (Q1) by placing a mark on the first vertical line on the visual scale, a score of 1 was entered into SPSS for this item. Marking on each of the vertical lines on the scale resulted in a different score range from 1 to 11. After entering the scores for the 15 questionnaire items for all participants, the score of the overall perceived sensemaking of each participant was calculated. Wilcoxon signed rank was used to compare the level of perceived sensemaking of participants across the two conditions. Each participant had one score for perceived sensemaking under each condition, which is the sum of the scores of the 15 items in the questionnaire.

To answer the second research question, Data was collected using the screen-recording software BB Flashback. Audio recordings were also used as participants were asked to verbalise their thinking during the study:

RQ1.2*: What is the relationship between the creation of user-generated external representations and query construction?*

An exploratory qualitative approach was adopted for this part of the study. Exploratory research is beneficial when little is known about the research problem, as it is effective in establishing hypotheses and further research questions for future work (Blandford 2013).

The adopted approach in this study is an inductive analysis to derive themes from the collected data.

3.4.7 Transcript

Data from both the screen-recording software and the audio recording related to query construction were transcribed and combined, in preparation for coding in the analysis stage. For each participant, descriptions of strategies of query construction during the task were detailed in the transcripts.

The following strategy was adopted during the process of transcribing for each participant. Each transcript was arranged as a two-column table. Each row in the first column contained a single strategy or behaviour that participants followed in constructing the query, as well as the constructed query, e.g. "participant created the following search term: Syria". Any data from the audio recording was placed in a separate row. However, the data from the audio recording was limited.

The second column in the table contained the coding from the analysis. A data-driven coding approach was followed to code the transcripts. To identify codes and themes, transcripts were read multiple times.

3.5 Results

This section reports on the results of both the quantitative and qualitative data analysis. The first part reports the quantitative analysis of the developed questionnaire and begins with a description of the collected data, before reporting on the reliability test of the developed instrument. It concludes by answering RQ1.1 through the analysis of the self-reported sensemaking by participants across the two conditions. The second part of the results section reports on the qualitative analysis of the participants' sensemaking activities by means of analysing the screen-recordings that were collected during the study. The last part reports on the results of the testing of one of the hypotheses that was drawn from the qualitative analysis of participants' sensemaking activities.

3.5.1 Self-reported questionnaire

The questionnaire was developed to answer the first research sub-question (RQ1.1) by testing the related hypothesis H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

3.5.1.1 Reliability of instrument

The questionnaires, which were given to participants after performing the task under each of the two conditions, were completed by all participants. All the items in the questionnaire were positively worded and, therefore, the scores of items were entered directly into SPSS without conversion.

The first step of the analysis included descriptive statistics to examine general patterns in the data in terms of central tendency and dispersion of individual questions. Table 3.3 shows the number of valid responses (N), means and standard deviations for each item.

Table 3.3: Dispersion statistics

Item	N	Mean	Standard Deviation
Q1	26	7.58	2.469
Q2	26	7.58	2.369
Q3	26	7.46	2.983
Q4	26	6.00	2.728
Q5	26	5.88	2.535
Q6	26	6.96	3.256
Q7	26	6.69	3.308
Q8	26	7.08	3.520
Q9	26	6.73	3.317
Q10	26	6.85	3.146
Q11	26	7.23	3.241
Q12	26	5.58	2.533
Q13	26	5.69	2.510
Q14	26	7.08	3.136
Q15	26	7.04	3.066

In general, the results showed that the average score of participants across items yielded values between 5.5 (Q12) and 7.4 (Q1), with measures of dispersion around 3 points (between 2.3 for Q2 and 3.5 for Q8). Although item means suggested that participants tended to score in the highest section of the VAS, there was no clear evidence of extreme response bias on this tail of the metric.

3.5.1.2 Instrument correlation

Cronbach's alpha coefficients were estimated to determine the internal consistency of items and the overall instrument. Table 3.4 illustrates the alpha values in the last two columns, corresponding to each part of the instrument.

Table 3.4: Reliability of items

	Item-test correlation	Cronbach's Alpha if item deleted
Q1	.776	.976
Q2	.766	.976
Q3	.834	.975
Q4	.778	.976
Q5	.805	.975
Q6	.915	.974
Q7	.902	.974
Q8	.905	.974
Q9	.844	.975
Q10	.898	.974
Q11	.834	.975
Q12	.872	.975
Q13	.872	.975
Q14	.867	.974
Q15	.880	.974

The instrument had a high internal consistency (Cronbach’s alpha =.976). As indicated in Table 3.4, the indicator of reliability across all the items was also high. Item-test correlations were all positive and strong, with the lowest value being for Q2 (.766). This result demonstrated that all the items were important in their contribution to measuring sensemaking in the same direction as the whole instrument.

Furthermore, deleting any item from the questionnaire would have decreased its internal consistency, which indicated that a reliable measure of sensemaking should include all these items**.**

3.5.1.3 Testing of parametric assumptions

In order to decide on the test to use to investigate the relationship between variables, an assessment of the normality of data was first investigated. The normal distribution of perceived sensemaking was tested by plotting histograms and by calculating the z-value of skewness and kurtosis scores (skewness or kurtosis value divided by its standard error) and Shapiro-Wilk (see Appendix E.1).The values for asymmetry and kurtosis between -1.96 and +1.96 are considered acceptable to prove normal univariate distribution (George & Mallery, 2010). The Shapiro-Wilk test was also applied to assess the normality of data. The test rejects the hypothesis of normality when the p-value is less than or equal to 0.05.

A Shapiro-Wilks test ($p > .05$) and a visual inspection of the histogram showed that perceived sensemaking under the non-representation condition scores was approximately normally distributed with skewness of .320 (SE =.616) and kurtosis of -.759 (SE=1.191). In contrast, the results showed that perceived sensemaking under the user-generated representation condition scores with Shapiro-Wilks test ($p<.05$) and a visual inspection of its histogram is a departure from normality, with skewness of-.963 (SE =.616) and kurtosis of -.271 (SE=1.191). (See Appendix E.1).

Based on these results, a decision was made to use the median and the non-parametric Wilcoxon signed rank test to compare perceived sensemaking across the two conditions (user-generated representation and non-representation), as the Shapiro-Wilk test of perceived sensemaking under the user-generated representation condition showed a significant departure from normality – $W(13) = .850$, $p<.05$.

3.5.1.4 User-generated representation affecting sensemaking quality in individual tasks

The median of perceived sensemaking of all participants across the two conditions was calculated and compared. Figure 3.2 depicts the median score of participants' sensemaking under the two different conditions (user-generated representation vs. non-representation).

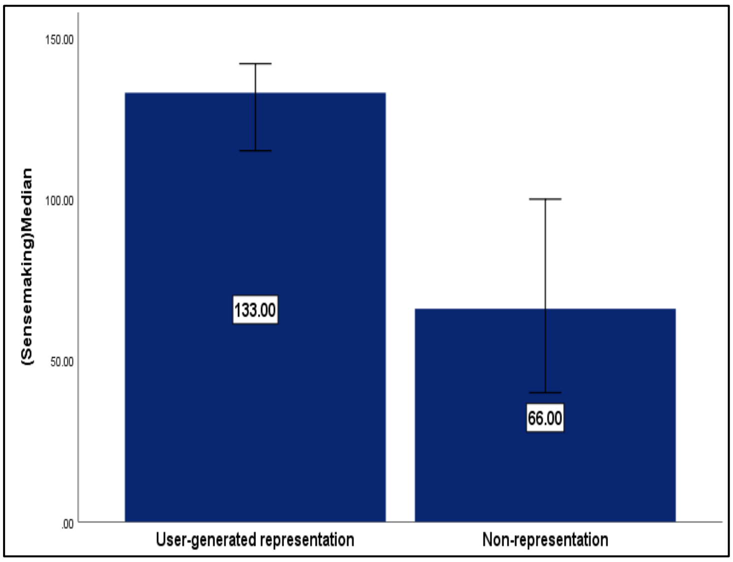


Figure 3.2: Median scores of perceived sensemaking across conditions

The bars in Figure 3.2 represent the level of participants' perceived sensemaking under the conditions of user-generated representation and non-representation. The median score of sensemaking under the non-representation condition was close to the midpoint of the whole instrument, while the median score for sensemaking under the user-generated representation condition was higher. Sensemaking under the user-generated representation condition (Mdn = 133) scored 67 points more than sensemaking under the non-representation (Mdn = 66). Results clearly showed differences between the median score of participants when they created user-generated external representations of the data and when they did not.

Testing of research hypothesis H_1 was conducted by using the Wilcoxon signed rank test to determine the significance between participants across the two conditions. The hypothesis predicted that the creation of external representations as "user-generated representation" helped to increase perceived sensemaking. As a result, the analysis indicated a significant difference between perceived sensemaking in the user-generated representation condition and the non-representation condition ($Z = -3.182$, $p < .05$). The results supported hypothesis H1, which predicted an increase in participants' perceived sensemaking when they structured their thinking externally by creating user-generated external representations.

3.5.2 Observation results

In this section, the results of the screen-recordings of the activities that participants performed regarding query formulation are presented. The main aim for the analysis was to answer RQ1.2: *What is the relationship between the creation of user-generated external representations and query construction?*

The analysis showed that participants adopted the following strategies under the two conditions (user-generated representation and non-representation):

- Construct a query.
- Select documents from the dataset in sequence one by one.
- Select documents based on their titles.

To select a document to read from the dataset, participants either created a search term or selected a document from the dataset in sequence (or based on its title).

Some participants followed one strategy during the two sessions. For instance, P9 and P11 followed the single strategy of selecting files from the dataset based on their titles. Under the non-representation condition, P9 specifically selected only files with Ukraine in their title – the task being about the crisis in Ukraine – whereas in the user-generated representation condition, they selected files with Syria in their titles. Participants made the following comments: P9: I *am just going to go through the titles of the documents to see what may be relevant' and added 'Ukraine conflict –I think this is a good title – I will read it*; Participant P11 (while selecting documents): *These are really relevant by title*.

Other participants (P8 and P13), simply followed the strategy of reading files in sequence, starting with the first in the data set, whereas P2, P3, P5, P6 and P12 used a mix of these two strategies.

Only four participants (namely P1, P4, P7 and P10) created search terms. After creating them, they selected documents from the search results based on either their titles or one-by-one in sequence. In total, these four participants created 78 search terms under both conditions (user-generated representation and non-representation): 38 under the user-generated representation condition and 40 under the non-representation condition. These search terms were analysed under the two conditions. First, a two-column table for each participant was created. The first column contained search queries created by the participant under the user-generated representation condition, while the second had those created under the non-representation condition.

Analysis of the developed search queries showed that they were either task-based (where participants used part of the information from the task brief as a search terms) or non-task-based (developed from other resources). Table 3.5 shows an example of search terms that were developed by one of the participants (P1). The left column in the table is the task brief given to the participants under the user-generated representation condition. The right column contains information on the search terms created by P1 during the session. The sequence of the search terms in the table is the same as when the participant created them while performing the task. In the table, search terms that were task-based are highlighted with the same colour in the task brief column and the search terms column. The non-highlighted search terms are those that the participant derived from other resources, such as background knowledge, or by creating external representations.

Table 3.5: Search terms created by P1

Task brief	Queries
The Syrian government, Russia and the USA, have reached an agreement on preparations for the Syrian government to step down. The government and some rebels have been accused of causing the civil war in Syria. Syria has been at war since the uprising in March 2011. Your task as a journalist is to gather the information, in preparation for writing a news story that sums up the key events that have occurred in Syria and led to the conflict.	Syria
	Russia
	USA
	Russia
	Syria
	Obama
	Refugee 2011
	Iran
	Lebanon
	Turkey
	2011
	2012
	2013
	Peace
	Explosion2014
	ISIS
	Kurdish
	Syria

Figures 3.3 and 3.4 compare the numbers of search queries created by each of the four participants under the two conditions. Figure 3.3 compares those that were task-based for each participant under the two conditions (user-generated representation and non-representation). In the figures, the X-axis represents individual participants and the Y-axis represents the number of search queries. The red bars represent the queries under the user-generated representation condition and the blue bars represent the queries under non-representation condition.

As illustrated in Figure 3.4, apart from P10, participants created almost the same number of task-based queries under the non-representation condition.

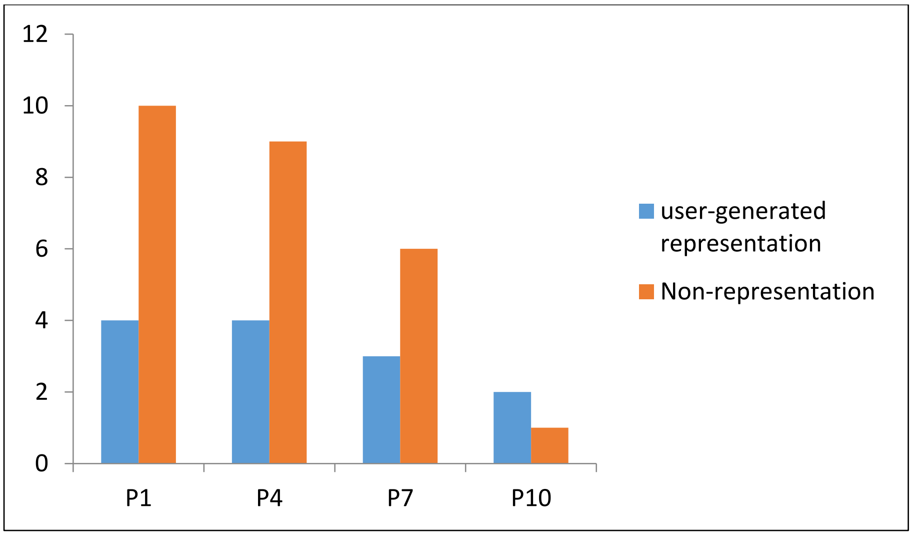


Figure 3.3: Numbers of task-based queries across conditions

The data also shows that, apart from P10, participants created more search terms that were task-based under the non-representation condition.

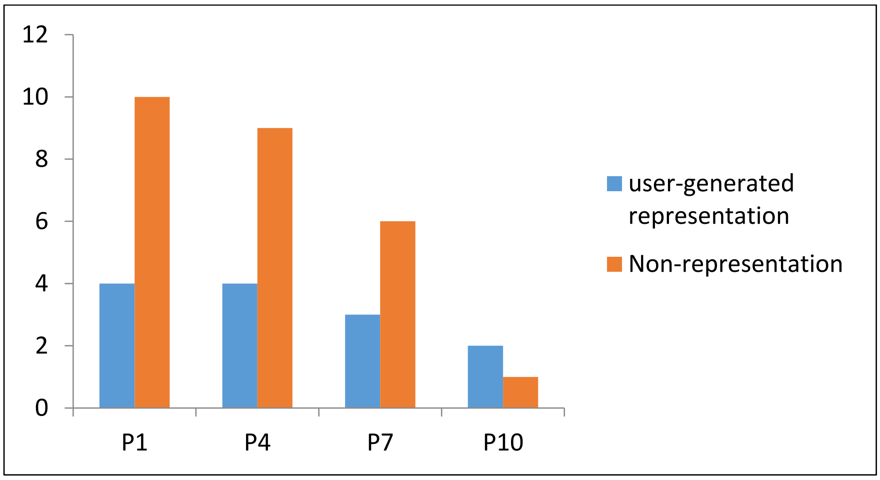


Figure 3.4: Numbers of non-task-based queries across conditions

Figure 3.4 shows that, apart from P10, the numbers of non-task-based search terms were higher under the user-generated representation condition.

These results strongly suggested that participants did not rely on the task brief to develop search terms under the user-generated representation condition.

Based on these results, the following hypothesis was developed:

H_2: Creating external user-generated representations during sensemaking helps to increase keyword novelty.

3.6 Discussion and conclusion

The collected data of each of the dependent variables was compared across the two conditions (user-generated representation and non-representation), through which the study helped to answer RQ1.1 quantitatively, using the developed questionnaire. The results confirmed (based on the self-reported questionnaire) that user-generated external representation helped to increase perceived sensemaking.

At the beginning of the study, RQ1.2, which investigated the effect of structuring thinking in user-generated external representations on query construction, was approached through qualitative analysis of the screen recording. The results helped to develop the following hypothesis H_2: Creating user-generated representation during sensemaking helps to increase keyword novelty. The hypothesis was then tested in a further study, which is reported in Chapter 5.

This section presents a discussion of the results presented by research sub-questions RQ1.1 and R1.2).

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

To answer this sub-question, hypothesis H_1 (Creating user-generated external representations during sensemaking helps to increase perceived sensemaking) was tested, using the data collected by the perceived sensemaking questionnaire.

A questionnaire was developed to investigate the effect of the use of external representations in perceived sensemaking. This was based on a number of significant models and definitions of sensemaking. A number of theoretical models and definitions that fitted the approach to sensemaking adopted in the study were operationalised. It was intended that these dimensions should cover different features of sensemaking. Hence, although the questionnaire was primarily developed to measure sensemaking as a whole, six theoretical subscales were defined to measure different features of sensemaking, inspired by relevant theories found in the literature review.

The results of testing H_1 confirmed that creating user-generated external representations helped to improve perceived sensemaking. Participants reported higher levels of sensemaking when externalising their thinking by using OneNote than when they did not. Although some studies presented cases where the use of external representations may not always have a positive effect on sensemaking (e.g. Kang, Kane & Kiesler, 2014; Russell, Jeffries & Irani, 2008), the results were consistent with other studies that do emphasise the role of creating representations in sensemaking (e.g. Klein, Moon & Hoffman, 2006a, 2006b; Pirolli & Card, 2005; Russell et al., 1993). It added studies a quantitative measure of the effect of using external representations during sensemaking to these studies.

Because this study was a controlled experiment, a causation relation among the use of external representations and higher levels of perceived sensemaking can be claimed. That is to say, using external representations causes an increase in the level of perceived sensemaking.

According to the sub-scales of the questionnaire, creating external representations helped participants to gain insight; find connections; draw on prior knowledge; bridge gaps; discover; structure; and reduce confusion.

The questionnaire reported in this chapter is a first draft, which was revised and redeveloped into a new version for the next chapter (Chapter 4). The same question RQ1 was revised in the third study in Chapter 5 by using the new version of the questionnaire.

RQ1.2: *What is the relationship between the creation of user-generated external representations and query construction?*

In this study, only four participants created search terms. This might be due the small size of the datasets used during the study. In each of the two datasets used separately under each condition (user-generated representation and non-representation), there were only 50 documents, which enabled participants to see the entire dataset without creating a search term.

When analysed, the search term results created by the four participants demonstrated that, under the user-generated representation condition, participants relied less on the task brief as a resource for search terms; instead, they developed other new search terms. This could be a sign that participants developed a deeper understanding of the topic and that their information needs changed. This result suggested a relation between the use of external representations and the process of developing search terms. To investigate this further, the following hypothesis was developed and tested in another study presented in Chapter 5.

H_2: Creating external user-generated representations during sensemaking helps to increase keyword novelty.

3.7 Limitation

This study had some limitations regarding the following issues. – Due to the size of the datasets (50 documents per each dataset), participants were able to see the entire documents and, therefore, only four participants created search queries, whereas the rest of participants selected from them without constructing queries. The data collected from the audio recording protocol were also limited. These limitations were avoided in the next study reported in Chapter 5.

3.8 Chapter summary

This chapter reported on a study that was conducted to investigate how structuring thinking in user-generated external representations alters the sensemaking process and how to measure that effect quantitatively. This chapter aimed at investigating the effect of externalising thinking on the quality of sensemaking during an individual task by answering RQ1. More specifically, this study focused on answering the following sub-questions RQ1.1 and RQ1.2. The study in this chapter helped to:

- Provide data and the type of representations, which are to be further analysed (reported in Chapter 4) and which lead to developing a quantitative measure of the level of structuring in external representations created by the participants. The results of this analysis lead to an answer for RQ1 and its sub-questions within the user-generated representation condition (reported in Chapter 5);
- Set outlines for the next study (reported in Chapter 5);
- Establish an instrument for measuring perceived sensemaking, which lead to developing a more generic version of the questionnaire (reported in Chapter 4) and
- Add new variables to be further examined through the development of H_2.

CHAPTER 4: THE DEVELOPMENT OF MEASURES FOR STRUCTUREDNESS AND PERCEIVED SENSEMAKING

This chapter reports on the development of the measure levels of structuring in user-generated external representation. In the applied paradigm in the first study (Chapter 3), creating user-generated external representations was an essential part of the same iterative process (sensemaking), and the effects of creating user-generated external representations on cognition may well propagate around that process and they may be detectable in different parts in ways that have not been previously explored. Therefore, external representations created by participants in the first study were analysed. The results showed that participants created different representations in terms of their types (the way in which information was organised) and the levels of complexity. These results lead to investigate the impact of such variation in external representations in sensemaking and the way in which these variations can be measured. The chapter also reports on a new version of the sensemaking questionnaire that was established in Chapter 3.

The objectives of the studies involved in this chapter were to:

- Analyse external representations created by participants in the first study (Chapter3);
- Develop a quantitative measure of the level of structuring in user-generated external representations;
- Validate the developed measures of the level of structuring;
- Develop a quantitative measure of perceived sensemaking by developing a new version of the self-reported questionnaire discussed in Chapter 3; and
- Validate the new sensemaking self-reported questionnaire.

The structure of the remainder of this chapter is as follows:

- Section 4.1.1 presents the analysis of the external representations created by participants during the exploratory study in Chapter 3 and the development of a metric to measure the level of structuredness of free-form external representations generated by users.
- Section 4.1.2 reports on the operationalising of the variable structuredness.
- Section 4.1.3 presents a validation study of the developed metric.
- Section 4.1.4 presents a dissection and a summary of the first part of this chapter.
- Section 4.2 covers the development of a new version of the questionnaire that was developed to measure levels of perceived sensemaking in Chapter 3.

- Section 4.2.1 reports on a validation study of the new version of the questionnaire by presenting the study design, analysis and results.
- Sections 4.3 and 4.4 present the discussion and conclusions of the study, as well as the chapter summary.

4.1 External representations

Creating a representation – whether internally using a mental model or externally, for example by creating maps or tables – is central to the process of sensemaking. Previous studies emphasise the role of creating external structure. In the learning loop complex theory (Russell et al., 1993), *sensemaking* is defined as "the process of searching for a representation and encoding data in that representation to answer task-specific questions". External representations are also central to the notional model of sensemaking of Pirolli and Card (2005). Their model showed that in the stage referred to as Schematise, the analyst uses data from the Evidence File stage to structure a representation to aid the analysis process.

Creating a representation through creating user-generated external representations was the manipulated variable in the exploratory study reported in Chapter 3. The task for participants under one condition was to create an external representation of the domain. During the exploratory study, participants were found to create a different type of representation. Analysis was conducted on the representations created in the exploratory study to investigate the type of structures created by participants; how they organised the information; and whether there were similarities and differences.

4.1.1 Analysing the types of structures created by participants

This section concerns the Structure stage in the process model shown in Figure 1.2. Accordingly, analysis was conducted on the data from the user-generated representation condition from the exploratory study in Chapter 3, as participants created structures only under this condition.

Under the user-generated representation condition in the exploratory study, participants were asked to create representations by using Microsoft OneNote as a way to externalise their thinking while working on the provided sensemaking tasks. Participants were allowed to create any type of external representation of the domain that would help them to tell a story of what they thought had happened regarding the incidents in the given tasks. Microsoft OneNote was chosen, as it allows participants to move documents that they judge as having news of key events from the dataset to the workspace and organise them in different ways. It also enables note-taking, drawing different shapes and the creation of lines and highlights.

As the aim of creating external representations in the study was to externalise their thinking, participants were asked to create the external representations while working on the tasks. By the end of user-generated external representations sessions, each participant produced an external representation in Microsoft OneNote format and in total 13 external representations were produced by the 13 participants (see Appendix A.4). An approach developed by Okoro (2014) and Okoro and Attfield (2016) was adopted to analyse the representations created by the participants.

Figure 4.1 illustrates the structure of the process, including analyses of the external representations created by participants; operationalisation of the variable "structuredness"; the development of a metric to measure the level of structuredness of external representation; and ending with a validation study of the developed metric.

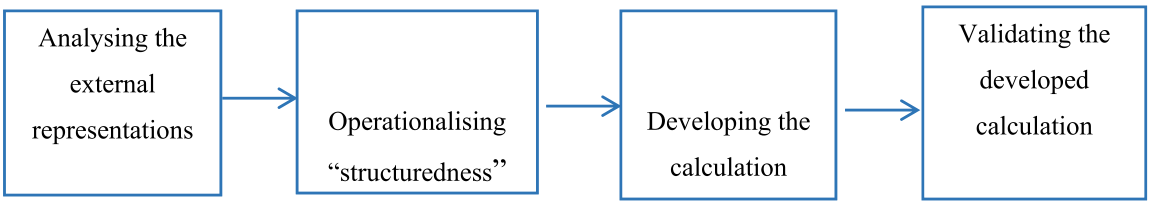


Figure 4.1: Structures of the next parts of the current section

4.1.1.1 Approach

In describing the representations that participants created, it is useful to make a distinction between two different types of user-generated external representations: semantic user-generated external representations and pragmatic user-generated external representations (Attfield et al., 2015). Semantic user-generated external representations relate to the meanings encoded within the artefacts provided for the tasks, as these relate to the external domain that is the subject of the sensemaking (e.g. historical events, a crime, the current political situation), such as creating a timeline of documents that were judged as relevant by participants. Pragmatic user-generated external representations, on the other hand, refer to the meanings the participant ascribed to the domain of the sensemaking task itself and in progress, such as creating a list of questions that needed to be answered during the tasks. One way of looking at this distinction is that the subject of pragmatic representation only exists while there is a sensemaking task in operation. The subjects of semantic representation exist whether someone is trying to make sense of them or not. In this thesis, the goal was to analyse the types of the semantic representations.

To describe the semantic structures generated by the participants, the approach developed by Okoro (2014) and Okoro and Attfield (2016) was adopted. Okoro and Attfield conducted a study to investigate how different kinds of information structuring can influence user performance in the context of intelligence analysis tasks. Part of the outcome of their study was the development of an approach for analysing the type of external representations created by users while involving them in a sensemaking task. This approach, underpinned by linguistic theory, developed a means of interpreting user-generated visual representations. The approach was based on the assumption that, similar to linguistic analysis, when people create external representations during sensemaking tasks, they adopt a visual language that has a grammar that can be described in terms of a set of production rules. Using this grammar, any given visual representations can be described in terms of parse trees (syntax trees) that describe it as entities embedded within other entities. The grammar is interpretively defined by interpreting the external representation in terms of what the analyst assumes the sensemaker's intent to be and by describing the underlying structure in a parse tree. Syntax trees (parse trees), which are visual representations of the production rules that users follow in creating the representations, consist of information object surrogate relations, source, summary, date, timeline, and themed grouping.

Okoro and Attfield (2016) defined a set of codes that refers to primitives and relations and that could be used to analyse the structure of the representation in terms of its semantics. These codes cover the different elements and relations that were created by participants while performing the investigation task. The set of relations and primitives used entirely depends on the representation under analysis. For example, primitives were sources (documents), summaries and dates, because the task for participants was to use the OneNote canvas to create representations by adding relevant sources and taking notes.

Because this approach can be used to analyse free-form external representations generated by users (which are the same types of representations that participants were asked to create during the two studies in Chapters 3 and 5 in this thesis), this approach was adopted as a basis for quantifying level of structure or "structuredness". By analysing participants' structures and syntax trees, their underlying production rules were created by using the same coding scheme developed by Okoro and Attfield (2016).

The coding scheme was used, while keeping any changes and amendments in mind, in case new codes emerged, such as new types of relations or new types of primitives. Six codes were added, based on the analysis of the type of representations that participants created during the exploratory study (Chapter 3). These six codes were:

- Notes;
- Folder relations;
- Themed grouping relations within a timeline;
- A timeline within themed grouping relations;
- Linear timeline relations; and;
- Ordinal timeline relations.

Okoro (2014) and Okoro and Attfield (2016) applied this approach to understand how the representations created by users evolved and changed over time. However, in this thesis, the approach was applied to the final representations created by participants, as the interest here was to explore the type of final representations created by participants. Table 4.1 shows the codes used when creating the syntax trees.

Table 4.1: Codes of relations and elements used for the analysis

Code	Description
Information objects surrogate relation	Set of elements that act as an identical alternative for a document or container of information. The elements within the surrogate could be source, date, title, and summary.
Source	A text file that contains information relevant to the given scenario in the task.
Title	Title given to sources by participants.
Summary	Information added to the representations to remind the sensemaker of the central idea communicated by the information object or an idea within it that is important for the current task.
Notes	Information added to the representations that is not part of an information object surrogate.
Date	A specific date on which the event occurred. It could be a day, a month, or a year or a combination of all three.
Ordinal timeline	Organising information chronologically within a representation without having a fixed timescale between them.
Linear timeline	Organising information chronologically within a representation with a fixed timescale between them.
Themed grouping relation	Organising information within a representation into groups based on their similarities.
Folder relation	Adding elements (notes, sources, etc.) into OneNote workspace without having a relation amongst them.

According to this approach, structures consist of elements that can be part of relations. Sources, dates and summaries are the primitive elements of the structure. When all the primitive elements represent the same information object, it is developed into an information object surrogate relation. Information object surrogate relations can become an element of other relations, such as timeline relations and themed grouping relations. A timeline relation consists of information object surrogate elements organised in chronological order; while a themed grouping relation consists of information object surrogate elements that have some thematic connections. In a syntax tree, the relations and primitives are abbreviated, as outlined in Table 4.2.

Table 4.2: Shortcut forms of codes to represent the different elements of the syntax tree

Relation/Primitive	Shortcut form
Overall representation	R
Information object surrogate relation	IOS
Source	S
Summary	SUM
Folder relation	Folder
Date	D
Timeline relation	Timeline
Themed grouping relation	Them
Title	T
Note	N

4.1.1.2 Applying the approach

The following section presents a worked example of how the approach of analysing external representations by Okoro (2014) and Okoro and Attfield (2016) was applied.

Worked example

Figure 4.2 shows a representation created by one of the participants (P4) in the study reported in Chapter 3. As illustrated, the participant copied and pasted 15 Word documents (sources) to OneNote workspace. Each of these Word documents included a news story that the participant judged to have news of a key event regarding the crisis in Syria (see the task described in Section 3.1.5.2). Summaries and dates were added to some parts of the representation. The participant also organised these documents in a different spatial area of the workspace, where certain documents were grouped together to reflect some type of relation between them. The first step in the analysis was to identify the sub-structures within the representations. A sub-structure in a representation is not only based on the spatial position within the representation; it is identified based on roles and functions (Okoro, 2014).

In this particular example (Figure 4.2), the participant organised the documents into three semantic groups: a group of documents in the top position of the workspace surrounded by a rectangle; a group of documents in the middle position of the workspace, listed from left to right (as illustrated by the arrow above them); and a final group of documents in the lower position of the workspace grouped by one title named CONTEXT.

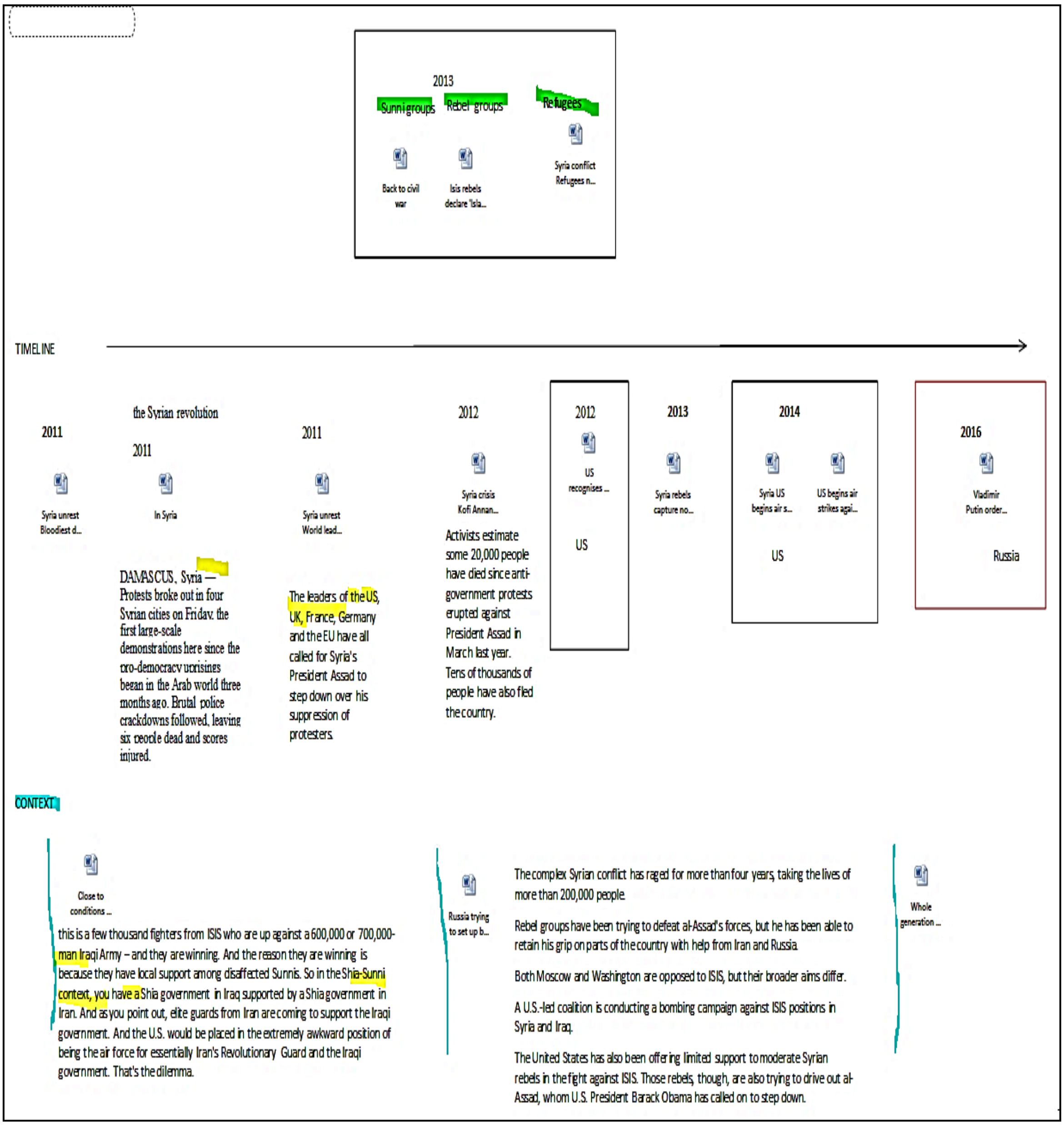


Figure 4.2: Representation created by Participant 4 in the exploratory study (Chapter 3)

To create the syntax tree that described this representation, the representation was divided into three parts: A, B and C (as can be seen in Figure 4.3). Other representations were divided into different numbers of parts, based on how the participant organised the documents.

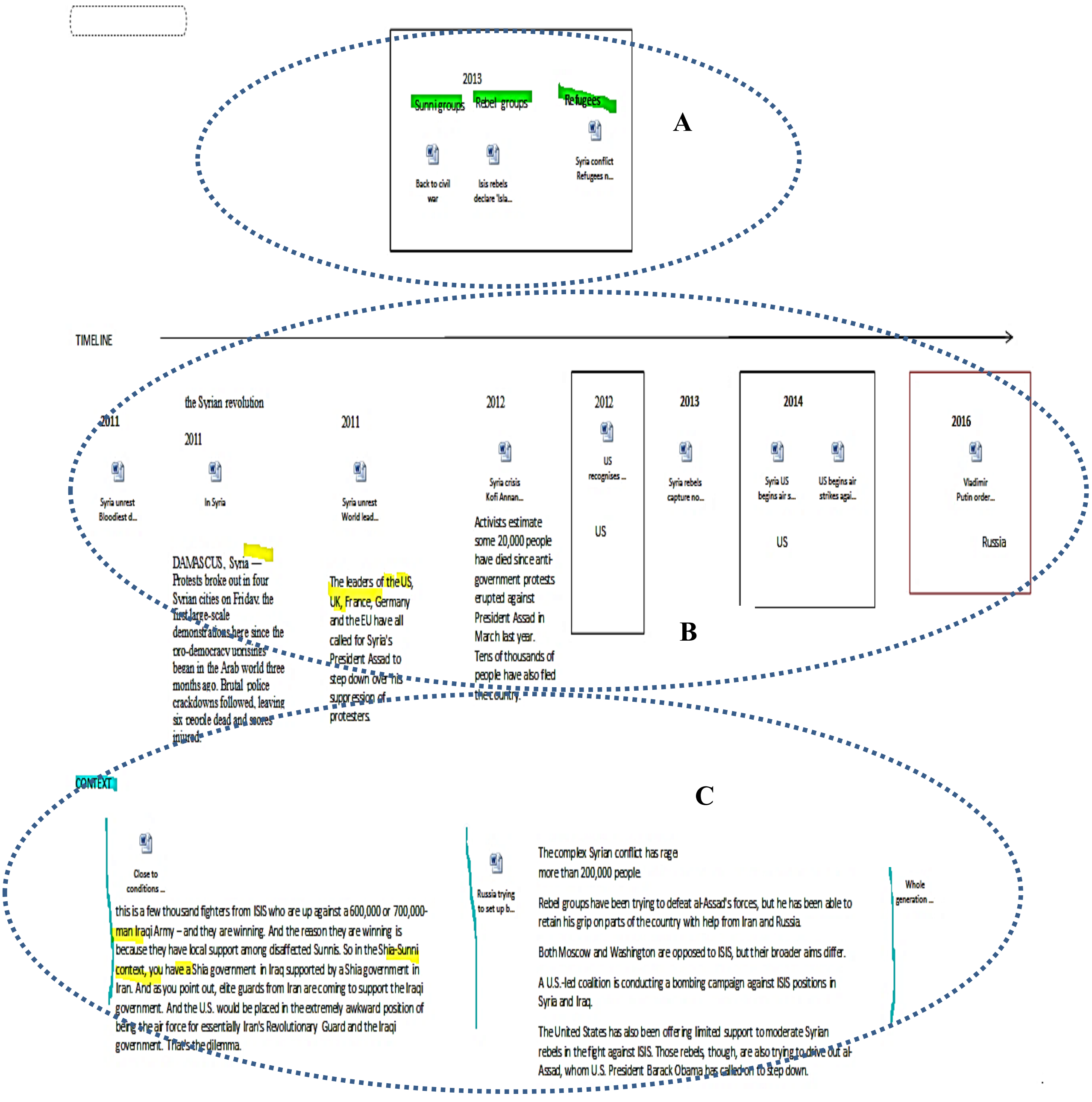


Figure 4.3: Identification of the different parts of the representation

Identifying the sub-structure of a representation helped to simplify the process of adding the relations and primitives into the parse tree generator. The syntax tree was generated by means of phpSyntaxTree software designed by Eisenbach (2003).

The three parts displayed in Figure 4.3 were then added to the syntax tree. However, the sequence of adding these parts of the representations to the parse tree generator is not the sequence by which the user added them to the representations during the task; it is a first step in the analysis process to create the syntax tree. Therefore, these three parts can be added to the syntax tree in any sequence. For instance, they can be added by following a top-down approach starting by part A, then B, and finally by adding C, or in another sequence, such as C, then A, and then B.

Figure 4.4 shows the first part of the representation (Part A). In this part of the representation, the participant added three documents (sources), each of which had a title and a summary. The three documents were grouped into one theme entitled 2013. In the creation of a syntax tree of a representation, titles were considered as one of the primitives. However, files within the datasets that were used during the exploratory study (Chapter 3) already had their own titles and, when participants copied one of the files from the datasets and pasted it into OneNote workspace, both the file and its title were added. Therefore, when creating the syntax trees of the representations from the exploratory study, titles that were not added by participants and that were part of files within the data were not involved when creating the syntax trees.

Figure 4.4: Representation consisting of a themed grouping relation

This part of the representation (Part A) can be visually described by using a syntax tree consisting of a themed grouping relation with three information object surrogates, where each consists of a source (S) and a summary SUM, as illustrated in Figure 4.5.

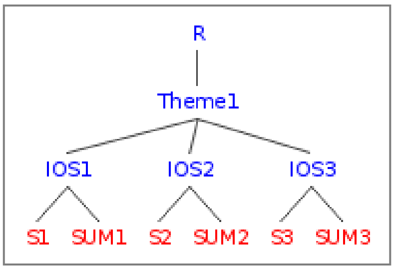


Figure 4.5: Syntax tree of a representation consisting of one themed grouping relation with multiple information surrogates

The minimal representational language that is used in the syntax tree can also be described by using the underlying production rules of the syntax tree as follows:

<Representation > ⟶ *< Themed grouping relation>*

<Themed grouping relation > ⟶ *<Information object surrogate>*$_n$

<Information object surrogate> ⟶ *<Source > <Summary>*

Where $_n$ refers to an infinite number of the sub-entity.

In the second part of the representation (Part B), which is shown in Figure 4.6, P4 created a timeline by organising the documents chronologically, from left to right. Some of these documents had a title or a summary and a date. Within the timeline, the participant created two sub-relations: a themed grouping relation entitled US, with one document dated 2012 and two documents dated 2014, together with a themed grouping relation entitled RUSSIA, with one document dated 2016.

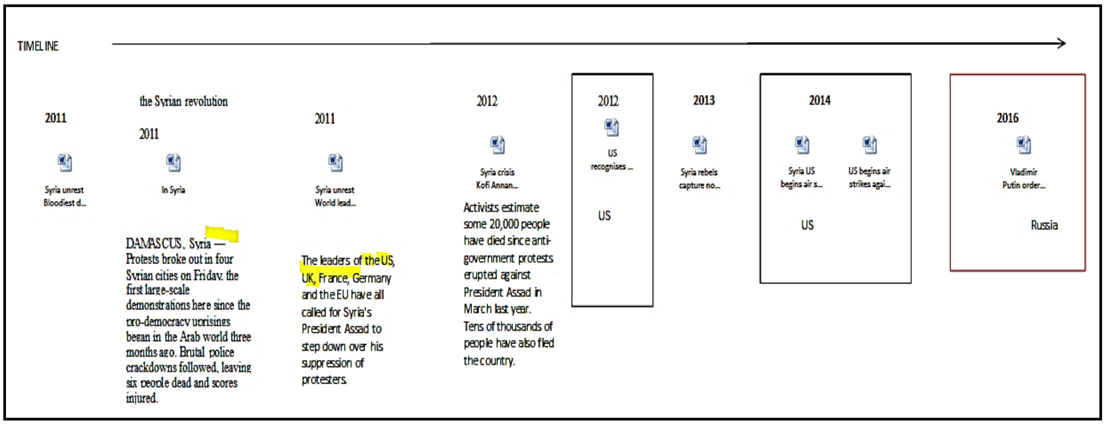


Figure 4.6: Representations consisting of themed grouping relations within a timeline

As illustrated in Figure 4.7, this part of the representation was then added to the syntax tree, where the representation so far can be described as consisting of two main relations: a themed grouping relation and a timeline. The themed grouping relation consisted of multiple information object surrogates, and the timeline relation consisted of multiple themed grouping relations (sub-relations) and multiple information object surrogates. Information object surrogates consist of primitives that are sources (S), summaries (SUM) and dates (D).

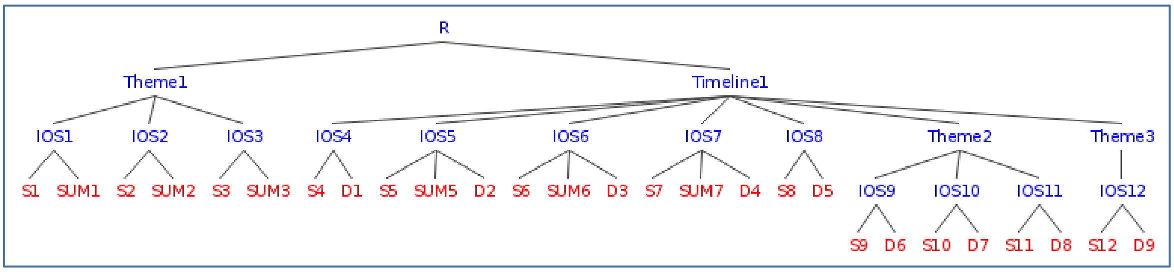


Figure 4.7: Syntax tree consisting of a themed grouping relation and themed grouping relations within a timeline

The minimal representational language that is used in the syntax tree can also be described by using the underlying production rules of the syntax tree as follows:

<Representation> $\longrightarrow$ *<Theme> <Timeline>*

<Timeline> $\longrightarrow$ *<Information Object Surrogate>* $_n$ |*<Theme>* $_n$

<Theme> $\longrightarrow$ *<Information Object Surrogate>* $_n$

<Information Object Surrogate> $\longrightarrow$ *<Source> <Date> < Summary> |<Source> < Summary>| Source> <Date>*

Where "|" acts as an OR operator.

Participant 4 also added a third part to the representation (Part C), which involved three documents. Two of these documents had a summary, as shown in Figure 4.8.

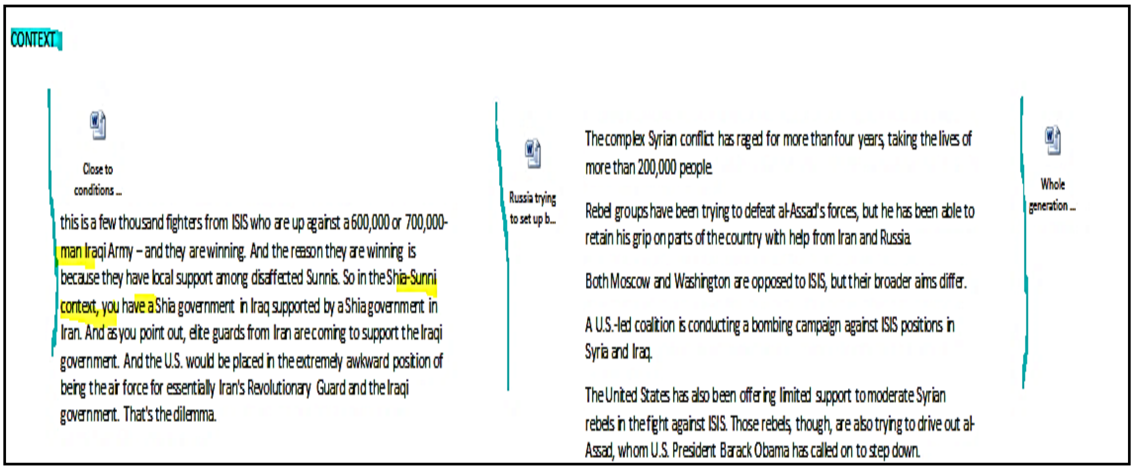


Figure 4.8: Representation consisting of themed grouping relation

As illustrated in Figure 4.9, Part C, which was the syntax tree that visually described the relation between entities, type of relations and primitives, within the overall representation, was added to the syntax tree.

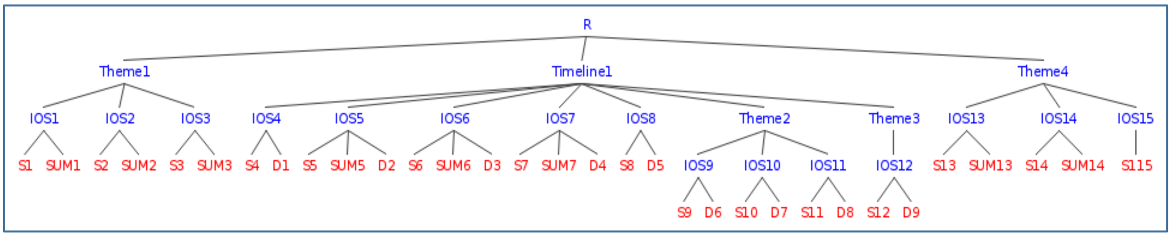


Figure 4.9: Syntax tree consisting of two themed grouping relations and themed grouping relations within a timeline

The minimal representational language that is used in the syntax tree can also be described by using the underlying production rules of the syntax tree as follows:

<Representation> $\rightarrow$ *<Theme>* $_n$ *<Timeline>*

<Timeline> $\rightarrow$ *<Information Object Surrogate>* $_n$ *|<Theme>* $_n$

<Theme> $\rightarrow$ *<Information Object Surrogate>* $_n$ *|<Source>*

<Information Object Surrogate> $\rightarrow$ *<Source> <Date> < Summary> |<Source> < Summary>| Source> <Date>*

As illustrated by the syntax tree (Figure 4.9), P4 created a representation that consisted of three main relations: a timeline relation and two themed grouping relations, which were at the second level of the hierarchy in this syntax tree. Both themed grouping relations (Themes 2 and 3) consisted of multiples primitives that are source (S) and summary (SUM), where each was a part of an information object surrogate relation (IOS). The timeline also contained multiples primitives that were source (S), summary (SUM) and date (D), and each was a part of an information object surrogate relation IOS. However, part of these information object surges were part of another level of sub-relations that were themed grouping relations.

The syntax tree (Figure 4.9) shows the meaning structure that the participant intended to create between the different entities within the representation. This step in the worked example was applied to all the representations that were created by the other 12 participants (see Appendix B.1).

Table 4.2 shows the types of representations created by the 13 participants. Cells in grey mean that the participant created one relation of this type, while cells in yellow mean that the participant created multiple relations of this relation type. For instance, P1 created an ordinal timeline relation and multiple themed grouping relations, whereas both P2 and P3 created a single timeline and P4 created multiple themed grouping relations, as well as multiple themes within a timeline relation.

The results summarised in Table 4.2 show that the participants created different types of representations. Some participants created representations that included one type of relation, e.g. two participants (P8 and P13) created a folder relation. Four participants created a single timeline relation: P2 and P3 created an ordinal timeline relation and both P6 and P10 created a liner timeline relation. Likewise, four participants created only themed grouping relations: P7, P9, P11 and P12. Other participants created representations consisting of multiple relations types; they either created the different type of relations separately, or the relations were overlapping. For instance, the representations created by P1 included the following separate sub-structures: an ordinal timeline and multiple themed grouping relations. Similarly, the representations by P4 included two separate sub-structures: themed grouping relations and an overlapped relation, which is themed grouping relations within a timeline. P5 also created a representation with overlapped timelines within a themed grouping relation. The results also showed that, apart from P1 and P13, all participants created an IOS relationship. Based on the results in Table 4.3, IOS relationship and themed grouping were the most created type of relations.

Table 4.3: Types of representations created by each participant

Participant	Folder	Ordinal timeline	Linear timeline	Timeline within a themed grouping relation	Themed grouping within a timeline	Themed grouping relation	IOS
P1							
P2							
P3							
P4							
P5							
P6							
P7							
P8							
P9							
P10							
P11							
P12							
P13							

Apart from the variations in the representations in term of relations types, there were also variations in the number of primitives (documents, notes and dates). The syntax tree created by the representation of each participant showed that the number of primitives (source, summary and date) e.g. Figures 4.10 and 4.11 show syntax trees of representations, created by P8 and P10 respectively, with different numbers of primitives.

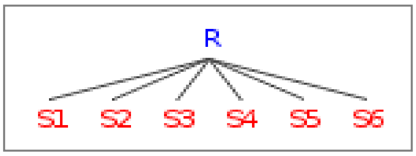


Figure 4.10: Syntax tree consists of six sources in a folder relation (P8)

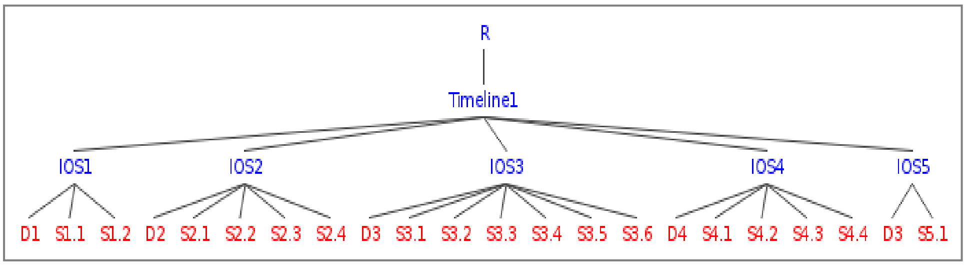


Figure 4.11: Syntax tree consists of a linear timeline with 17 sources (P10)

Most importantly, there were variations in the complexity of the representations, as it varied from a simple level of organisation, where participants used OneNote workspace as a folder to save relevant documents or take notes, to complex levels where information was organised in overlapping relations, such as themed grouping relation within a timeline. Syntax trees of the representations varied from a single to multiple levels of relations. Some syntax trees only had two levels of relations, while in others the relations between the leaf and root (the overall representation and the primitives) were explained with more than one level of relation.

Keeping these results in mind and based on the assumption in previous research that structuring is central to the process of sensemaking, as proposed by Russell et al. (1993) and Pirolli and Card (2005), as well as the results from the exploratory study in Chapter 3, it could be proved that structuring through creating user-generated external representations enhances levels of perceived sensemaking. It could be hypothesised that creating a structure will not only have an impact on sensemaking, but also that the amount of structuring created in the representations may have an impact on the sensemaking process. In this thesis, a new a variable referred to as "structuredness" was defined to describe the level of structuring in the created representations. Therefore, RQ1 was also investigated in relation to levels of structuredness of external representations.

RQ1: *How does the creation of user-generated external representations measurably affect the sensemaking process?*

Continuing the work in Chapter 3, existing hypotheses (H_1 and H_2) were further developed and the following new hypotheses were implemented to examine the relation between structuredness and the other variables that creating user-generated external representations was assumed to have effects on:

H_3: Structuredness correlates with perceived sensemaking.

H_4: Structuredness correlates with keyword novelty.

The testing of these hypotheses is reported in detail Chapter 5, because they were examined by using data from a different study.

To investigate the effect of levels of structuring through testing these hypotheses, a calculation was developed to measure the level of structuredness by operationalising the variable structuredness. Operationalising structuredness stem from the results of analysing external representations created by participants reported in this sections, which showed the following two important factors to consider when thinking about structuredness: different types of relations within external representations and different levels of complexity.

4.1.2 Operationalising the variable structuredness

Although structuredness can be measured in different ways, the results of analysing external representations created by the participants during the first study suggested some factors that could be considered. For instance, the parse trees that described the representations had some differences in terms of their depth and length. Moreover, the representations involved different type of relations, such timeline and themed group relation. The following section describes the operationalising of structuredness, while considering such factors.

According to the data frame theory of sensemaking of by Klein et al. (2007, p. 119), the frame, which is the internal structure that people use or develop to interpret a situation, is described as follows:

> *A frame is not a collection of inferences drawn from the data, although it can include inferences. Elements are explained when they are fitted into a structure that links them to other elements.*

Klein et al. (2007, p. 119) add:

> *The purpose of the frame is to define the elements of the situations, describe the significance of these elements, describe their relation to each other, frame can*

organise the relation that are spatial (maps), causal (stories and scenario), temporal (stories and scenario), or functional (scripts).

Therefore, the level of structuring of external representations in general can be thought of as the amount of information that is involved within them, but also the extent to which this information is connected. Accordingly, the level of structuredness of representations created during the studies in this thesis was not only the number of files that participants collected and judged as relevant in OneNote canvas, but also about whether there were relations between them, e.g. timelines relations, or themed grouped relations. Therefore, the level of the variable structuredness was considered high, if the amount of structuring in the representations was enough to build a satisfactory understanding of the domain.

4.1.3 Development of the calculation

The calculation of the level of structuredness was also based on the approach by Okoro and Attfield (2016) and the idea of creating a syntax tree that visually describes the relations and primitives within a representation, the connection among them, and how they relate to the overall representation.

The approach was applied on the final representations created by participants, as in the worked example in Section 4.1.3. In this example, the root of the syntax tree represents the overall representations, branch nodes represent relations within the representation, and leaf nodes represent the primitive elements. Primitives refer to source, notes, titles and dates.

Creating a syntax tree of a representation helps to see the embodiment between these elements and relations. The length and depth of the created parse tree were taken into account in calculating the level of structuredness of the external representation. Therefore, the length and depth were considered when developing the metric to measure the level of structuredness.

Apart from demonstrating the embodiment between these elements and relations within a representation, the parse tree reveals another important part of the level of structuredness: it shows the hierarchical nature of the created structures. In a hierarchical structure, higher nodes control lower nodes by some roles or constraints. In a parse tree of a representation (e.g. Figure 4.9), any child nodes are constrained by some roles form the parent node; i.e. primitives and sub-relations in the created structure are controlled by some roles from the parent relations, at a higher level of syntax, to which they belong. Therefore, constraints imposed by each relation were also considered during the development of the metric to measure the level of structuredness.

In this study, it was assumed that different types of relations would impose different types of roles and constraints on primitives and sub-relations to which they belonged (i.e. that provide different degrees of structure). Some researchers argue for the same idea. For example, Scaife and Rogers (1996) suggest some explanations of how graphical representations work and aid cognition, and among these explanations they mentioned "graphical constraining", which refers to the idea that the way we graphically represent information imposes some constraints on how we interpret and infer from this information. For example, organising the same data in two different ways, chronologically and themed grouping relation, may lead us to draw different conclusions.

Relation types impose different constraints on information, such as position constraints. Every relation type has its semantics that imposes some level of constraint. When a primitive or a relation becomes part of a relation, the relation imposes some constraints on where to place that primitive and relation and that positioning carries meaning.

The semantics of each relation is related to the variable type that can be mapped by each. For example, in themed grouping relations, primitives are organised based on the category (theme) to which they belong. In timeline relations, primitives can be chronologically organised in a specific sequence (such as by years or months) or linearly (where the distance between years and months is fixed). In the former type of timeline, the variable type is ordinal, while in the latter it is continuous.

The degree of constraints imposed by each variable type is different when compared to each other. Categorical types of variables are constrained by the themes in which they are placed. Similar to themed grouping relations, IOS relation primitives are organised based on the category (IOS) primitives to which they belong. However, IOS imposes more semantic constraints than themed grouping relations, because each contains one each of a finite set of primitives. Once primitives have been added to a particular category, they can be placed at any position within the category and they will still carry the same meaning. Ordinal variable types have more constraints in terms of positioning than categorical, and contentious variables are more constrained than categorical and ordinal. In the folder type of representations there are no constraints.

Accordingly, a score was given to each type of relation regarding how much it constrains the position of primitives compared to each other, as illustrated in Table 4.4. The assigned scores were then included in the developed metric.

Table 4.4: Scores assigned to each relation based on level of semantic constraints

Relation type	Type of variable	Variable type score
Folder	None	1
Themed grouping	Categorical	2
IOS	Categorical	3
Timeline (order)/Directional	Ordinal	4
Timeline (Liner)	Continues	5

Each relation within a representation has a structuredness value, whether a higher-level relation (which involves other sub-relations and possibly some primitives) or a lowest-level relation, which joins only primitives. The calculation started from the top and continued to the bottom of the syntax tree. The structuredness of a representation first propagated down through a tree from top to bottom, as follows:
$ST(R) = \sum (ST\ (HLR)$

where ST = structuredness, R = representation, and HLR = higher-level relations in the parse tree.

However, the structuredness higher-level relations depended on:

- Relation type;
- Number of primitives; and
- Structuredness of lower-level (sub-relations) relations.

Therefore, the calculation at this level became:

$ST\ (HLR) = (ST\ (LLR) \times VH)$

where LLR = lower-level relations embodied within this higher-level relation and VH = variable type of the higher-level relation.

Lowest-level relations have a structuredness value that depended upon:

- Relation type;
- Primitives; and
- St (LLR) = (P × VL)

where VL = variable type of the lower-level relation and P = Primitives within the lower–level relation.

Once the structuredness of the lower-level relation had been calculated, the structuredness of a representation propagated up through a tree from down to up again. Each sub-relation added their structuredness to the calculation of the higher-level relation to which they belonged.

Figure 4.12 presents a worked example that calculates structuredness of an ordinal timeline relation. The worked example in Figure 4.1 was divided into sections (A, B, C, D, E and F) to illustrate how the calculation of structuredness was performed. As explained by the blue dot arrows, the structuredness calculation started from the top (section A) and continued to the bottom of the syntax tree structuredness of a representation propagated, and up through a tree from down to up again (section F). Each sub-relation added its structuredness to the structuredness of the representation.

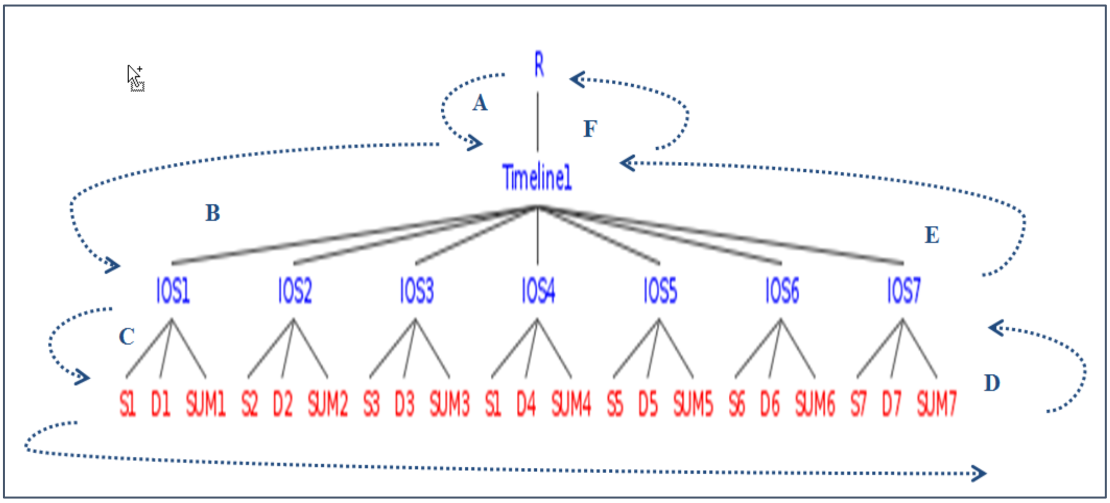


Figure 4.12: Syntax tree consisting of timelines relations

- The calculation of the overall structuredness of the representation starts by calculating the structuredness of the timeline relation (section A). The formula to calculate structuredness of this sub-relations is :

$$ST(R) = ST\ (Timeline).$$

- However, the structuredness of the timeline relation is based on the structuredness of its sub-relations (the ISO relations) and the semantic constraint imposed by the timeline relation, which, in this thesis, refers to relation type (section B). In this example, timeline is ordinal and, therefore, it imposes ordinal constrains on the position of each or its related elements. The formula to calculate structuredness of this sub-relations becomes:

$$ST\ (Timeline) = (Timeline\text{'s variable type} \times (ST\ (IOS1)_{n})$$

  At this point, the structuredness of a representation propagated down through a tree from top-to-bottom.

- Similarly, the structuredness the IOS is based on the primitives within the ISO relation and the semantic constraint imposed by it (section C). IOS relations imposed categorical constraints on the position of each or its related elements. The formula to calculate structuredness of this sub-relations is:

$$ST\ (IOSi) = IOS1\text{'s variable type} \times (S1+D1+SUM1)_{n}$$

- As the primitives within the ISO are the lowest-level elements within this representations, the calculation of the structuredness of the ISO can be now proceed (section D). The calculation the formula to calculate structuredness of this sub-relations is:

$$ST\ (IOS_{i}) = ((3\times3) + (3\times3) + (3\times3) + (3\times3) + (3\times3) + (3\times3) + (3\times3))$$

  Where in each bracket, the first (3) is the score given to IOS relation regarding how much it constrains and the second (3) is the number of primitive within the IOS.

  At this point, the calculation of the structuredness of the overall representations propagated up, through a tree from bottom-to-top of the syntax tree. The structuredness of the ISO then added to the structuredness of the timeline relation (section F). The calculation at this point is:

$$\text{ST (Timeline)} = \text{Timeline's variable type} \times (63)$$

$$\text{ST (Timeline)} = 4 \times 63$$

Where (4) is the score given to ordinal timeline relation regarding how much it constrains and the second (63) is the structuredness of its sub-relations.

Calculating the structuredness of the timeline relation, which is the highest-level relation, gives the overall structuredness value of the representation (section G). The calculation at this point is:

$$\text{ST (R)} = 252.$$

4.1.4 Validation study

This section reports on a validation that was conducted, in order to assess the extent to which the calculation of structuredness corresponded to the intuitive judgement that people would actually make about how much structure there was in a representation.

Participants were provided with five samples of representations, adopted from the first exploratory study (Chapter 3), each printed on a separate piece of A4 paper. The task for participants was to rank the samples from low to high, based on their level of structuring.

This section reports a validation study that was conducted to evaluate the measurement developed in Section 4.1.6. It presents the study design and materials, participants, procedure, and data analysis.

4.1.4.1 Study design and materials

The samples chosen to cover the different types of representation created by participants in the first study were: timeline; timelines embedded within themed grouping relations; themed grouping relations embedded within the timeline; folder; and themed grouping relations.

Some changes were made to the selected representations to fit the purpose of the current study. Most of these changes were made to enhance the clarity of representation. For instance, the chronological sequence in some of the created timeline relations in the exploratory study (Chapter 3) were implicit, as the chronological sequence of the files could only be seen when the files were opened. Therefore, dates were added explicitly to timeline relations of this kind of representation, as participants were provided with hard copies of the representations, and would not be able to open files and track such implicit relations.

Other changes were also made to unify the format and style of the different relations. For instance, participants in the exploratory study (Chapter 3) used different types of lines (e.g. different line styles, different colours and different widths) to represent the same concept (e.g. timeline). Themed grouping relations were also represented differently by participants, e.g. P1 drew rectangles around similar documents, while P4 highlighted similar documents with the same colour. Therefore, to meet the purpose of the current study and to focus on measuring the main variable that had to be measured (i.e. the level of structuredness) and to eliminate confusion, one style of line in terms of colour, shape and width was adopted in all the samples. In addition, themed grouping relations in the samples were unified into one style by drawing rectangles around documents that belonged to the same theme. Moreover, the same files were used in all the samples of representations. The only difference between the five representations was the type of relations (See Appendix B.2).

4.1.4.2 Participants

In total, 17 postgraduate students from the Science and Technology School at Middlesex University took part in the study, comprising 12 males and 5 females, with 4 participants being from the Psychology Department and 13 from the Computer Science Department. Participants were recruited by email.

4.1.4.3 Procedures

After placing the A4 papers showing the representations on a table, participants were verbally given the following instructions:

“In front of you there are five hypothetical structures. Each is assumed to explain the crisis in Syria. All the structures tell the same story; in other words, all include that same information (i.e. they are the same Word document). However, each structure represents the information from a different point of view and each has a different level of structuring information. Your job is to decide the level of structuring of these representations by ranking the five given representations from 1 to 5, where 1 is the lowest level of structuring and 5 is the highest level of structuring”.

The idea of the evaluation study was to compare people’s intuition of what structuredness was to the levels of structuredness calculated by the developed metric. Therefore, information about how the variable structuredness was operationalised to developed metrics was not provided to participants. Participants ranked the representations by assigning a number from one to five for each paper. To make the process easier for the participants and to allow them to compare between the five representations, they were asked to place the A4 paper on the table vertically next to each other, from the least to the highest structured. There was no fixed duration time for the study as it was estimated that it would not take more than five minutes for all participants. Participants were allowed to review and adjust the rating during the study.

4.1.4.4 Analysis

The analysis involved the following three steps: (i) the levels of structuredness of the five samples were calculated by using the developed metrics (see Appendix B.3); (ii) the consistency of how participants ranked each representation were examined; and (iii) the correlation between the way the metrics measured the level of structuredness of the five representations and people’s intuition of structuredness was measured.

4.1.4.5 Results

To prepare the data for the analysis, the scores given by each participant were entered into SPSS. Each of the five representations had 17 ranks each from a different participant.

A syntax tree was created to analyse and lay out all the components of each representation for all five samples (see Appendix B.3). Structuredness of the external representations in the five samples was then measured by using the metric. The first step of the analysis aimed to describe the pattern of ranks assigned by participants to the five types of representations.

Figure 4.13 depicts the distribution of responses on the ranking scale (vertical axis) for each case (horizontal axis). Lines in the graph indicate medians and stars outline observations.

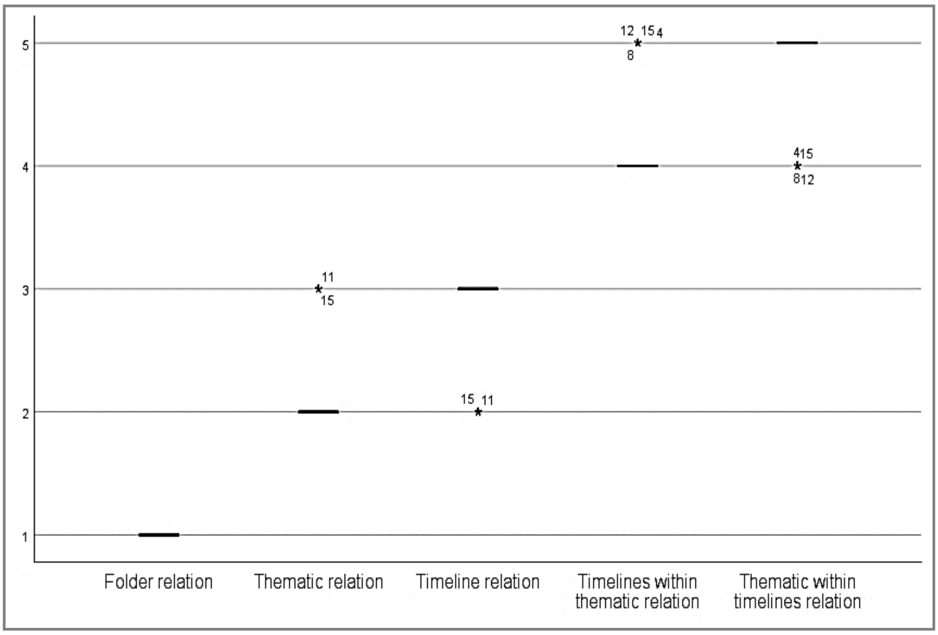


Figure 4.13: Structuredness ranking distribution on each representation

The data revealed a clear ranking pattern across the five types of representation. All participants agreed that the folder relation was the least structured representation, whereas themed grouping and timeline relations were ranked in second and third place respectively, except for two participants (P11 and P15), who graded them the other way around. In turn, the timelines within themed grouping and themed grouping within timelines relations were ranked in fourth and fifth place respectively, with only four participants asserting the opposite ranking. These results showed a significantly high concordance with the ranking assigned by participants (Kendall's $W = .93$, $p < .05$) and suggested that their judgements on the structuredness of representations increased according to their actual value in the structuredness metric.

To depict the association between both variables accurately, Figure 4.14 illustrates the correlation between the structuredness of the level, as measured by mean ranks assigned by participants (horizontal axis) and as measured by the metric value (vertical axis).

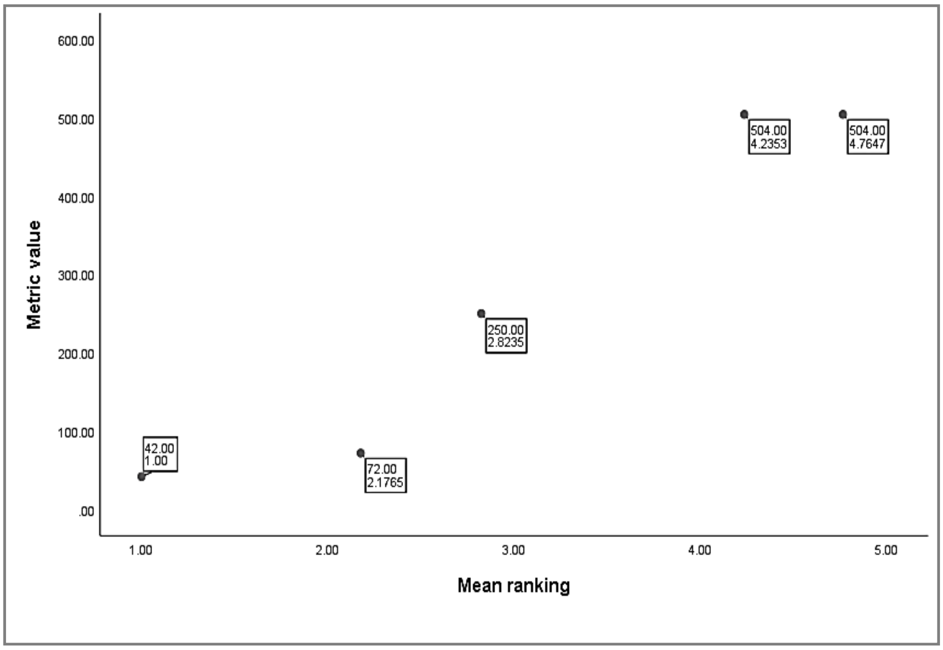


Figure 4.14: Correlation between mean ranking and metric values of structuredness

Overall, the plot showed a positive association between both variables. In other words, as the ranking values asserted by participants increased – i.e. their perception of the structuredness of the representations – the objective measure of this attribute of representations also increased, namely the metric values. The Spearman's coefficient of correlation also confirmed that this relation was significantly strong ($r = .97$, $p < .05$). However, it is worth noting that a plateau could be observed in the top right corner of the plot, whereby participants tended to rank thematically within timelines relations (4.8 mean ranking) as more structured than timelines within thematic relations (4.2 mean ranking). Considering that both representations had the same objective level of structuredness (504 points in the metric value), these results indicated that, when participants were requested to prioritise their judgement on the level of structuredness between both categories, thematic within timelines representations prevailed as the most structured type of representation.

4.2 Measuring perceived sensemaking

This part of this chapter reports on the development of a new version of the questionnaire that was developed to measure perceived sensemaking based on sensemaking theories, as reported in Chapter 3. Although the questionnaire proved to be suitable for measuring perceived sensemaking, it did demonstrate some limitations. Some statements included words related to building a story, which eliminated its applicability to measure only perceived sensemaking when the main task was to build a story. Therefore, measuring the validity of the questionnaire by using statistics tests, such as principal component analysis (PCA), required a larger sample size. It also took a longer time to find the right task to fit the old version of the questionnaire. To avoid this and to produce a more general version that could be used in any future studies about sensemaking, a further step was taken.

A new version of the questionnaire was developed by rewording some of the statements in the old version (see Appendix C.2). Table 4.5 compares the statements between the old and new versions of the questionnaire. All statements remained the same in terms of being built on sensemaking theories; the changes were only made to some statements that contained words such as “conflict”, “event”, “people” and “countries”. Table 4.6 details the sub-questions included in the new version of the instrument and the name given to their corresponding subscales.

Table 4.5: Compression of the statements in the old version of the questionnaire compared to the new statements in the new version

	Old version of the questionnaire	New version of the questionnaire
Q4	Draw a link between the conflict you read about and similar previous conflicts.	Draw a link between the available information and things you were aware of already.
Q5	Draw a link between the story you read about and similar previous stories.	Draw a link between information you encountered and your prior knowledge.
Q6	Develop a coherent representation of the information.	Develop a coherent view of the information.
Q8	Find a way to organise the information.	Find a way to (mentally or otherwise) organise the information.
Q9 (Q10 & Q11)	Understand connections between people (countries). Understand connections between places. Understand connections between events.	Understand connections between things.
Q12	Discover the gaps in your information about the given task.	Discover where the gaps are in how you understand a situation.
Q13	Bridge gaps in your information about the given task.	Bridge gaps in your understanding of a situation.

Table 4.6: Questions and subscales of the instrument used to survey sensemaking

Subscale	Questions
Comprehension and gaining insight	Q1: Gain insight from the available information. Q2: Construct an understanding from the available information. Q3: Make sense of the available information.
Drawing on prior knowledge	Q4: Draw a link between the available information and things you were aware of already. Q5: Draw a link between information you encountered and your prior knowledge.
Structuring	Q6: Develop a coherent view of the information. Q7: Find structure in the information. Q8: Find a way to (mentally or otherwise) organise the information.
Understanding connections	Q9: Understand connections between things.
Gap discovering and bridging	Q10: Discover where the gaps are in how you understand a situation. Q11: Bridge gaps in your understanding of a situation.
Reducing confusion and ambiguity	Q12: Reduce any confusion.
	Q13: Reduce any ambiguity.

Similar to the old version of the questionnaire, the 13 sub-questions in Table 4.5 each effectively foregrounded key content, which correlated with a particular theory of sensemaking. For example, "… find a way to organise information" correlated with the structuring subscale. Each subscale was scored on a visual analogue scale (VAS), ranging from 1 (to a small extent) to 11 (to a large extent). Sub-question 3 particularly addressed sensemaking directly: "To what extent do you think conducting the given task under this condition helped you to … Make sense of the available information?"

4.2.1 Method

This section reports on the study that was conducted to validate the new version of the questionnaire. It presents the participants, procedures and data analysis.

4.2.1.1 Participants

Participants were postgraduate students or staff members at Middlesex University. PhD students were approached in person in their research rooms and their informed consent to participate was collected before data collection. To distribute the questionnaire to participants after performing a sensemaking task (such as attending a lecture), emails were sent to module leaders in different schools (see Table 4.7 for more details). In total, 120 subjects participated in the study.

4.2.1.2 Procedure

Data were collected from participants after they performed the following sensemaking tasks:

1) Reading an academic article;
2) Attending a lecture;
3) Attending a seminar;
4) Attending a workshop;
5) Participating in a lab study; and
6) Students who had just submitted course work.

PhD students were selected for reading an article as they are more used to performing such an activity; hence, it was not necessary to ask them to read a paper specifically to fill in the questionnaire. The task for them was to fill in the questionnaire regarding an article that they recently read. The questionnaires were also collected from participants attending lectures in a different topic (to provide some variation regarding difficulty).

All participants filled in the questionnaire at the end of the sensemaking task that they were performing. They were asked to fill in the questionnaire to report how much they made sense from the available information in the task, whether it was a lecture, or a seminar.

Table 4.7 outlines characteristics of the tasks performed by participants, as well as their educational level and their participant numbers.

Table 4.7: Task details and number of participants by task

Type of tasks	Details about the tasks	Participants' educational level	Number of participants
Attending lectures	Lecture in human computer interaction	Masters' students	9
	Lecture in Psychology	Masters' students	16
	Lecture in Law	Masters' students	9
	Marketing	Masters' students	1
	Lecture in computer networks and security	Masters' students	5
Seminars	Human computer interaction	Masters' students and staff	16
Workshops	Programming journalism	Masters' students	6
	Print journalism work shop	Masters' students	14
Students who just submitted a coursework	Podcasting TV news packages	Masters' students	10
Reading an article	Computer science	PhD students	14
	Law	PhD students	2
	Science	PhD students	2
Lab study	A study of reflection on personal health information conducted by another PhD researcher (participants were HIV+ adults)	N/A	10

4.2.1.3 Analysis

Principal component analysis (PCA) (Field, 2009) was initially used to examine the dimensionality of the instrument based on its sub-questions. Eigenvalues greater than 1 and factor loadings greater than .3 were used as the main criteria to define the minimum number of factors explaining the total variance among these items. Based on these results, the internal consistency (Nunnally & Bernstein, 1994) of this group of items was estimated to determine the reliability of the instrument. Cronbach's alpha values greater than 0.6 were considered acceptable indications of internal consistency of the scales. Additive indices were calculated as an overall score of sensemaking for each individual.

In summary, PCA and reliability analysis were used to complete the development of the instrument for measuring sensemaking empirically. In addition, correlation analysis was performed to examine the subscales associated with Item 3, which asked respondents directly how much they make sense of a task ("To what extent do you think conducting the given task under this condition helped you to… Make sense of the available information").

Finally, one-way ANOVA (Field, 2009) was executed on the sensemaking score to understand how individuals conceptualised their sensemaking process while performing different tasks. In this context, mean differences in sensemaking scores were compared between participants who performed different tasks.

Of the total questionnaires collected, six were eliminated, because one of the participants did not complete it and five did not fill it in as requested (e.g. instead of crossing on the vertical lines of the VAS, they crossed the area between the lines). This resulted in 114 completed questionnaires being used in this study.

4.2.2 Results

4.2.2.1 Descriptive analysis

The first step of the analysis involved producing descriptive statistics to examine general patterns in the data in terms of central tendency and dispersion of individual questions. Table 4.8 shows the number of valid responses (N), means and standard deviations for each item.

Table 4.8: Descriptive statistics

Item	N	Mean	Standard deviation
Q1	114	8.7281	1.82065
Q2	114	8.4123	1.99029
Q3	114	8.5789	1.88095
Q4	114	8.6579	1.82330
Q5	114	8.4035	1.98543
Q6	114	8.3509	1.91862
Q7	114	8.1228	2.19065
Q8	114	8.3333	1.96728
Q9	114	8.5526	2.09125
Q10	114	7.7982	2.25058
Q11	114	7.9035	1.95511
Q12	114	7.7719	2.24608
Q13	114	7.6930	2.17438

In general, these results showed that the average score of participants across items yielded values between 7.7 (Q13) and 8.7 (Q1), with measures of dispersion around 2 points (between 1.8 for Q1 and Q4 and 2.3 for Q10 and Q12). Although item means suggested that participants tended to score in the highest section of the VAS, there was no clear evidence of extreme response bias on this tail of the metric.

4.2.2.2 Principal component analysis and reliability analysis

PCA was performed on the questionnaire items to explore the dimensionality of the whole instrument. Table 4.9 shows the number of underlying factors (components) that explained a relevant proportion of the total variance of the questionnaire.

Table 4.9: Eigenvalues and percentages of total variance explained

Component	Eigenvalue	% of Variance	Cumulative %
1	7.832	60.248	60.248
2	1.050	8.074	68.322
3	.828	6.371	74.692
4	.697	5.362	80.055
5	.596	4.583	84.637
6	.435	3.347	87.984
7	.331	2.548	90.532
8	.266	2.049	92.581
9	.246	1.891	94.472
10	.217	1.669	96.141
11	.204	1.566	97.707
12	.171	1.313	99.020
13	.127	.980	100.000

These results suggested two underlying factors as candidates for extraction, as their values were greater than 1. These results indicated that 60% of the total variance yielded by items was explained by the first underlying factor. However, adding a second or third factor to this solution would only increase this percentage by 8% and 6.3% respectively.

A decision on how many factors to return was made, based on the results from the scree plot shown in Figure 4.15, the correlation matrix in Table 4.11 and the loading factors of items presented in Table 4.12.

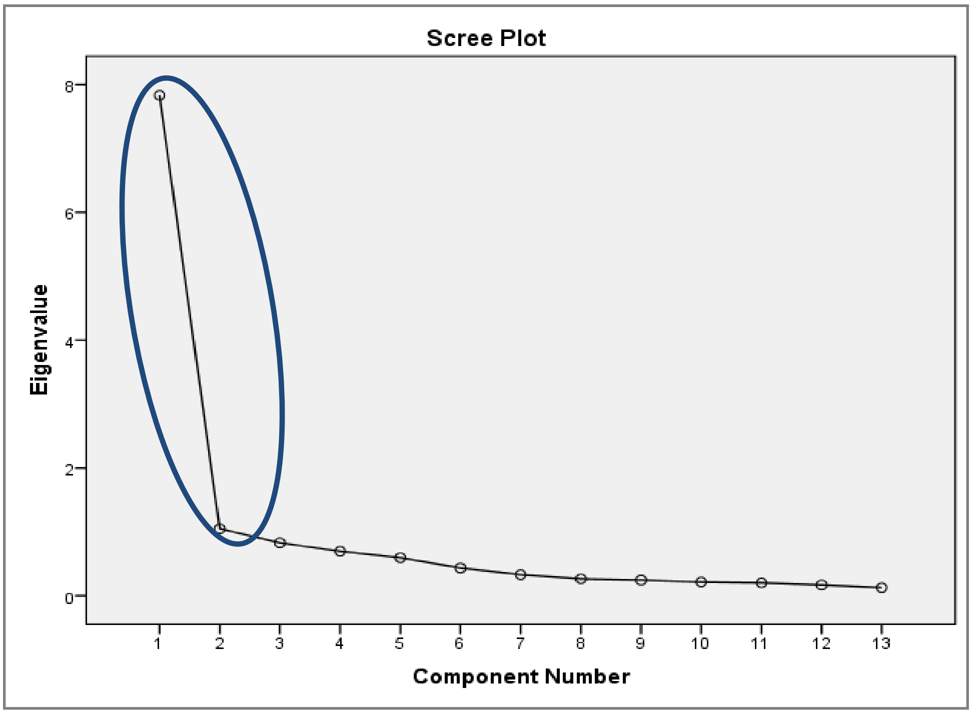


Figure 4.15: Scree plot for the exploratory factor analysis

Although the screen plot (Figure 4.15) shows that the eigenvalues start to form a straight line after the second principal component, it illustrates a clear main point of inflexion before the second factor, which supported the argument to retain only one factor.

To investigate the strength of correlations between variables and the two latent factors further, the factor loadings when rotating two-factor solutions was examined. Table 4.10 shows the factor loadings from *direct oblimin* rotation when two solutions are rotated.

Table 4.10: Factor loadings of two-factor solutions

	Factor loadings	
	1	2
Q1	.907	-.053
Q2	.924	-.081
Q3	.951	-.157
Q4	.665	.165
Q5	.309	.425
Q6	.643	.279
Q7	.567	.293
Q8	.643	.272
Q9	.573	.342
Q10	-.059	.839
Q11	-.067	.929
Q12	.139	.736
Q13	.195	.685

The results showed strong loading of Q1, Q2, Q3, Q4, Q6, Q7, Q8 and Q9 with Factor 1. The results also showed a cross loading of Q5 with Factor 1 and Factor 2, and a strong loading of Q10, Q11, Q12 and Q13 with Factor 2. These results suggested that there are two distinct factors.

However, the results from the component correlation matrix (presented in Table 4.11) indicated strong correlations between the two factors. These results suggested that, although these two factors may look distinct, they were strongly related to each other and, with a correlation of 0.6, this confirmed that they are not orthogonal.

Table 4.11: Component correlation matrix

Component	1	2
1	1.000	.647
2	.647	1.000

The pattern of factor loadings suggested that the unidimensional solution fitted well with the data, as all correlations between individual questions and this factor showed salient values.

Therefore, a decision was made to retain only one factor. Table 4.12 shows factor loadings of the single factor solution. In this case, no rotation was applied, as only one factor was retained.

Table 4.12: Factor loadings of the single factor solution

	Factor loadings
Q1	.806
Q2	.797
Q3	.756
Q4	.769
Q5	.660
Q6	.846
Q7	.787
Q8	.840
Q9	.836
Q10	.674
Q11	.744
Q12	.770
Q13	.779

The data clearly supported the extraction of only one factor, particularly because the relation between this factor and each item was strong and positive for all items. To be more precise, one standard deviation increase in the factor score would lead to more than .68 (Q10) standard deviation increase in all the item scores. Hence, the extraction of a unique factor as an overall measure of sensemaking was strongly supported by results from PCA.

Reliability of this instrument was also high (Cronbach's alpha = .943). Table 4.13 details item-test correlations and estimation of Cronbach's alpha if the corresponding item would have been dropped from the analysis.

Table 4:13: Item-test correlation and internal consistency if items were deleted

	Item-test correlation	Cronbach's alpha if item deleted
Q1	.759	.938
Q2	.747	.938
Q3	.702	.940
Q4	.720	.939
Q5	.607	.943
Q6	.808	.937
Q7	.743	.939
Q8	.800	.937
Q9	.796	.937
Q10	.626	.943
Q11	.711	.939
Q12	.728	.939
Q13	.738	.939

These results demonstrated that all the items significantly contributed to measuring one concept in the same direction as the whole instrument, which was clear, because the item-test correlations were all positive and strong, with the lowest value being for Q5 (.6). Furthermore, deleting any item from the instrument would have decreased its internal consistency, which suggested that a reliable measure of sensemaking should include all these items simultaneously.

Based on these results, an additive factor score-average of items was calculated for each participant. Figure 4.16 depicts the distribution of this score across the 114 participants.

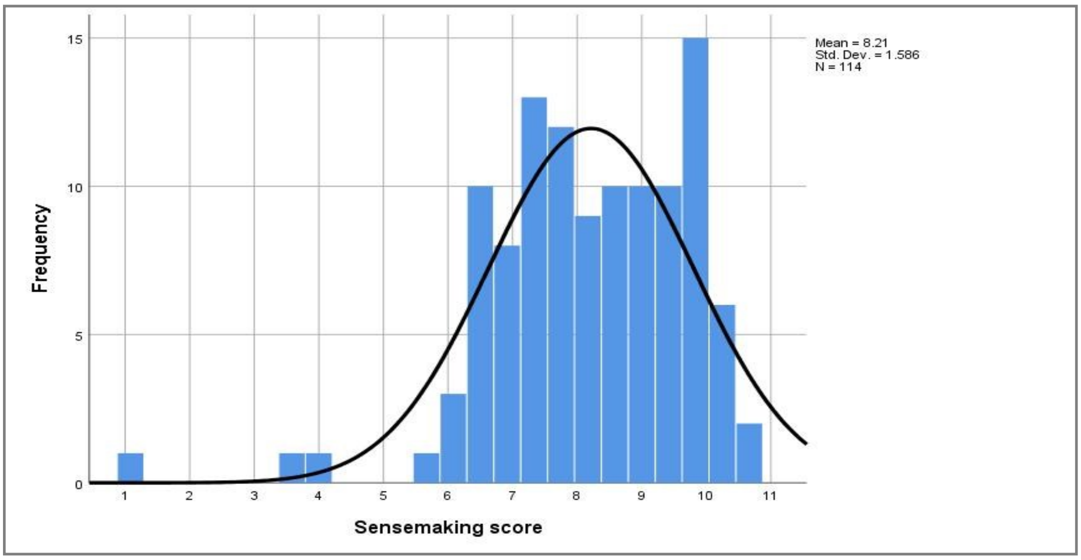


Figure 4.16: Distribution of sensemaking score

It is worth mentioning that the shape of the distribution depicted a negatively skewed pattern. In other words, participants tended to score highly on the VAS of sensemaking provided in the questionnaire. In fact, few individuals obtained scores lower than the midpoint of the metric (5.5 points). Similar to the descriptive analysis reported above for the items included in this scale, the central tendency of the distribution yielded a mean value of 8.2 points, whereas the dispersion indicated a standard deviation of 1.6 points.

4.2.2.3 Correlation analysis

A correlation analysis was performed to examine the association between Q3, which directly assessed the sensemaking perception of participants, and the items in the questionnaire. Results indicated a significantly strong and positive relation between both indicators (Pearson's r =.7, p < .05). Figure 4.17 depicts this association, with the sensemaking score on the vertical axis of the plot and Q3 on the corresponding horizontal axis. Dots represent participants and the line between them represents the positive association between variables – the line of best fit.

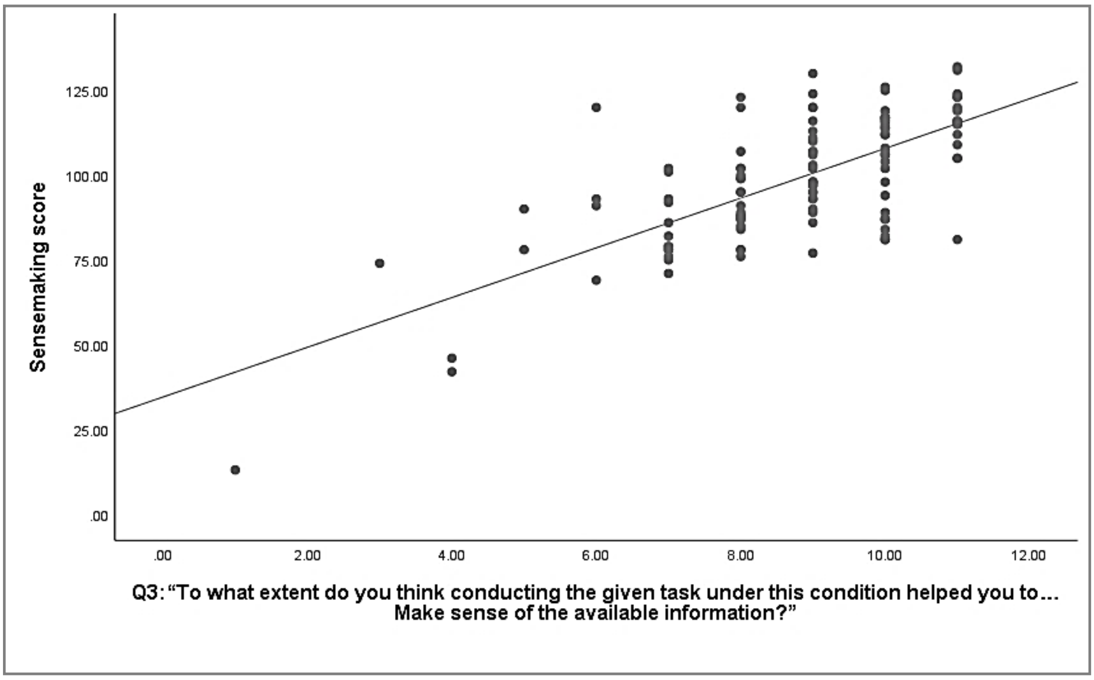


Figure 4.17: Correlation between Q3 and other items within the instrument

The plot shows that participants who scored high in Q3 also tended to score high in the sensemaking variable and vice versa, which was accounted for by a positive association between these variables. However, the result also suggested that Q3 did not accurately capture what was happening and other items in the instrument were needed to measure that construct.

4.2.2.4 One-way ANOVA

Finally, a one-way ANOVA was conducted to understand how individuals conceptualised their sensemaking process while performing different tasks. Figure 4.18 illustrates mean scores (blue bars) on the sensemaking scale for each of the tasks performed by participants. The lines at the top of the bars represent the standard errors of each mean score and the values in the centre of the bars correspond to their mean score estimate.

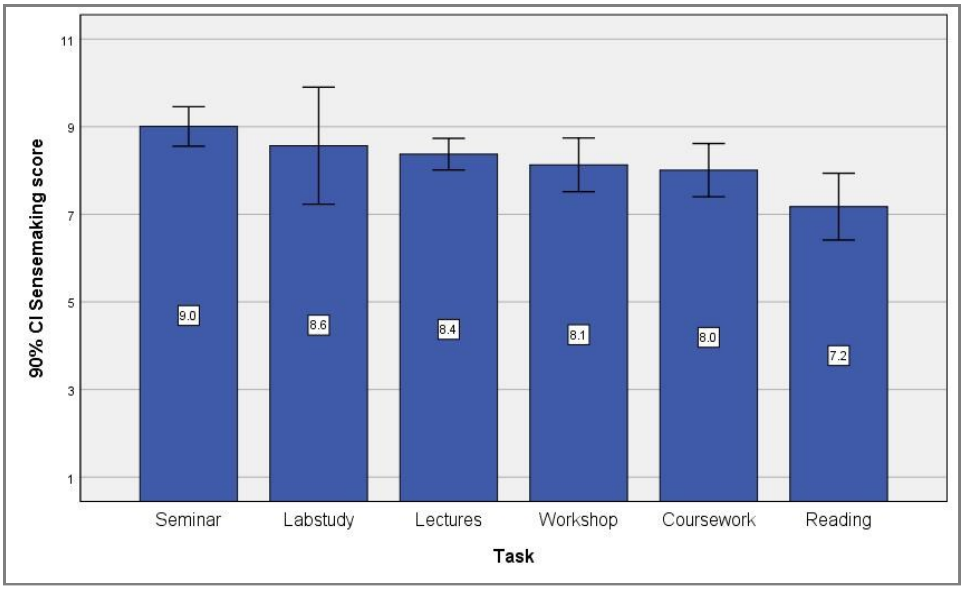


Figure 4.18: Mean scores in sensemaking by tasks performed

According to this data, participants who attended a seminar obtained the highest score on the sensemaking scale (9 points) and the lowest score corresponded to the reading task (7.2 points). In descending order, the following mean scores were reported: lab study (8.6 points); lectures (8.4 points); workshops (8.1 points); and coursework (8 points) yielded values close to the mean for the whole group.

Results from the one-way ANOVA revealed significant differences in the mean scores of sensemaking between tasks, $F(5, 113) = 2.76$, $p < .05$. Post hoc Tukey HSD analysis indicated that sensemaking in the reading task significantly underperformed by 1.8 points, compared with the results obtained in the seminar group ($p < .05$) and by 1.1 the score of the lectures ($p < .1$). These results suggested that some activities systematically lead to more sensemaking than others did. In particular, participation in the reading task produced significantly lower perceptions of sensemaking, compared to the participation in face-to-face learning activities, such as seminars and lectures.

4.3 Discussion

This section presents a discussion on the results of the two developed measures and their evaluation studies. Similar to the first part of the chapter, it follows the following structure: a discussion on the external representations created by users, followed by a discussion on the instrument for measuring perceived sensemaking.

4.3.1 External representations

4.3.1.1 The nature of external representations generated by participants

External representations from the exploratory study (Chapter 3) were analysed by adopting an approach that was based on the idea of generative grammar (Sections 4.1.1.1 and 4.1.1.2). The results showed that participants created different representations in terms of their types and complexity. These results were directly aligned with previous findings by Okoro (2014) and Okoro and Attfield (2016), who found that the representations created by participants during investigative sensemaking tasks were heterogeneous and embedded within one another hierarchically.

One of the main interests of the exploratory study in Chapter 3 was to investigate the effect of using external representations in sensemaking during individual sensemaking tasks. The results presented in Chapter 3 showed some evidence to prove that the use of external representations had an effect on perceived sensemaking. It showed that participants reported a higher level of perceived sensemaking when they externalised their thinking during the task through user-generated representations using OneNote than when they did not and only used a folder to save relevant documents (Section 3.3.4). It also showed some evidence of a relation between the use of external representations and the way participants developed search terms.

Keeping this in mind and considering the results from this chapter (Section 4.1.13), it could be concluded that the level of structuring within a representation may also have an effect on the process of sensemaking and, therefore, further investigation is required. Accordingly, the following hypotheses were developed (which are tested in Chapter 5):

H_3: Structuredness correlates with perceived sensemaking.

H_4: Structuredness correlates with keyword novelty.

4.3.1.2 Measuring structuredness

To test the developed hypotheses $H_{4,}$ H_3, a metric was developed. The metric calculated structuredness of the embodied relations within a representation, taking into account the number of relation elements multiplied by relation variable types to which these element belong.

The metric was evaluated by comparing the levels of structuredness in a sample of representations measured by the metric of people's intuition of levels of structuredness of the same samples. The results confirmed a significantly strong positive association between the way the metric calculated the level of structuredness and people's intuition of that concept. In other words, when participants' perception of the structuredness of the representations increased, the objective measure of this attribute of representations measured by the developed metric also increased.

These results suggested that the level of structuredness was not about how much information was included in a representation; but rather about how much this information was connected by some relationships, such as belonging to the same group or being chronologically ordered. Moreover, the results suggested that each type of relation imposed some constraint on information and these constraints – the semantic of positioning – made some relations constrain information more than others.

The developed metric can be used as a quantitative measure of how the use of external representations changes sub-tasks during sensemaking.

4.3.2 Measuring perceived sensemaking

The questionnaire that was developed to measure perceived sensemaking in Chapter 3 was revisited and a new version was created. In the new version, some statements were revised to make the questionnaire more generic and not specific to certain types of sensemaking tasks. An evaluation of the new questionnaire was conducted by means of PCA and reliability analysis. Although the results suggested two underlying factors to explain the data, the results from the scatter plot, component matrix and the factor loading of items when extract one factor, all confirmed that the questionnaire items were explained by one factor. The results of the reliability analysis also indicated that these items were coherent and measured the same concept. The results concluded that the questionnaire could be considered a valid estimation for measuring what is believed to be perceived sensemaking, as the subscales of the questionnaire were built on sensemaking theories and definitions.

Sensemaking frequently provides a context for the use of technologies for information seeking and exploration (such as information retrieval, information extraction, data mining and data visualisation), as well as tools for visually structuring and reflecting on information. For example, Selvaraj et al. (2016) conducted a study of police analysts who made sense of crime data by iteratively querying information resources and using resulting information to construct elaborate link charts and timelines for the generation and testing of hypotheses. In this way, operationalising the concept of sensemaking within instruments for measuring it can make a useful contribution to the design of such tools.

A correlation was also calculated between Q3 in the questionnaire, which asked respondents directly how much they made sense, and the other questions. Although the plot illustrated by Figure 4.18 does show a positive association between these variables, it was suggested that Q3 did not totally capture what was occurring and the other the items in the instrument were actually needed to measure that construct. This result suggested that people do not necessarily use word sense in the same way. Finally, the results presented in Figure 4.19 indicated that levels of perceived sensemaking differed according to the task type, e.g. participants, who attended a seminar, reported higher levels of perceived sensemaking than other participants.

4.4 Chapter summary

This chapter reported on the development of two measurements: a metric to measure levels of structuring within external representations and a questionnaire to measure perceived sensemaking. It also reported on two studies to validate the developed measurements.

The analysis of external representations created by participants revealed differences in their complexity and types. Based on this result, some hypotheses were developed to be further tested (H_3 and H_4). The level of structuredness was operationalised as the amount of information within a representation, the number of relations that semantically connected this information, and the degree of constraints of each relation (type of variable). Results from the validation of the metric demonstrated a correlation between the levels of structuredness measured by the metrics and people's intuition of level of structuredness. The results concluded that the metric could be considered a valid estimation for measuring the level of structuring of external representations.

The questionnaire for measuring perceived sensemaking in Chapter 3 was revisited and a new version was developed. The questionnaire was evaluated in a study where the data was collected from participants performing different sensemaking tasks. The results demonstrated that the questionnaire could be considered a reliable and valid instrument to measure the construct "perceived sensemaking".

CHAPTER 5: THE EFFECT OF USER-GENERATED EXTERNAL REPRESENTATIONS ON PERCEIVED SENSEMAKING, PERCEIVED UNCERTAINTY AND KEYWORD NOVELTY

The intention of this doctoral research was to conduct quantitative measurements, in order to establish a better understanding of what occurs during sensemaking when externalising thinking in user-generated representations. When creating user-generated external representations becomes part of the sensemaking process (as in the paradigm applied in this study and illustrated in Figure 1.2), its effect on cognition may well propagate around the process and can be detectable in different parts of the process. Therefore, measuring the effect of user-generated external representations and structuredness (levels of structuring in external representations) in some of the sensemaking sub-tasks seemed important.

The current study replicated and expanded on the findings of the previous studies (Chapter 3) by assessing a set of additional hypotheses. It replicated the investigation of the effect of external representations (user-generated external representations) in perceived sensemaking by using the new questionnaire developed in Chapter 4. It investigated the role of external representations in sensemaking further by assessing new dependent variables: novelty of search terms, which refers to participants' capacity to generate keywords beyond those given in a task brief, and perceived uncertainty. It is expected that, when people make sense of a domain and their sensemaking improves, they will perform better in other sub-tasks of the process, for instance their tendency to construct better search terms will improve and at the end of process they will feel less uncertain. Therefore, investigating the effect of user-generated external representations in sensemaking on such sub-tasks (keyword construction) and some final product (level of uncertainty at the end of the sensemaking process) during sensemaking tasks seemed significant. The current study also investigated the relationship between the level of structuring of external representations structuredness and other variables, namely perceived sensemaking, perceived uncertainty and keyword novelty. The motivation for this stemmed from the results of the second study, discussed in Chapter 4, where a metric was developed to measure the structuredness of external representations.

By using a paradigm similar to that used in the first study (illustrated in Figures 1.2 and 1.3), the study in this chapter followed a controlled experimental. Participants were asked to perform a mock investigation by using a collection of documents. The task involved constructing queries over a dataset; searching for documents; and reviewing the results to decide on individual document relevance (known as a *document triage*), in order to create a narrative understanding of what had happened in an incident given in the provided tasks.

The main objective for this doctoral research was to establish a paradigm for measuring sensemaking. In order to meet this objective, the study in this chapter used the paradigm presented in Figures 1.2 and 1.3 to measure the following quantitatively:

- Effect of user-generated external representations on perceived sensemaking;
- Effect of user-generated external representations on query construction;
- Effect of user-generated external representations on perceived uncertainty;
- Relationship between the levels of structuring in user-generated external representations and perceived sensemaking;
- Relationship between the levels of user-generated external representations and query construction; and
- Relationship between the levels of user-generated external representations and perceived uncertainty.

The remainder of this chapter is structured as follows:

- Section 5.1 presents a review of the uncertainty concept in Information Science;
- Section 5.2 presents the research questions and related hypotheses;
- Section 5.3 outlines of the method that was used in this study and describes the experiment design, participants, procedures and data analysis;
- Section 5.4 presents the measures used to analyse the data;
- Section 5.6 presents the results;
- Section 5.7 presents a discussion on and conclusion of the results; and
- Section 5.8 provides a chapter summary.

5.1 Uncertainty and sensemaking

In previous studies of this doctoral research (Chapter 3); it was found that creating user-generated external representations during sensemaking increased perceived sensemaking. Moreover, the results from Study 1 strongly suggested that user-generated external representations helped participants to generate more novel search terms. In addition, the results of analysing the external representations reported in Chapter 4 showed that these representations varied in their levels of complexity and types. These results motivated the development of a metric to measure the structuredness of representations to be used in further investigations of the effect of structuredness on other parts of the sensemaking process.

In this study, the scope was increased to include the notion of uncertainty. Previous researchers (i.e. Kuhlthau, 1993b) reported a reduction in the level of uncertainty over the period of performing extended information seeking. It was also anticipated that, over that same period, the level of sense will increase in some domains. Investigating the relationship between sensemaking and uncertainty appeared to be important, in that the two constructs seem to represent two sides of the same coin, in the sense that uncertainty is a proxy for not making sense of something.

Uncertainty is central to some of the information seeking models, e.g. in the information seeking model of Kuhlthau (1993b) and the problem-solving model of Wilson (1999), which are discussed in Sections 2.2.2 and 2.2.3. Kuhlthau (1993b) states that uncertainty is a cognitive state that leads to the generation of emotions of confusion, frustration and the loss of confidence among users.

Belkin (1980) developed the ASK hypothesis from a cognitive viewpoint as an alternative approach to thinking about traditional best-match information retrieval systems. According to the ASK hypothesis, people are often uncertain about the information they are seeking, which makes it difficult to construct effective queries when interacting with information systems. Belkin (1980) claims that, based on the side of the IR system with which they interact, two different types of users of information retrieval (IR) systems can be identified – generators of documents and information seekers – and, therefore, it is essential to consider that each will have a different state of knowledge.

Generators of documents, who generate a text that they want to share with others on an IR system, usually base these documents on firm knowledge of the topic. Their state of knowledge is also influenced by factors, such as their beliefs and values. After being reformed by some linguistic and pragmatic rules, the generated documents are stored in IR systems. Investigators, on the other hand, start to use the system by seeking help, after identifying gaps in their knowledge relating to a particular problem. They submit their information requests, which, at this stage, are anomalous and unspecified. The submitted requests are then transformed by the linguistic and pragmatic requirements of the system. Best-match systems assume that the process by means of which information seekers express their information needs is straightforward, as they know what they are looking for. However, what these systems are trying to match is two different states of knowledge: the generator's coherent state and the information seeker's anomalous state. Belkin (1980) suggests that, instead of asking users to submit their requests to IR systems as specific questions, information seekers should in some way be allowed to describe their state of knowledge and goals, for instance by explaining their information needs in paragraphs.

Some researchers emphasise the centrality of uncertainty to the process of information seeking by using it as a measurement of the progress of the effectiveness of the search process. For example, D'Ambra and Wilson (2004) developed a framework to examine the use of online websites as an information resource, based on information seeking models that comprise the concept of uncertainty. In the proposed framework, D'Ambra and Wilson consider the reduction in the level of uncertainty as an essential measurement of the effectiveness of the use of online platforms to find information. They hypothesised that the reduction in the level of uncertainty and the effectiveness of using the web to find information are positively correlated. The researchers examined their framework by measuring the uncertainty of people using a travel website to book flights by using a questionnaire they developed. The results indicated that using online resources helps to reduce uncertainty. Similar to that, Ramirez, Walther, Burgoon & Sunnafrank (2002) suggest the use of uncertainty as a measurement of the effectiveness of information searches in a framework they proposed to understand information seeking on social media platforms.

In the context of the digital archive and historians' information seeking behaviour, Duff and Johnson (2002) found that, when introduced to a new archive, even experts experience unfamiliarity with the collection, resulting in a feeling of confusion and panic. In contrast, Mohammad, Amini, Sadatmoosavi and Ahmadi (2018) found that users with more experience in research obtain lower levels of uncertainty. Mohammad et al. (2018) conducted an empirical study to evaluate the uncertainty in information seeking among post-graduate medical students. The evaluation was based on the Kuhlthau information search model. The findings indicated that students experienced uncertainty during the initial stages of the information search, but as the search process progressed towards the last stages, the uncertainty levels reduced. The study also showed that demographic attributes, such as age, had an impact on the level of uncertainty: older participants were more uncertain during most of the search stages.

Although some research presents uncertainty as a negative factor that needs to be reduced, in order to progress in the search process, other researchers argue that uncertainty can play a positive role in the information seeking process. The results of two years of ethnographic study by Anderson (2006) showed that, although uncertainty during information searches is an inescapable experience, it may act as an essential motivator to move the search forward. Anderson (2006) found that, although uncertainty results in negative feelings, such as concern, anxiety and danger, it can also cause positive feelings, such as excitement. Where Anderson observed researchers encountering a positive type of uncertainty, he found that it helped them to create boundaries on which to judge the relevance of a document and, therefore, they engaged more with the search process. However, Neuberger and Silk (2016), who suggests that uncertainty is not sufficient to motivate information seeking, argue that it is important for individuals to find information with value, in order to continue information seeking.

Similar to uncertainty, sensemaking also occurs at the heart of information seeking and it has been studied as an important positive outcome of the information seeking journey on which the goal of searching for information is to make sense of a particular domain. Brenda Dervin, for instance, explored the concept of sensemaking in 1983 in the Information Science field and she introduced a methodological framework that suggests a range of assumptions about people and their sensemaking processes. The framework emphasises the importance of understanding sensemaking from the sensemaker's perspective, rather than from that of an observer. It centres on the user by considering what is real to them and what is understood in their own terms. Dervin (1998) suggests that, instead of studying individuals' information needs and information use, based on characteristics that are static across space, such as their demographic and their personality, it is important to consider that people move through two dimensions – time and space – and, as they move through their context, their situation changes.

Both sensemaking and uncertainty have been investigated separately in information seeking research. Uncertainty has been viewed as important to the information seeking process (Belkin, 1980; Kuhlthau, 1993a), while sensemaking has been important as a positive outcome of the information seeking journey (Dervin, 1998, 1992). Part of the motivation for relating these two constructs in the current study was the idea that they might be more or less equivalent constructs, viewed from a different perspective. However, these two concepts have rarely been studied in relation to each other. Based on that, the new sub-research question and hypotheses were developed.

5.2 Research questions and related hypotheses

This study helped to answer RQ1: *How does the creation of user-generated external representations measurably affect the sensemaking process?*

More specifically, this study focused on answering sub-questions RQ1.1, RQ1.2 and RQ1.3 which are:

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

RQ1.2: *What is the relationship between the creation of user-generated external representations and query construction?*

RQ1.3: *What is the relationship between the creation of user-generated external representations and perceived uncertainty?*

These research sub-questions were approached in the following two ways. In the first way, the questions were addressed through an experimental manipulation of the independent variable creating user-generated external representations. The dependent variables – i.e. perceived sensemaking, keyword novelty and perceived uncertainty – were compared across the two conditions of user-generated representation and non-representation.

The following hypotheses were tested across the two conditions of user-generated representation and non-representation:

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

H_2: Creating user-generated external representations during sensemaking helps to increase keyword novelty.

H_5: Creating user-generated external representations during sensemaking helps to reduce perceived uncertainty.

The second way involved measuring the correlations within the user-generated representation condition only between these same variables (perceived sensemaking, perceived uncertainty and keyword novelty) and a new variable called structuredness. *Structuredness* refers to the amount of structuring within external representations.

The following hypotheses were tested within the user-generated representation condition:

H_3: Structuredness correlates with perceived sensemaking.

H_4: Structuredness correlates with keyword novelty.

H_6: Structuredness correlates inversely with perceived uncertainty.

5.3 Method

This section presents an account of the experiment design, the amendments that were made to avoid the limitations in the first study (reported in Chapter 3), as the current study followed the same design, experiment setup, procedure, participants, materials, data collection and data analysis.

5.3.1 Experiment design

The study was a controlled experiment in which the participants' task was to conduct a search for news stories in preparation for writing a hypothetical news report. The study had a single independent variable (user-generated representation) with two levels (user-generated representation and non-representation). In the user-generated representation condition, participants were asked to create an external representation in which they organised documents they considered relevant by using Microsoft OneNote. They were asked to create a representation that provided information on the threats that answered questions such as "who", "what", "where", "when" and "how". In the non-representation condition, they were required to put documents they considered relevant aside in a digital folder.

The dependent variables were self-reported levels of sensemaking, self-reported levels of uncertainty and search terms novelty, which refers to the extent to which keywords used in queries did not appear in the brief text. The study followed a repeated measures design.

To avoid bias due to task learning and condition order effects, participants were assigned to tasks and sessions, as illustrated in Table 5.1, ensuring that task orders were counterbalanced across participants. For instance, a participant assigned to Group A started with the user-generated representation condition by using the VAST Challenge 2006 task. The next session was the non-representation condition by using VAST Challenge 2011.

Table 5.1: Groups to which participants were assigned to avoid order effects

Group	Condition 1	Scenario 1	Condition 2	Scenario 2
Group A	User-generated representation	VAST Challenge 2006	Non-representation	VAST Challenge 2011
Group B	User-generated representation	VAST Challenge 2011	Non-representation	VAST Challenge 2006
Group C	Non-representation	VAST Challenge 2006	User-generated representation	VAST Challenge 2011
Group D	Non-representation	VAST Challenge 2011	User-generated representation	VAST Challenge2006

5.3.2 Amendments

The study broadly followed the same design as that of the first study (Chapter 3), with some amendments to overcome its limitations. This section explains the amendments that were made to overcome the limitations of the exploratory study, after which it presents the other parts of the design of the experiment.

Due to the small size of the original datasets – 50 documents at each dataset section – participants in the exploratory study (Chapter 3) were able to view all 50 documents without using the search tool to create search terms. As a result, only four participants created search terms. Participants either selected files from the datasets, based on titles, or looked at them all systematically and one-by-one.

In order to avoid this limitation and to encourage participants to create search terms, as one of the aim in this doctoral research was to investigate the effect of creating external representations on query constructing, larger datasets were used in the current study. Each dataset included 1200 news stories. Another reason for most participants not using the search tool in the exploratory study was that the files within the datasets were accessible to participants since the beginning of the tasks.

See Figure 5.1.

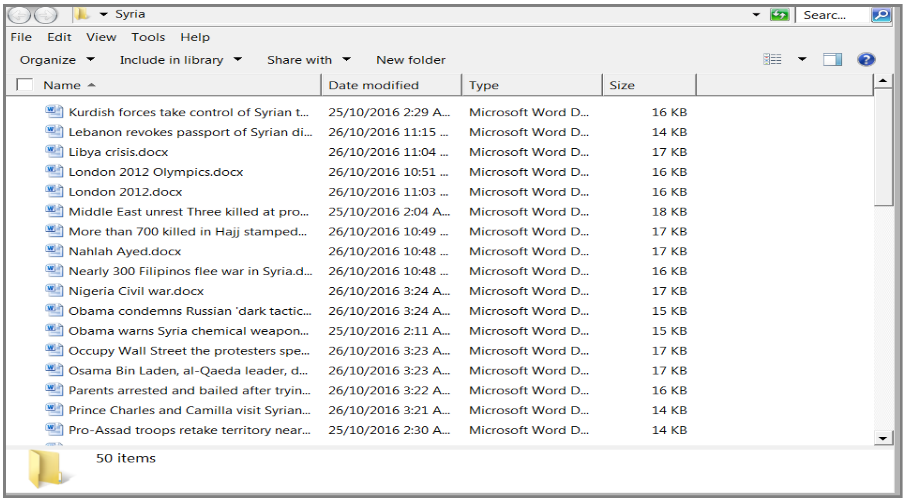


Figure 5.1: The dataset of Syria crisis task from the first study in Chapter 3 before participants create any search terms

To avoid this limitation and to encourage participants to use the search tool, the datasets were hidden in three folders and files would only appear when a search term was submitted to the search engine (see Figures 5.2 and 5.3).

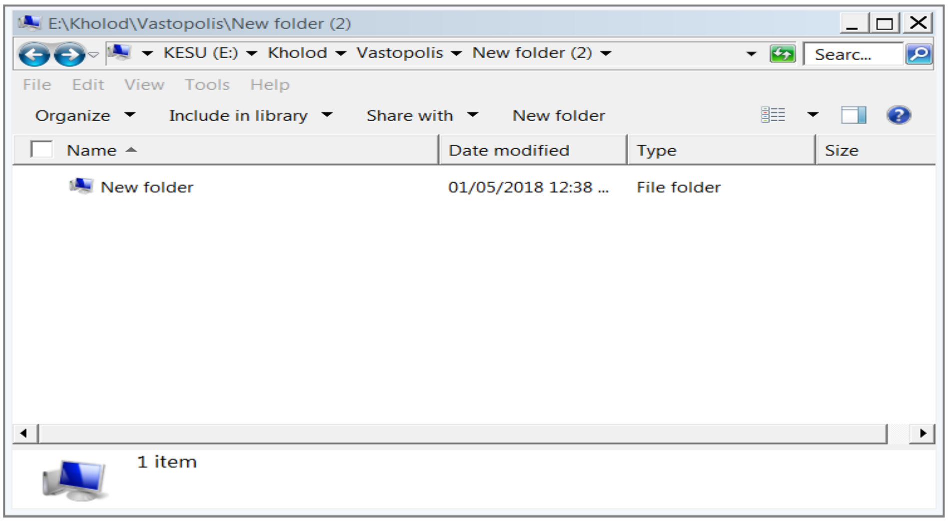


Figure 5.2: The dataset of Vastopolis task from the current study before participants create any search terms

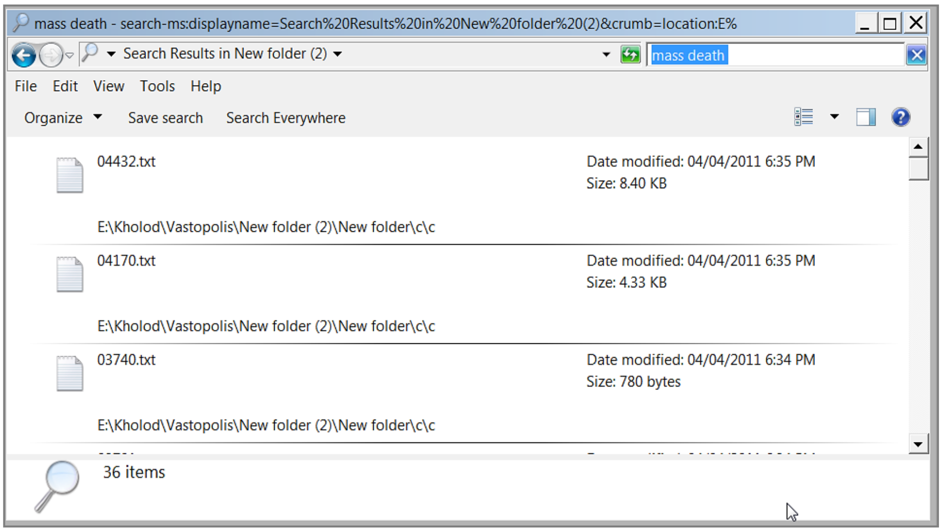


Figure 5.3: The dataset of Vastopolis tasks from the current study after a participant submit a search terms

Another amendment was made by using the VAST challenge datasets. VAST is the acronym for Visual Analytics Science and Technology and VAST challenges are designed to give visual analytics researchers, developers and designers the opportunity to use and test their tools by investigating scenarios of fictitious incidents. These challenges also involve data and lists of questions (Cook, Grinstein & Whiting, 2014). In the VAST challenges, titles of the files were number strings, rather than representative text strings. Therefore, when the participants submitted search terms, they were confronted with a search result consisting of a long list of file numbers and, because they could not select documents based on their titles, they were compelled to think of different search terms to obtain the search results.

5.3.3 Experiment setup

Participants were provided with a computer connected to three monitors. One monitor was used to display the data set on a folder and Windows Explorer as a search tool. The second monitor supplied participants with a dictionary, so that they could translate unknown words, and the third was used to provide users with two solutions, depending on the user-generated representation condition. In the user-generated representation condition, participants were provided with a tool to support external representation (Microsoft OneNote), as illustrated in Figure 5.4. Using this tool, participants could create the type of structure that would help them during the sensemaking process, including taking notes and highlighting. In the non-representation condition, it provided participants with a folder.

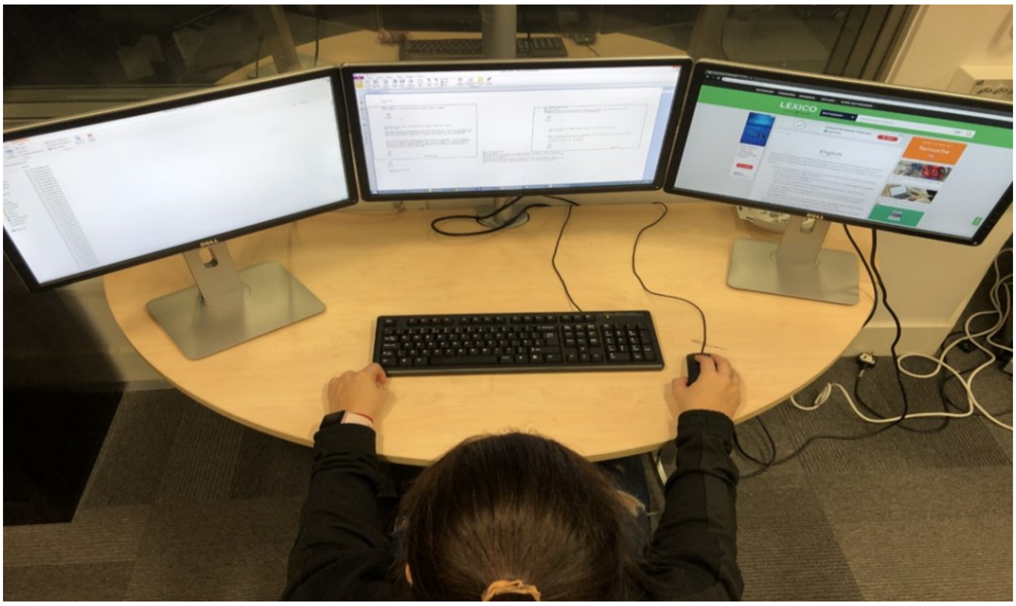


Figure 5.4: The set up for the experiment: the screen on the left displays the data set and the search engine Windows Explorer; the central screen displays Windows OneNote under the user-generated representation condition and displays a folder where participants can save relevant documents under the non- representation condition; and the screen on the right displays Oxford Dictionary for translating purposes

5.3.4 Participants

Participants, who were recruited by email, were 16 postgraduate students from Middlesex University. A monetary incentive of £20 was given to each participant at the end of the study.

5.3.5 Datasets

Participants were provided with a set of files related to a given scenario. Each file was a newspaper article covering various aspects of the given scenario. The datasets were VAST Challenge 2006 and 2011.

5.3.6 Tasks

Given two conditions and a repeated measures design, two similar tasks were required and matched for complexity. The two tasks both requested the participants to investigate and construct a story related to terrorism and politics. The two tasks were VAST Challenge 2006 and 2011.

Task 1

Vastopolis is a major metropolitan area with a population of approximately two million residents. On 1 April 2011, mass deaths of livestock had been reported on farms a short distance outside the metropolitan area. The police suspected of a possible bioterrorism. Professor Edward Patino states that it has become much easier to engineer dangerous microbes with the right equipment. Experts stated that Vastopolis City Officials need to do more to protect the residents from well-organized terror groups. By May 19, 2011, the flu season was out of control in Vastopolis.

Use the documents in the data set to construct a story that explains the situation there. The story should provide detailed information on the threat or threats (e.g. who, what, where, when and how), so that officials can conduct counterintelligence activities.

Task 2

Welcome to Alderwood, Washington, a fictitious American town in central Washington State. Alderwood was having some economic problems that began when the dot com bust virtually destroyed the tourism economy. Then the mad cow outbreak wreaked havoc with the local agriculture industry. People were out of work. Voters were moving away to the larger cities of Seattle and Portland.

The mayor, Rex Luthor, realized if something drastic was not done, both the town and his mayorship would be lost. One piece of good news is the recent unexpected opening of a new private laboratory facility specializing in agri-business. On 02/02/2002, Alderwood Mayor, Rex Luthor, announced the building of a new laboratory that he believes would increase economic prosperity and development in the city. A famous scientist has relocated to Alderwood to run it, and the residents hoped this could be the locus of a business renaissance. However, in January 2003, the FBI was tipped off to possible political shenanigans associated with unethical behaviour related to laboratory activities.

Use the documents in the data set to construct a story that explains the situation there. The story should provide detailed information on the threat or threats (e.g. who, what, where, when, and how).

Participants were instructed to include all the evidential documents supporting their story in a folder under the non-representation condition or in OneNote in the user-generated representation condition.

5.3.7 Procedure

Similar to the exploratory study reported in Chapter 3, the experiment involved an information-gathering task for a given scenario, in preparation for writing a news story. The study followed a repeated measures design that required participants to perform two sessions, each under a different condition. Participants were given a maximum of one hour to complete each task. The following procedures were followed under each condition:

- Participants were asked to read and sign an informed consent form.
- Participants were given a brief tutorial on the software provided.
- Participants were tasked to perform a mock investigation, which involved reading the scenarios, conducting a search for documents and reviewing the search results to determine individual document relevance (i.e. document triage).

Similar to the first study conducted in Chapter 3, this study involved the two conditions of user-generated representation and non-representation and the participants performed this data-gathering part of the experiment under the following two conditions.

- In the user-generated representation condition, they were asked to structure the documents they judged relevant to the given task during their search by using OneNote software as a way to externalising their thinking while performing the provided sensemaking tasks. This allowed them to create different types of representations in a free-form workspace by using different drawing features, such as lines linking added files and circles or rectangles around added files they considered related. It also allowed taking notes, drawing different shapes and lines, and highlighting.
- Under the non-representation condition, they were asked to put (copy and paste) the documents they judged relevant to the given task into a folder. The content of the folder could be viewed, but not altered in any way (e.g. reorganise documents inside the folder chronologically or rename them). This was provided in the non-representation condition for participants to add documents after judging their relevance, without taking notes or performing any type of structuring.

According to the think-aloud protocol, participants were encouraged to verbalise their thoughts while performing the task. Participants were also asked to complete a questionnaire at the end of each task to report on their perceived sensemaking and another questionnaire to report on their perceived uncertainty.

5.3.8 Ethics

The School of Science and Technology at Middlesex University granted ethical approval to conduct this study. Participants were asked not to divulge any confidential information and they were advised that they were free to withdraw themselves and their data from the study at any point. Detailed consent forms and further information about the study were provided to all research subjects (see Appendix D.1).

5.3.9 Data collection

Perceived sensemaking was measured at the end of each session by using the sensemaking questionnaire described in Chapter 4 (see Appendix C.2). Perceived uncertainty was measured by means of a questionnaire adopted from a previous study that aimed at developing a tool to measure uncertainty in users seeking information in digital archival collections (Pugh 2017) (see Appendix D.2). Each participant had one score for perceived sensemaking and one score for perceived uncertainty under each condition, which was the sum of the scores of the 14 items in the questionnaires. To measure keyword novelty, search terms created by participants were collected by means of the screen-recording software, Flashback. The final representations created by participants in OneNote were used to measure the variable structuredness.

5.3.10 Data analysis

IBM SPSS Statistics 24 software was used to perform these tests. Keyword novelty, which refers to the participant's capacity to generate keywords beyond those given in a task brief, was measured as the number of search terms that participants used that were not included in the task brief as a proportion of all search terms used by participants in that condition, expressed as a percentage. Structuredness was measured by using the metric given in Section 4.1.2. The normal distribution of each of the three dependent variables – i.e. perceived sensemaking, perceived uncertainty and keyword novelty – as well as structuredness was tested by plotting histograms and by calculating the z-value of skewness and kurtosis scores (skewness or kurtosis value divided by its standard error) and Shapiro-Wilk (see Appendix E.2).The values for asymmetry and kurtosis between -1.96 and +1.96 were considered acceptable to prove normal univariate distribution (George & Mallery, 2010). The Shapiro-Wilk test was also applied to assess the normality of data. The test rejects the hypothesis of normality when the p-value is less than or equal to 0.05.

5.4 Results

Sixteen participants took part in the study. Table 5.2 shows the demographic information that was collected from participants at the beginning of the experiment.

Table 5.2: Demographic information of the participants

Characteristics		Frequencies
Age	18–24	5
	25–34	8
	35–44	3
Gender	Female	7
	Male	9
Degree	Master	7
	Doctorate	9
Specialty (area of study)	Computer Science	9
	Telecommunication and networking area	1
	Wireless networks	1
	Cognitive Neurobionics	1
	Health Psychology	1
	Biomedical Science	1
	Computer Forensics	1
	Design Engineering	1

5.4.1 Use and non-use of user-generated external representations during sensemaking

The following section reports on the results across the two conditions of the user-generated representation and non-representation and, in this way, it reports on testing the following hypotheses:

H_1: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.

H_2: Creating user-generated external representations during sensemaking helps to increase keyword novelty.

H_5: Creating user-generated external representations during sensemaking helps to reduce the level of perceived uncertainty.

5.4.1.1 Testing of parametric assumptions

Before conducting hypothesis testing to decide what test should be used to investigate the relationship between the variables, the normality of data was first assessed. The parametric assumption of normal distribution calculated for the seven continuous variables included in the study were tested. The normal distribution of each of the seven continuous variables was tested by plotting histograms and by calculating skewness and kurtosis scores and Shapiro-Wilk (See Appendix E.2)

The results of the Shapiro- Wilks test ($p > .05$) and the visual inspection of the histograms showed that the scores were approximately normally distributed for perceived sensemaking under the non-representation condition, with Skewness of .485 (SE = .564) and kurtosis of -.932 (SE = 1.091); perceived uncertainty under the user-generated representation condition with Skewness of .658 (SE = .564) and kurtosis of .145(SE = 1.091); keyword novelty under the user-generated representation condition with Skewness of -.186 (SE = .564) and kurtosis of -.593(SE = 1.091); and keyword novelty under the non-representation condition with Skewness of .466 (SE = .564) and kurtosis of -.979 (SE = 1.091)

However, the results of Shapiro-Wilks test ($p < .05$) and the visual inspection of the histograms showed significant departures from normality for perceived sensemaking under the user-generated representation condition, with Skewness of -1.624 (SE = .564) and kurtosis of 3.010 (SE = 1.091); perceived uncertainty under the non-representation condition with Skewness of -.921 (SE = .564) and kurtosis of .111 (SE = 1.091); structuredness with Skewness of 1.284 (SE = .564) and kurtosis of 1.257 (SE = 1.091).

Based on these results the following tests were used in the next sections of the analysis:

- To test H1, which predicted an increase in participants' perceived sensemaking when creating user-generated external representations, median and an non-parametric test – Wilcoxon signed-rank – were used, as Shapiro-Wilk test of perceived sensemaking under the user-generated representation condition showed a significant departure from normality: $W(16) = .855$, $p = .016$.
- To test H5, which stated that creating user-generated external representations during sensemaking helps to reduce perceived uncertainty, median and an non-parametric test

– Wilcoxon signed-rank – were used, as the Shapiro-Wilk test of perceived uncertainty under the non-representation condition showed a significant departure from normality: W(16) = .886, p = .048 and

- To test H2, which predicted an increase in users' tendency to generate novel search terms when creating user-generated external representations during sensemaking, the main and a parametric test – paired-sample – were used, as the variable keyword novelty was found normally disturbed in both user-generated representation and non-representation.
- To investigate the correlation between structuredness and perceived sensemaking, perceived uncertainty and keyword novelty, an non-parametric test – Spearman's rank correlation – was used, as the Shapiro-Wilk test showed a significant departure from normality for sensemaking: W (16)= .855, p = .016 and structuredness W(16) = .873, p = 0.030.

5.4.1.1 User-generated representation and perceived sensemaking

The levels of perceived sensemaking across the conditions of user-generated representation and non-representation, as reported by participants, were compared to see if there were any significant differences. These results are illustrated in the chart in Figure 5.5.

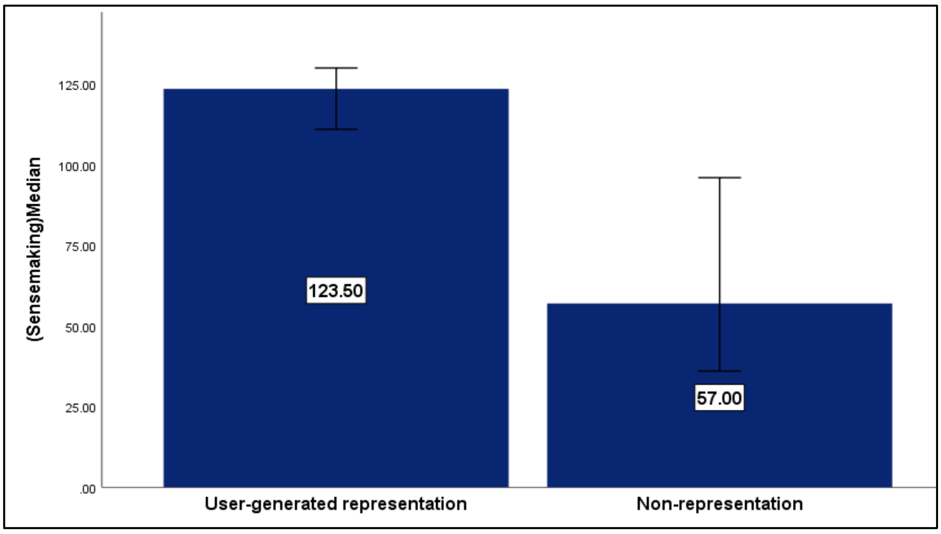


Figure 5.5: Median scores of perceived sensemaking under the two conditions

Figure 5.5 illustrates the median of participants' perceived sensemaking under the two conditions of user-generated representation and non-representation. The results showed that, when participants created external representations, perceived sensemaking (Mdn = 123.50) scores 66. 5 pointed higher than perceived sensemaking when participants did not create external representations (Mdn = 57). The results clearly indicated differences between the median score of participants when they structured information and when they did not.

In order to evaluate whether the participants' perceived sensemaking was statistically different across conditions, the Wilcoxon signed-rank test was performed. The analysis indicated a significant difference between perceived sensemaking in the user-generated representation condition and non-representation condition ($Z = -3.516$, $p < 0.05$). The results supported hypothesis H1, which predicted an increase in participants' perceived sensemaking when they create user-generated external representations.

5.4.1.2 User-generated representation and perceived uncertainty

The levels of perceived uncertainty, as reported by participants, were also compared across structuring and non-structuring to establish if there was a difference between participants creating external representations and when they did not.

The median scores of perceived uncertainty under these two conditions are reflected in the graph in Figure 5.6.

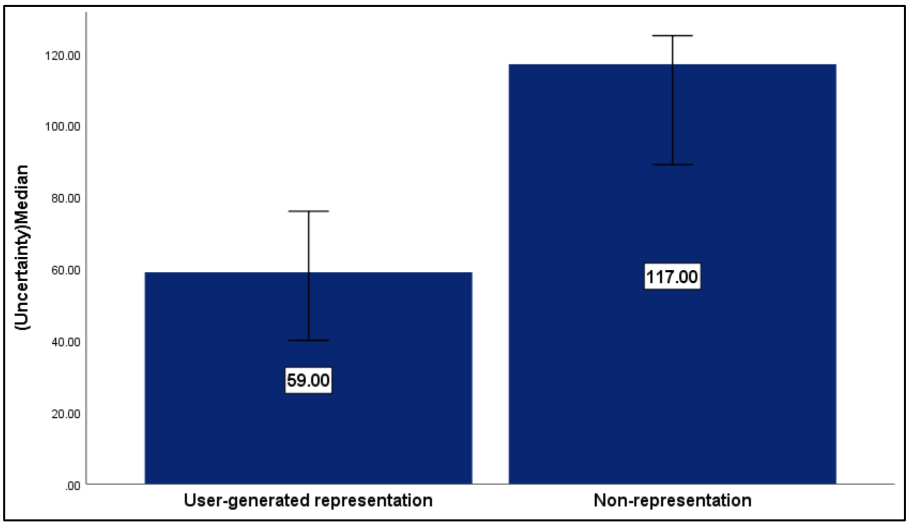


Figure 5.6: Median scores of perceived uncertainty under the two conditions

Figure 5.6 shows the median of participants' perceived uncertainty under the two conditions of user-generated representation and non-representation. The results showed that, when participants created external representations, perceived uncertainty (Mdn = 59) scores 58 pointed lower than perceived uncertainty when participants did not create external representations (Mdn = 117).

In order to evaluate whether the participants' perceived uncertainty was statistically different across conditions, a Wilcoxon signed-rank test was conducted. The results of the Wilcoxon signed-rank test indicated a significant difference between perceived uncertainty in the user-generated representation condition, as opposed to the non-representation condition ($Z = -3.362$, $p < .05$). These results suggested that, when participants created external representations, they reported lower levels of perceived uncertainty than when they did not. These results supported hypothesis H5, which states: Creating user-generated external representations during sensemaking helps to reduce perceived uncertainty.

5.4.1.3 User-generated representation and keyword novelty

Participants used 565 queries in total across the conditions of user-generated representation and non-representation. The results of paired samples t-test showed a statistically significant difference in the number of search terms used between the participants under the non-representation condition (mean = 21.81, SD = 14.41) and the ones under the user-generated representation condition (mean = 13.50, SD = 5.41), $t(15) = -2.83$, $p = .01$).

The results indicated that, when participants did not create user-generated external representations, they used more search quires than when they did. Participants either used information from the task sheet as search queries or they created new search queries.

Table 5.3 shows examples of task-based and new search terms created by some participants.

Table 5.3: Examples of search queries created by some participants

Participant	Task-based search terms	New search terms
P12	Political shenanigan Rex Luthor unethical	Jhon Toruch Scandal Laurel Sulfate Biotechnology Laboratory
P11	FBI investigation Alderwood new laboratory Political shenanigans January 2003 Lab cow disease	Torch mayor race Starbucks scandal John torch women December 2002 Misconduct
P5	Mass death Flu season Flue death FBI terror	Beattric Brothers Network of hate Paramurders of Ghoas Tony Grenier
P9	Livestock Flu Mass death Metropolitan	Robbery Contamination Explosive Nitroglycerin
P4	Suspicious behaviour Bioterrorism livestock	Food transportation Food supply Vasopolise FDA

The percentages of non-task-based queries (new search queries) were compared across user-generated representation and non-representation to see whether there was a difference between when participants creating external representations and when they did not. The graph in Figure 5.7 illustrates the mean scores of keyword novelty under the two conditions.

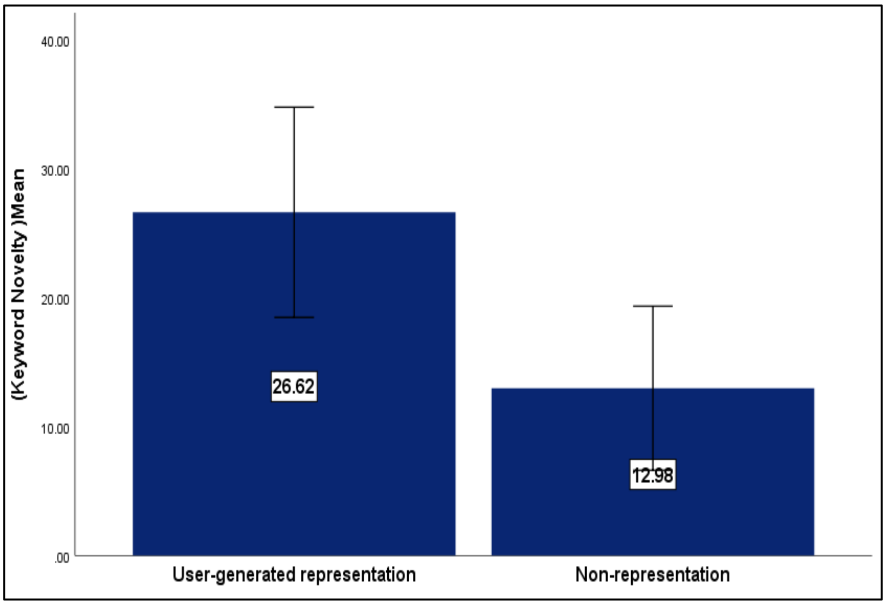


Figure 5.7: Mean scores of keyword novelty under the two conditions

Figure 5.7 reflects the mean of keyword novelty under the two conditions of user-generated representation and non- representation. These results indicated that, when participants created user-generated external representations, keyword novelty (M = 26.62, SD = 15.3) scores 13.64 pointed higher than keyword novelty when participants did not create external representations (M =12.28, SD = 11.94). The results suggested a difference between the mean score of the percentage of new search terms when participants structured information and when they did not.

The percentage of new search terms created by participants to the overall search terms they created during each session were compared across the two conditions of user-generated representation and non-representation. A paired sample t-test was conducted to establish whether there was a significant difference in keyword novelty across the two conditions.

The results of the test indicated a significant difference in keyword novelties across the two conditions ($t (15) = 5.65$, $p < 0.05$). When participants created user-generated external representations, their tendency to generate novel search terms increased, compared to when they did not. These results supported hypothesis $H_{2,}$ which predicted an increase in users' tendency to generate novel search terms when create user-generated external representations during sensemaking.

5.4.2 Level of structuring within user-generated external representations and sensemaking

Under the user-generated representation condition the following hypotheses were also tested:

H_3: Structuredness correlates with perceived sensemaking.

H_4: Structuredness correlates with keyword novelty.

H_6: Structuredness correlates inversely with perceived uncertainty.

Hypotheses H_3, H_4 and H_6 were only tested under the user-generated representation condition, as participants only created external representations under the user-generated representation condition. The levels of structuredness of the external representations created by each participant were calculated by using the metric developed in Chapter 4. In this study, participants created representations that varied in their types and levels of complexity.

Table 5.4 presents the type of representations created by participants and their structuredness by using the metric from Chapter 4 (more details are provided in Appendices D3 and D4).

Table 5.4: Type of relations created by participants and their level of structuredness

Participants	Type of representation	Level of structuredness
P1	Folder	11
P2	Themed grouping relation + Timeline within themed grouping relations	522
P3	Folder and themed grouping relation	216
P4	Ordinal timeline	82
P5	Folder and themed grouping relations	89
P6	Folder	36
P7	Folder	39
P8	Themed grouping relations, an independent IOS, and an ordinal timeline	168
P9	Ordinal timeline	369
P10	Themed grouping relation and an independent IOS	150
P11	Themed grouping relation and an independent IOS	192
P12	Ordinal timeline and an independent IOS	342
P13	Themed grouping relation	162
P14	Ordinal timeline	108
P15	Directional	109
P16	Folder	12

Using the Spearman's rank correlation, the correlation between structuredness and perceived sensemaking, perceived uncertainty and keyword novelty were then calculated. These results are summarised in Table 5.5.

Table 5.5: Spearman's rank correlation between structuredness and perceived uncertainty, keywords novelty and perceived sensemaking

		Structuredness
Keywords novelty	Spearman's rank	.260
	Sig. (2-tailed)	.331
	N	16
Perceived sensemaking	Spearman's rank	.185
	Sig. (2-tailed)	.492
	N	16
Perceived uncertainty	Spearman's rank	-.293
	Sig. (2-tailed)	.271
	N	16

5.4.2.1 Structuredness and perceived sensemaking

The results in Table 5.5 showed no correlation between participants' levels of perceived sensemaking and structuredness: r = .185, n = 16, p = .492. The results did not show enough evidence to accept hypothesis H_3: Structuredness correlates with perceived sensemaking.

Although the results showed no significant correlation between the two variables of perceived sensemaking and structuredness, the scatter plot in Figure 5.8 indicates that participants, who created representations with levels of structuredness lower than 168 values, scored different levels of perceived sensemaking, ranging from 63 to 143. However, all participants, who created representations with level of 170 and higher, reported perceived sensemaking with scores always higher than 115. These results do suggest a relation between a certain level of structuredness and the reported levels of perceived sensemaking by participants. When participants created representations with higher structuredness than a certain value – in this case 168 – they always reported high and stable levels of sensemaking.

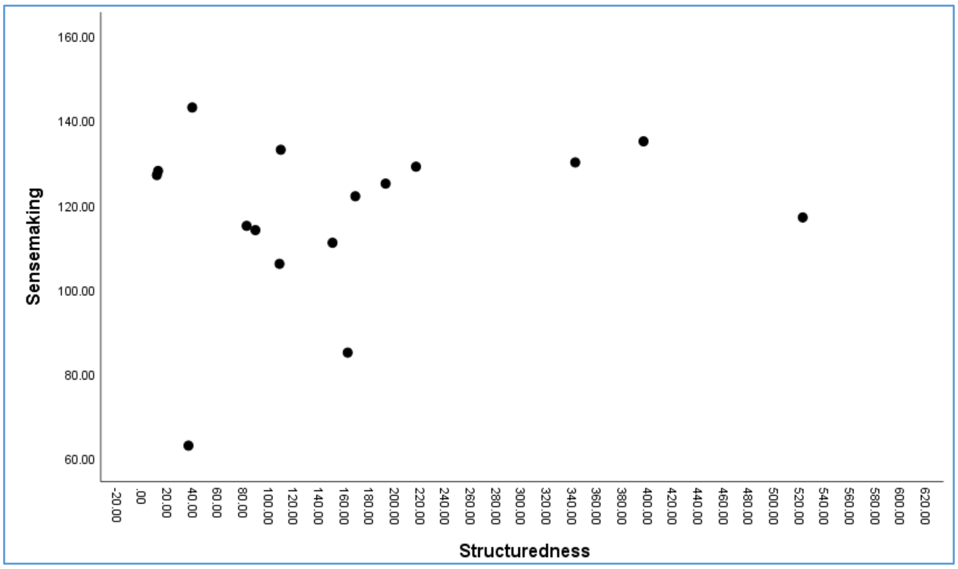


Figure 5.8: Scatter plot of structuredness and perceived sensemaking

5.4.2.2 Structuredness and keyword novelty

The results in Table 5.5 showed no correlation between the two variables structuredness and keywords novelty: r = .331, n = 16, p = .260. The scatter plot in Figure 5.9 also illustrates no correlations between the two variables: increases in keyword novelty were correlated with increases in structuredness. These results did not support hypothesis H_4, which predicted that structuredness correlates with keyword novelty.

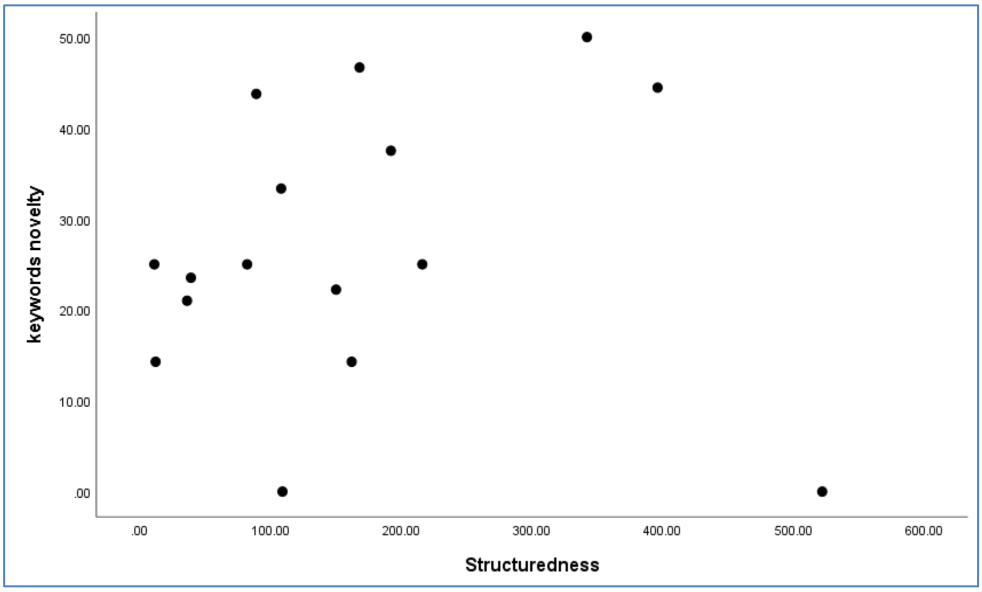


Figure 5.9: Scatter plot of structuredness and keywords novelty

5.4.2.3 Structuredness and perceived uncertainty

The results in Table 5.5 also showed no negative correlation between structuredness and perceived uncertainty, with a Spearman's rank correlation of r = -.293, n = 16, p = .271. The results suggested that, when participants created representations with a higher level of structuredness, they reported less perceived uncertainty and vice versa. The scatter plot in Figure 5.10 illustrates no negative correlations between the two variables. These results did not support hypothesis H_6: Structuredness correlates inversely with perceived uncertainty.

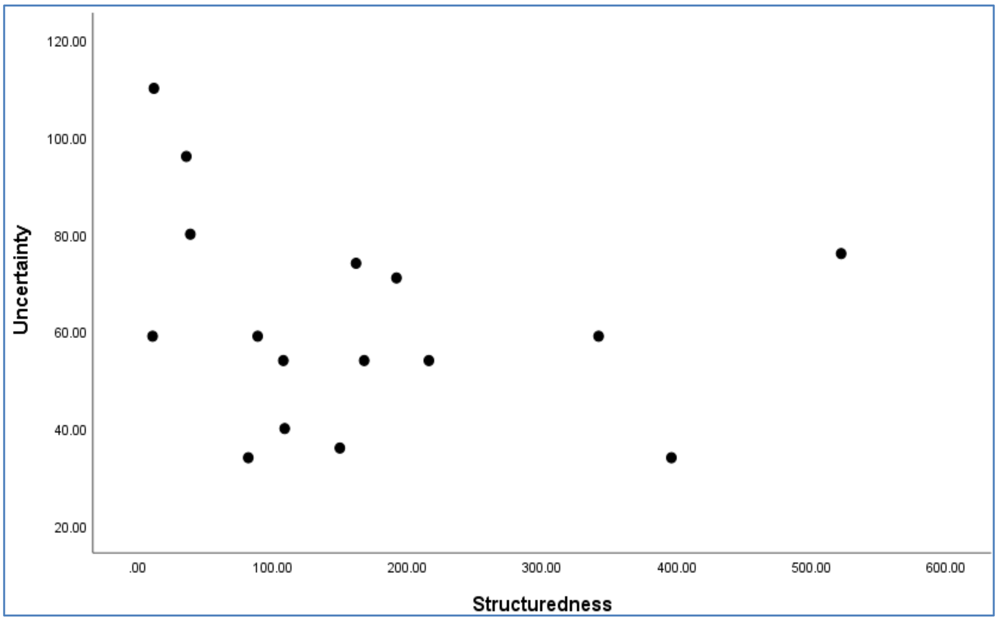


Figure 5.10: Scatter plot of structuredness and perceived uncertainty

5.5 Discussion and conclusion

The current study was designed to investigate the impact of user-generated external representations in the context of sensemaking. By testing a set of hypotheses, the study particularly investigated the way in which the use of such representations affected the process of sensemaking. The results of the study confirmed the importance of representations in the process of sensemaking and contributed to existing scholarship by providing empirical evidence of how external representations help sensemaking.

In this part of this doctoral thesis, it was hypothesised that the use of external representations during sensemaking would have a positive impact on participants' self-reported sensemaking, while, at the same time, their perceived uncertainty would decrease. Both of these were found to occur. It was also hypothesised that the use of external representations would result in participants tending to use novel terms in their keyword searches – i.e. terms not contained within a task briefing. The results also confirmed this hypothesis.

Under the user-generated representation condition, a positive correlation was expected between levels of structuring in the created representations, structuredness and self-reported levels of sensemaking and keyword novelty, and negative correlation with self-reported uncertainty. With the exception of self-reported levels of sensemaking, where the positive correlation occurred at certain values of structuredness, this did not occur.

The following section presents the results of each of the sub-questions, each of which was investigated in two ways: (i) through an experimental manipulation of the effects of the use and non-use of external representations on perceived sensemaking, keyword novelty and uncertainty by using the paradigm in Figure 1.2, and 1.3 from; and (ii) through testing the correlation between structuredness and perceived sensemaking, keyword novelty and uncertainty.

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

This research sub-question aimed at investigating the effects of the use and non-use of external representations on perceived sensemaking through an experimental manipulation, as well as through testing the correlation between perceived sensemaking and structuredness.

Based on Wilcoxon signed-rank test, it was possible to accept H_1, which stated that the creation of user-generated external representations during sensemaking helps to increase perceived sensemaking. The results aligned with the results of the exploratory part of the first study reported in Chapter 3. The results suggested that, when they did not have a 'schematise' stage, participants in the non-representation condition achieved lower levels of perceived sensemaking. On the other hand, when they did externalise their thinking in the user-generated representation condition, they made more sense of the data, as subjectively reported. Since this study was a controlled experiment, a causation relation among the use of external representations and higher levels of perceived sensemaking could be claimed – i.e. the use of external representations caused an increase in the level of perceived. These findings supported the assumption that the use of external representations was significant to the sensemaking process (Pirolli & Card, 2005; Klein et al., 2006b; Russell et al., 1993). It also extended the findings of these studies by adding quantitative evidence of such an effect through the use of the developed instrument.

According to the sub-scales of the questionnaire, when participants used external representations, they felt they were better able to gain insight; find connections; draw on their prior knowledge; discover and bridge gaps in their knowledge; find a structure in the information; and reduced confusion.

The relationship between perceived sensemaking and the level of structuring within a representation was also investigated. The results of the Spearman's rank correlation test (Table 5.5) showed no evidence to support H_3, which predicted a positive correlation between perceived sensemaking and structuredness. The results of the scatter plot in Figure 5.5 suggested that, when structuredness values lower than 168 were reached, participants reported unstapled levels of perceived sensemaking (participants' perceived sensemaking had more variability between low and high values), ranging from 63 to 143 scores. However, when structuredness values ranged from 168 and above, participants reported perceived sensemaking, with no scores lower than 115. High structuredness always correlated with high levels of perceived sensemaking. Such results suggested that structuredness may increase perceived sensemaking after a certain point: the increase in perceived sensemaking did not start until it reached some points.

The results of analysing the levels of perceived sensemaking when participants create user-generated external representations and when they did not, as well as the results of the relation between structuredness and perceived sensemaking can be summarised as follows: during sensemaking, the creation of user-generated external representations helps to increase perceived sensemaking. The results also suggested the possibility of such an increase being achieved when external representations with high values of structuredness are created.

The developed instrument and the design of the study (Figure 1.2) helped to measure the effect of the creation of user-generated external representations in the sensemaking process quantitatively.

RQ1.2: *What is the relationship between the creation of user-generated external representations and query construction?*

This research sub-question aimed at investigating the effects of the use and non-use of external representations on keyword novelty through an experimental manipulation and by testing the correlation between keyword novelty and structuredness.

Based on the results of the paired sample t-test, it was possible to accept H_2 (Creating user-generated external representations during sensemaking helps to increase keyword novelty). The results suggested that the use of external representations helped participants to develop new questions that were reflected in the new search terms that they used. An explanation of these results could be also that, when participants created a visual structure, they drew on them, in order to construct their information need. Since this study was a controlled experiment, a causation relation among the use of external representations and higher levels of keyword novelty could be claimed. However, based on the results of the Spearman's rank correlation test (Table 5.5), $H_{4,}$ which predicated a positive correlation between structuredness and keyword novelty, was not accepted. The results showed no evidence to support that, when the values of structuredness of the external representations created by participants increased, their tendency to generate novel keywords increased.

When searching for information in an electronic environment, formulating and using a keyword is an initial step. Users form their information needs as search terms – a construct that is referred to as a *query*. The quality of the constructed query may be affected by the status of the user's information need. Failing to express an information need, e.g. when information seekers use poor search terms, may hinder their progress in the search process (Savolainen, 2015). In a study in which he investigated the changes in students' search term creation throughout the proposal writing process, Vakkari (2001) found that, when information seekers are not familiar with the topic, their level of uncertainty is high, their understanding of the task is vague, and their mental models of tasks are less differentiated. However, over time as they progress in the search process, participants create more specific search terms Vakkari (2001).

When participants visually externalised their thinking in user-generated external representations, they were able to generate more new search terms, compared to when they did not visually externalised their thinking. This meant that they developed their own understanding of the tasks; they progressed in the search process; and their information needs became more differentiated, which resulted in asking new questions represented by the new search terms that they used. However, when participants did not create user-generated external representations, they did not develop their own understanding of the tasks. Instead, they apparently relied more on the tasks brief to construct queries and their understating of the tasks was seemingly more limited to the information provided by the task brief. However, the results suggested no relation between the number of primitives, relations and constraints imposed by relation into information increased and the tendency of participants to generate new search queries.

One possibility is to understand this distinction in terms of a psychological theory, such as the model of level of processing by Craik & Lockhart (1972). They investigated the relation between levels of processing, shallow or deep, and memory recall. Deep processing includes semantic processing and elaboration, which involves more thinking and association, while shallow processing tends to focus on surface level aspects of stimuli, such as structural and phonetic features. The results of this study suggested that user-generated external representations may support participants in deeper semantic processing of the domain of which sense was being made, thereby allowing them to derive search terms based on semantic relationships than when they do not use of external representations. The results may also be described in light of the spreading activation theory of Collins and Loftus (1975). According to their theory, "knowledge" is stored in a conceptual semantic network in memory, where nodes (concepts) are connected with links that differ in their numbers and lengths, based on the strength of the relation between them: the closer the closer the connection between concepts (nodes), the more and shorter the links between them. When a concept is triggered, activation spreads in the network to activate all relevant concepts – i.e. user-generated external representations may allow participants to activate greater semantic networks within the mind, which leads them to generate more new search terms than when they do not create external representations.

RQ1.3: *What is the relationship between the creation of user-generated external representations and perceived uncertainty?*

The effects of the use and non-use of external representations on perceived uncertainty and the relationship of perceived uncertainty to structuredness were investigated during this study. Based on the results of the Wilcoxon signed-rank test, it was possible to accept H_5, which predicted that the creation of user-generated external representations during sensemaking helps to reduce the level of perceived uncertainty. These results demonstrated that the use of external representations had an impact on the level of perceived uncertainty. When participants did not use external representations, they were more uncertain than when they did not create user-generated external representations.

Since this study was a controlled experiment, a causation relation among the use of external representations and higher levels of perceived uncertainty could be claimed. However, based on the results of the Spearman's rank correlation t-test (see Table 5.5 and Figure 2.12), H_6 (Structuredness correlates inversely with perceived uncertainty) was not accepted. The results suggested no relation between the increase in the values of structuredness of representations created by participants and the decrease in their perceived uncertainty.

Previous research (Belkin, 1980; Kuhlthau, 1993b) has argued that, when searching for information, people are often uncertain about what they are looking for and their needs are ill defined. Uncertainty is important at the early stages of the search process, to motivate the search process Anderson (2006). In this study participants' perceived uncertainty was measured at the end of sessions and, therefore, a reduction in the level of uncertainty was expected. Levels of perceived uncertainty as reported by participants confirmed this expectation: when participants created user-generated external representations, the effect of visually structuring information was to help reduce uncertainty by the end of the information seeking process. However, when participants did not externalise their thinking, they reported higher levels of perceived uncertainty. However, the results showed that the numbers of primitives, relations and constrains imposed by these relations on information in the external representations had no relation with the decrease in perceived uncertainty.

These results can be explained in the light of the information seeking model by Kuhlthau (1993b), which states that, as information seekers progress in the search process, their feeling of uncertainty decreases. For instance, during the initiation and exploration stages, both of which are early stages, the information seekers experience feelings of uncertainty and confusion. These feeling are replaced with clarity when they progress to the formulating stage.

The empirical results of this study extended those of Kuhlthau (1993b) by showing the effects of the creation of user-generated external representations on perceived uncertainty. The results indicated that, when they did not create user-generated external representations visually under the non-representation condition, participants were still at earlier stages of the search process at the end of the tasks, compared to when they did create of user-generated external representations, as suggested by Kuhlthau's model of information seeking (1993). These results extended the information seeking model by adding quantitative evidence of the changes in the levels of uncertainty by linking those to the user-generated representations and structuredness of users' externalised thinking in user-generated external representations.

To summarise: the results of this study suggested that external representations – in particular user-generated external representations created to construct a narrative understanding during individual sensemaking tasks – change the way sensemakers think about things. The results suggest that, by explicitly representing the domain, sensemakers will be able to perform sensemaking better; reduce uncertainty; and think more deeply about the problem through keywords novelty. However, through the developed metric to measure structuredness, the results also suggest that changes in the levels of structuring of the external representations do not correlate with changes in some other sub-tasks of the sensemaking process. It is suggested no relation between the constraints imposed on the semantic position of elements within an external representations increase, and sensemakers' tendency to generate more novel queries or the reduction in their perceived uncertainty. The results also show that people need to create more complex structures to show differences in their sensemaking levels.

Sensemaking was studied qualitatively (i.e. Pirolli & Card, 2005; Klein, Moon & Hoffman 2006a, 2006b); Russell et al., 1993) and the tools of sensemaking were evaluated qualitatively. The design of the study (Figures 1.2 and 1.3 in Chapter 1) and the manipulation of the independent variable user-generated representation helped to investigate the effect of the creation of user-generated external representations in sensemaking. Through the use of the paradigm, these results helped to detect the effect of the creation of user-generated external representations on sensemaking quantitatively by measuring such an effects on some of the sensemaking subtasks (queries construction). Such a paradigm can be used when evaluating tools that support the use of external representations during sensemaking.

5.6 Chapter summary

This chapter reported on a study that was intended to expand on the first study (Chapter 3), but with a broader scope. It also corrected some of the limitations of the first study and added new variables that were worth exploring. The study aimed at investigating the effect of the creation of user-generated external representations on the quality of sensemaking during an individual task by answering RQ1. More specifically, this study focused on answering sub-questions RQ1.1, RQ1.2 and RQ1.3 in the following two different ways:

- Investigating the effect of the creation of user-generated external representations on sensemaking through an experimental manipulation of the independent user-generated representation; and
- Investigating the relationship between the level of structuring in external representations and some of sensemaking sub-tasks and some of its final products.

The results of this study shed light on the way in which sensemaking and the creation of user-generated external representations in individual sensemaking can be quantitatively measured when studying the phenomena by using the developed paradigm (Figures 1.2 and 1.3).

The results of the study also provided:

- Quantitative evidence of the effect of the creation of user-generated external representations on perceived sensemaking, query construction and perceived uncertainty; and
- Quantitative evidence of the relationship between the levels of structuring in user-generated external representations and perceived sensemaking, query construction and perceived uncertainty.

CHAPTER 6: DISCUSSION AND CONDLUSION

This chapter presents an overview of the studies undertaken in the course of this doctoral research, answers to the research questions, research contributions, research limitations and boundaries, as well as suggestions for future research directions.

6.1 Overview of the studies

This section presents a summary of the four studies that were conducted in the course of this research. Two controlled experiments were conducted in which participants searched for documents relevant to a given task brief. In one condition, they created an external representation in the form of a narrative and, in another; they collected relevant documents in a folder. The former controlled experiment (Figure 6.1 and details in Chapter 3) was a combination of a confirmatory (i.e. addressing a hypothesis) and an exploratory study conducted to investigate the effects of using external representations in sensemaking. The latter controlled experiment (Figure 6.2 and details in Chapter 5) was conducted to replicate and expand on the findings of the former experiment by testing additional hypotheses. The third study (Figure 6.3 and e details in Chapter 4) aimed at validating a metric of structuredness in the external representations created by users during sensemaking tasks. The fourth study (Figure 6.4 and details in Chapter 4) aimed at validating a questionnaire developed to measure the levels of perceived sensemaking. These four studies are summarised in Figures 6.1–6.4 as follows Figures 6.1 and 6.2 summarise Study 1 and 4 respectively, as they have the same experimental design, followed by Figure 6.3, which presents Study 3 and, finally, Figure 6.4, which summaries Study 4.

1. Aim

The study aimed to investigate the effect of user-generated external representations in individual sensemaking tasks when searching for information within an electronic environment. The experimental part of the study was conducted to measure quantitatively the effect of structuring thinking in user-generated external representations on perceived sensemaking, whereas the exploratory part aimed to investigate the effect of user-generated representations thinking in external representations on query construction

2. Study design

A controlled experiment that follows a repeated measure design. There is a single independent variable (user-generated representation) with two levels (user-generated representation vs. non-representation). Under the user-generated representation condition, the paradigm in Figure 1.2 in Chapter1 was applied, where participants were asked to create external representations while performing the sensemaking task by using Microsoft OneNote. Under non-representation condition, the paradigm in Figure 1.3 was applied and, under this condition, participants saved files they judged as relevant in a folder without creating any representations. A questionnaire was developed to measure perceived sensemaking.

3. Methods used to collect the data

A questionnaire was designed to measure participants' perceived sensemaking/screen recording by using BB Flashback software)

4. Participants

Thirteen postgraduate students from the Science and Technology Department at Middlesex University.

5. Methods used to analysed the data

Wilcoxon signed-rank test to compare participant's levels of perceived sensemaking across conditions. A qualitative data driven approach was used to analyse activities related to query construction.

6. Results

- Creating user-generated external representations helps to increase perceived sensemaking (H_1).
- Creating user-generated external representations seems to have an effect on query construction (H_2).

Figure 6.1: Study 1: The effect of user-generated external representations in perceived sensemaking and construction of a query

<table>
<tr><td colspan="2">1. Aim

This study is conducted to replicate the findings of the first exploratory study, presented in Chapter 3, and to expand on the findings by testing additional hypotheses H_3, H_4 from Chapter 4. In this study, the scope is also increased to include the notion of uncertainty.</td></tr>
<tr><td>2. Study design

The study follows the same paradigm design (Figures 1.2 and 1.3) of the first study reported in Chapter 3. The study, which follows a repeated measure design, involves a controlled experiment. There is a single independent variable (user-generated representation) with two levels (user-generated representation vs. non-representation). Some amendments have been made to overcome the limitations of the exploratory study. (Details of the amendments are provided in Chapter 5).</td><td>4. Participants

Sixteen postgraduate students from the Science and Technology Department at Middlesex University</td></tr>
<tr><td>3. Data collection methods

The new version of the sensemaking questionnaire from Study 3 (Chapter4), the perceived uncertainty questionnaire adopted from a previous study (Pugh, 2017), representations created by participants by using OneNote and Screen recording (using BB Flashback software).</td><td>5. Methods used to analysed the data

Paired sample t-test, Wilcoxon signed-rank test, Spearman's rank correlation and the developed metric in Study 2 to measure structuredness.</td></tr>
<tr><td colspan="2">6. Results

– User-generated representation helps to increase perceived sensemaking and keywords novelty and reduce uncertainty.
– Structuredness does not correlate either positively or negativity with keyword novelty and perceived uncertainty, however it correlates positively with sensemaking at certain point of high structuredness.</td></tr>
</table>

Figure 6.2: Study 4: The effect of user-generated external representations on perceived sensemaking, perceived uncertainty and keyword novelty

1. Aim

The study aims at developing a quantitative valid measure of the level of structuring "structuredness" of user-generated external representations.

2. Development of a metric to measure structuredness

A metric was developed, based on an approach that was introduced by Okoro (2014) and Okoro and Attfield (2016). According to the approach, visual representation can be described in terms of syntax trees (parse trees) that consist of entities that are embodied within other entities. The metric added to the approaches the semantic constrains that impost the positions by relations within a parse tree. The structures of each relation within a representation, based on its semantic constrains (variable types), multiplied by the number of its sub-relations and primitives.

4. Data collection methods

Participants were asked to rank different samples of external representations from high to low, based on their levels of structuring.

5. Participants

Seventeen participants from the Science and Technology Department at Middlesex University.

3 Validation of study design

The structuredness of some samples was measured by using the metric. The same samples were given to participants to rank them from low to high, based on their level of structuring. The results of these two ways of measuring structuredness were compared.

6. Methods used to analyse data

The distribution of responses on each representation were plotted to analyse the central tendency and dispersion of ranks assignment by participants. Kendall's coefficient of concordance ranks, a correlation analysis, and Spearman's rank correlation coefficient were used.

7. Results

- A valid metric to measure structuredness of user-generated external representations.
- New hypotheses regarding the relationship between structuredness, perceived sensemaking and keyword novelty ($H_3$and H_4).

Figure 6.3: Study 2: Development of a metric to measure structuredness

1. Aim To produce a more general version of the questionnaire developed in Chapter 3 to measure levels of perceived sensemaking that can be used in any future studies about sensemaking.	
2. Validation of study design The new version of the questionnaire has been developed, based on rewording some of the statements in the old version presented in Chapter 3. The second aim is to validate the new version of the questionnaire. The data is collected from participants after they have performed one of the following sensemaking tasks: - Reading a paper (academic article); - Attending a lecture; - Attending a seminar; - Attending a workshop; - Participating in a lab study; and - Submitting coursework.	**3. Data collection methods** A new version of the sensemaking questionnaire in Chapter 3 **5. Analysis** Principle component analysis (PCA) and Cronbach's alpha are used to validate the instrument for measuring sensemaking.
6. Results The results show that the developed questionnaire is a valid and reliable instrument to measure what is believed to be sensemaking, since the development of the questionnaire is based on definitions and theories of sensemaking.	

Figure 6.4: Study 3: Development of an instrument to measure perceived sensemaking

6.2 Answers to research questions

This section presents the answers to main research question RQ1 by presenting the results of sub-questions RQ1.1, RQ1.2 and RQ1.3 and linking those to the studies conducted in the course of this doctoral research.

RQ1: *How does the creation of user-generated external representations measurably affect the sensemaking process?*

Sensemaking can be defined as the process of building understanding when facing complex situations. Creating a representation of a domain of interest is central to sensemaking, whether stored internally as a mental model, or externally by using maps or tables, for example. The latter is generally assumed to be helpful, but little is known about how external representations affect the sensemaking process.

Despite the literature explicitly recognising the significance of external representations during sensemaking, it is not addressed in depth. The aim of this doctoral research was to investigate the effect of the creation of user-generated external representations in the process of sensemaking when searching for information in an electronic environment. It aimed conducting quantitative measurements to form a better understanding of what happens during sensemaking when using external representations.

The following three sub-questions were developed to answer the mean research question:

RQ1.1: *What is the relationship between the creation of user-generated external representations and perceived sensemaking?*

RQ1.2: *What is the relationship between the creation of user-generated external representations and query construction?*

RQ1.3: *What is the relationship between the creation of user-generated external representations and perceived uncertainty?*

RQ1 was answered in two ways. In the first way, the research questions were addressed through an experimental manipulation of the use and non-use of user-generated representations to externalise thinking during sensemaking. A paradigm was designed, as illustrated by Figures 1.2 and 1.3. The dependent variables – namely perceived sensemaking, keyword novelty and perceived uncertainty – were then compared across two conditions (user-generated representation and non-representation). The paradigm was applied in Studies 1 and 4 and reported on in Chapters 3 and 5. Both studies were controlled experiments that followed a repeated measures design. Participants were provided with scenario tasks related to incidents (e.g. the war crisis in Syria) and datasets of news stories. During the experiments, participants' task was to search for information and judge the relevance of evidence in the datasets to develop an understanding of what had occurred regarding a particular incident. Under the user-generated representation condition, the paradigm in Figure 1.2 was applied, where participants were asked to externalise their thinking through the creation of user-generated external representations while performing the sensemaking task by using Microsoft OneNote. Under the non-representation condition, the paradigm in Figure 1.3 was applied and, under this condition, participants saved files that they judged as relevant in a folder without creating any representations.

The second way that was followed to answer RQ1 involved the investigation of the relationship between the level of structuring within the created external representations "structuredness" and perceived sensemaking, keyword novelty and perceived uncertainty. The sub-questions were answered by testing a set of hypotheses.

Table 6.1 shows the research sub-questions and related hypotheses and the conditions under which these hypotheses were tested.

Table 6.1: Research sub-questions, related hypotheses and conditions under which each hypothesis was tested

Research sub-question	**Related hypothesis**	**Across condition**	User-generated representation **condition of testing**
RQ1.1	***H_1**: Creating user-generated external representations during sensemaking helps to increase perceived sensemaking.*	*	
RQ1.2	***H_2**: Creating user-generated external representations during sensemaking helps to increase keyword novelty.*	*	
RQ1. 3	***H_5**: Creating user-generated external representations during sensemaking helps to reduce the level of uncertainty.*	*	
RQ1.1	***H_3**: Structuredness correlates with perceived sensemaking.*		*
RQ1.2	***H_4**: Structuredness correlates with keyword novelty.*		*
RQ.13	***H_6**: Structuredness correlates inversely with perceived uncertainty.*		*

RQ1 was partly answered through RQ1.1, which aimed at investigating the effect of user-generated external representations on perceived sensemaking. RQ1.1 was answered by testing H_1 and to test the hypothesis, data was collected by means of the questionnaire and by comparing across the two conditions of user-generated representation and non-representation. In Study 1 (reported in Chapter 3), a questionnaire was developed, based on a number of significant theories and definitions of sensemaking. The questionnaire was revised and a new version was developed and validated in Study 3 (reported in Chapter 4). The new version of the questionnaire was developed by rewording some of the statements in the old version of the questionnaire in Chapter 3 to be more general and useful in any future studies of sensemaking. The old version of the questionnaire involved some statements that could only be used when the sensemaking task was to construct a story. For example, the statements in Q9, Q10 and Q11 in the old version were respectively: *understand connections between people (countries); understand connections between places;* and *understand connections between events*. In the new version of the questionnaire, these statements were combined into the following general statement: *understand connections between things*. The developed questionnaire proved to be valid and reliable to measure what is believed to be sensemaking, as it was based on theories and definitions of sensemaking. The new version of the questionnaire was then used in Study 4 (reported in Chapter 5) to answer RQ1.1. The questionnaire was given to the participants after they had performed sensemaking tasks under the conditions of user-generated representation and non-representation. The old version of the questionnaire was used in Study 1 and the new version was used in Study 4.

In both Studies 1 and 4, the results of testing H_1 showed that creating user-generated external representations during sensemaking did have some effect on participants' levels of perceived sensemaking. When creating external representations, such as timeline relations, themed grouping relations, and when they taking notes, participants reported higher levels of perceived sensemaking than when they did not. The results, which aligned with studies that emphasise the importance of external representations to the sensemaking process (e.g. the studies of Pirolli & Card, 2005; Klein, Moon & Hoffman, 2006a, 2006b; Russell et al., 1993), also extended on them by adding quantitative evidence of the way in which external representations help sensemaking. According to the sub-scales of the questionnaire, when participants used external representations, they felt that they were more able to gain insight, find connections, draw on their prior knowledge, discover and bridge gaps in their knowledge, find a structure in the information and reduce confusion. The results represented the second and part of the forth contribution in this thesis, which was the development of an instrument to measure perceived sensemaking and empirical results of the effect of user-generated external representations during sensemaking on self-reported sensemaking.

RQ1 was also partly answered through RQ1.2, which aimed at investigating the effect of creating user-generated external representations on keyword construction when searching for information in an electronic environment. The results of experimental manipulation of Studies 1 and 4 showed another change that occurred when creating user-generated external representations during sensemaking to the search queries construction process in particular. In Study 1, participants' activities regarding query construction, which were collected by using screen-recording (software BB Flashback), were analysed. Due to some limitations in the study, only four participants were observed creating search queries, but the results did shed a light on the type of changes that occurred on query construction when participants created user-generated external representations and when they did not. The results suggested that, when participants externalised their thinking, they created more new search queries. These results lead to the development of H_2, which states that creating user-generated external representations during sensemaking helps to increase keyword novelty. The hypothesis was then tested to answer RQ1.2 in Study 4. The percentages of new queries created by participants were analysed across the two conditions of user-generated representation and non-representation.

The results of Study 4 showed that participants generally used more search terms – whether new or task-based queries – under the non-representation condition. However, the higher percentages of these search terms were based on information from the task briefs. On the other hand, when participants created external representations, they developed more new search terms. The results suggested that creating user-generated external representations during sensemaking did help to increase keyword novelty.

The results can be explained in the light of the model of level of processing by Craik & Lockhart (1972), where the researchers investigated the relation between levels of processing, shallow or deep, and memory recall. Deep processing includes semantic processing and elaboration, which involves more thinking and association, while shallow processing tends to focus on surface level aspects of stimuli, such as structural and phonetic features. Keeping this in mind, the results of testing H_2 suggested that the use of external representations may support participants in deeper semantic processing of the domain of which sense is being made, thereby allowing them to derive search terms based on semantic relationships than when they do not use of external representations.

The results also suggested that the use of external representations changed participants' information needs and helped them to developed new questions that were reflected in the new search queries that they used. When they did not create user-generated external representations, they were not able to develop their own understating of the domain; instead they relied more on the information given in the task brief.

The results may also be described in light of the spreading activation theory of Collins and Loftus (1975). According to their theory, "knowledge" is stored in a conceptual semantic network in memory, where nodes (concepts) are connected with links that differ in their numbers and lengths, based on the strength of the relation between them: the closer the closer the connection between concepts (nodes), the more and shorter the links between them. When a concept is triggered, activation spreads in the network to activate all relevant concepts – i.e. user-generated external representations may allow participants to activate greater semantic networks within the mind, which leads them to generate more new search terms than when they do not create external representations.

These results made it partly possible to achieve the fourth and the sixth contributions of this thesis. The results also provided empirical results showing how creating user-generated external representations affected the sensemaking process by quantitatively measuring such an effect on one of its subtasks (keyword novelty). It also showed user-generated representation as part of the same sensemaking iterative process and the effects of structuring on cognition may well propagate around that process and be detected and measured in different parts in ways that have not been previously explored.

Study 4 showed another effect of creating user-generated external representations during sensemaking, in that it showed how external representations changed participants' levels of perceived uncertainty at the end of the sensemaking tasks. In this study, the scope was increased to include the notion of uncertainty. Previous researchers, such as Kuhlthau (1993) reported a reduction in the level of uncertainty over the period of performing extended information seeking. It was also expected that, over that same period, the level of sense would increase in some domains.

Uncertainty is central to some of the information seeking models, as in the information seeking model by Kuhlthau (1993) and the problem-solving model by Wilson (1999). Kuhlthau (1993) states that uncertainty is a cognitive state that leads to the generation of emotions of confusion, frustration and loss of confidence among users. In the ASK hypothesis, Belkin (1980) suggests that people are often uncertain about what information they are seeking, which makes it difficult to construct effective queries when interacting with information systems. Uncertainty has been viewed as important to the information seeking process (Belkin, 1980; Kuhlthau, 1993), while sensemaking has been important as a positive outcome of the information seeking journey (Dervin, 1998, 1992). Although uncertainty results in negative feelings, such as anxiety and ambiguity, it is important at the early stages of the information seeking process.

A negative effect of the use of external representations on the levels of perceived uncertainty was predicted, as presented by H_3. The results of comparing participants' levels of uncertainty at the end of the sessions by using a questionnaire that was developed by Jonathan (2017) showed that, when participants created user-generated external representations, they reported lower levels of uncertainty than when they did not. The result suggested that the effect of visually structuring information was to help reduce uncertainty at the end of the information seeking process. However, when participants did not create user-generated external representations, they reported higher levels of perceived sensemaking. This suggested that, when participants did not externalise their thinking visually in user-generated external representations under the non-representation condition at the end of the tasks, they were at earlier stages of the search process compared to when they did create user-generated external representations. As suggested by Kuhlthau's (1993) model of information seeking, externalising thinking helps to make better progress in the search process. By quantitatively measuring such an effect on one of its final products (perceived uncertainty), the results partly helped to achieve Contribution 4 of this thesis by providing empirical results that showed how user-generated external representations affected the process of sensemaking.

To summarise: the results of answering RQ1 through the experimental manipulation of user-generated representation suggested that creating user-generated external representations during sensemaking helps to increase sensemaking, keyword novelty and reduce perceived uncertainty.

The results of answering RQ1.1, RQ.12, and RQ1.3 represented the first contribution in this thesis – the development of a paradigm to measure the changes that occur during sensemaking. The designed paradigm helped to detect the changes that occurred in some of sensemaking sub-tasks (keyword construction) and some of the final products (perceived sensemaking and perceived uncertainty). As these results were achieved through external manipulation of user-generated representation, it was possible to claim that creating user-generated external representations caused an increase in perceived sensemaking, keywords novelty and a decrease in perceived uncertainty during sensemaking.

RQ1 was also investigated in relation to the levels of structuring within the external representations (structuredness). By the end of Study 1, each of the 13 participants produced a representation in notebook format by using Microsoft OneNote. A total of 13 representations were produced. Participants generally used OneNote to organise the documents that they judged as relevant and they also added summaries, titles and dates, and took notes. As reported in Chapter 4, further analysis of these representations was conducted by using an approach developed by Okoro (2014) and Okoro and Attfield (2016). The results of the analysis showed that participants' representations varied in terms of their types and levels of complexity. For example, some participants created representations with only one relation type, such as a timeline, while others created representations with more than one relation embodied within each other, such as a themed timeline embodied within a themed grouping relation.

These results lead to the development of new hypotheses regarding the relationship between the level of structuring in the representations and some of the sensemaking process subtasks and final product, namely keywords novelty, perceived sensemaking and perceived uncertainty. To test these hypotheses, a quantitative measure of the level of structuring in external representations was developed, which helped in answering RQ1 and its sub-questions within the user-generated representation condition (reported in Chapter 5).

The metric was developed, based on the approach by Okoro (2014) and Okoro and Attfield (2016). The approach was based on the assumption that, similar to linguistic analysis, when people create external representations during sensemaking tasks, they follow production rules of visual language that the users follow. These visual representations can be described in terms of parse trees (syntax trees) that consist of entities that are embodied within other entities. The created parse trees of representations show the embodiment of the relationships and primitives within representations. The metric added to the approach of Okoro (2014) and Okoro and Attfield (2016) in terms of the role of semantic constraints imposed by each relationship on their sub-relations and primitives (details in Chapter 4). The metric was validated in a study reported in Chapter 4 and was found to be valid to measure the structuredness of free-form external representations.

It was predicted that, when participants created external representations with high structuredness, their tendency of generating new search queries would increase and their perceived uncertainty would decrees. The results of testing H_4 and H_6 did not confirm this predication. It showed no correlation between participant's tendency to generate new search queries and the structuredness of the created representations and no negative correlation between participants' perceived sensemaking and the structuredness of the created representations. By operationalising the variable structuredness in Study 2, the results can be summarised as follows. – The number of relations (e.g. timeline relations, themed grouping relations or complicated relations, such as timelines embodied within themed grouping relations), the number primitives and notes and the constraints imposed by each relation on its primitives, a sub-relation within a representation – as measured by the developed metric – may have no relation to participants' tendency to generate new search and the reduction on their levels of uncertainty.

Regarding perceived sensemaking, the results of Study 4 showed no correlation between structuredness of the representations and participants' perceived sensemaking. However, the results in the screen plot in Figure 5.8 suggested that, when values of structuredness were lower than a certain point – in the study in Chapter 5, the point was 168 – levels of perceived sensemaking were unstable. Before this point, participants reported high and low levels of perceived sensemaking. However, when the structuredness value of a representation was equal to or higher than 168, participants reported perceived sensemaking with no scores lower than 115. These results may suggest that at a certain high value of structuredness perceived sensemaking correlated positively with structuredness.

To summarise: the results of this study suggested that external representations change the way in which sensemakers think about things. In addition, the results suggest that, by explicitly representing the domain in some way, particularly as a narrative, sensemakers will be able to improve their sensemaking, reduce uncertainty and think more deeply about the problem through keywords novelty. The results also show that people need to create more complex structures to see the differences in their sensemaking levels, but only a few differences in the level of structuring show a difference in the level of uncertainty and their tendency to generate new search queries.

Figure 6.5 presents a model that summarises the results of answering RQ1. It shows the effect of using external representations on keywords novelty, perceived sensemaking and perceived uncertainty, as well as the relationship between these variables and levels of structuring within the created external representations. The single arrows in Figure 6.5 represent the caution relations between variables, while double arrows represent correlations relations.

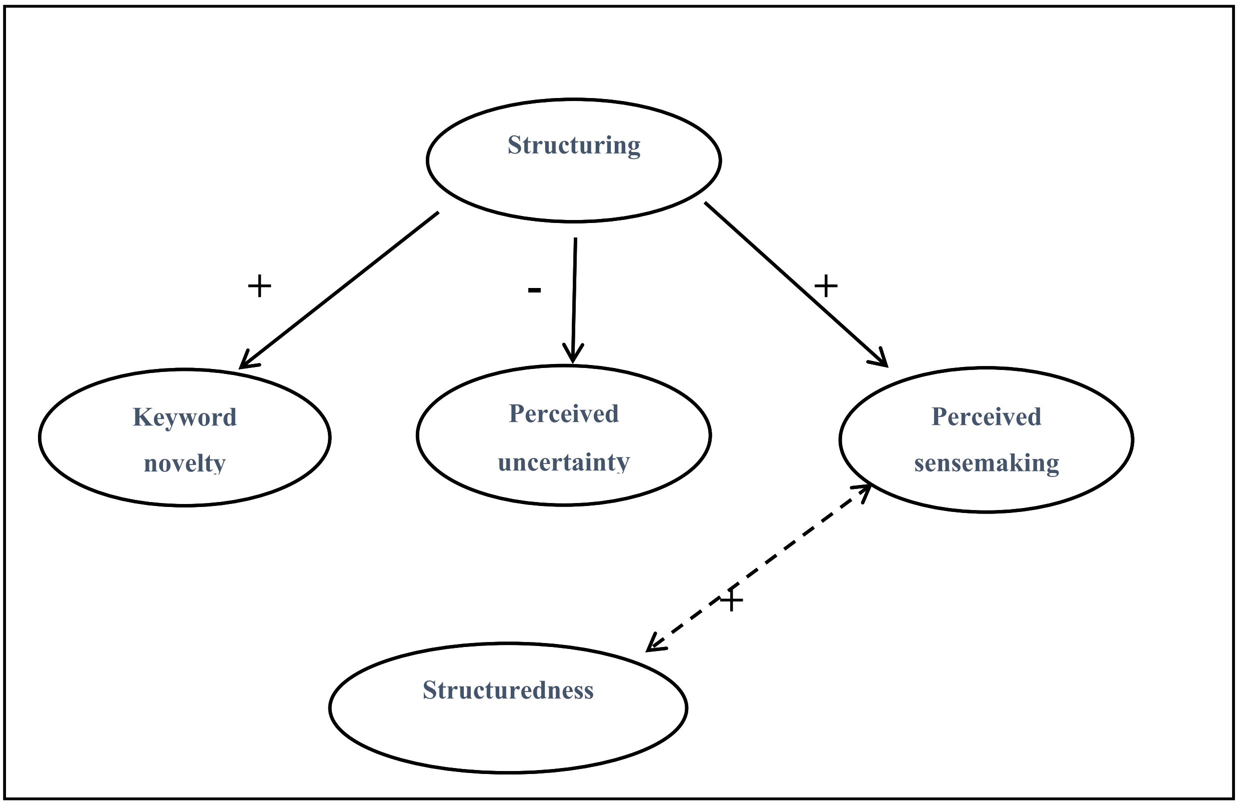


Figure 6.5: Summary of the findings

6.3 Contributions

This PhD thesis contributes to the research in HCI, particularly to existing research on the effect of external representations during sensemaking in electronic environments. These contributions are outlined in the following sections.

6.3.1 A paradigm to study the role of external representations during sensemaking

By introducing an experimental paradigm to measure sensemaking, this doctoral research makes a methodological contribution. The designed paradigm (Figure 1.2 and Section 1.3) represents sensemaking as an iterative process that consists of sub-tasks. It also brings the notion of external representations into the sensemaking process. Creating user-generated representation in the paradigm is part of the sensemaking iterative process and the effects of creating user-generated representation on cognition may well propagate around that process and be detectable in different parts in ways that have not been previously explored. As reported in Chapter 3, the manipulation of the use and non-use of user-generated representation enables the measuring of changes that user-generated external representations cause on some sub-tasks of sensemaking (keyword novelty) and some of the final products (perceived sensemaking and perceived uncertainty). An experimental paradigm is needed to understand the relationships between variables of interest reliably – particularly the way in which different kinds of tools may impact on outcomes in electronic environments.

6.3.2 An instrument to measure perceived sensemaking

Based on Studies 1 and 3, as reported in Chapters 3 and 4 respectively, this doctoral study makes a second methodological contribution. A questionnaire was developed, based on some of the significant models and definitions of sensemaking, each covering a different perspective of the phenomenon. The instrument consists of six sub-scales, namely: comprehension and gaining insight; drawing on prior knowledge; structuring; understanding connections; gap discovering and bridging; and reducing confusion and ambiguity.

The first version of the instrument was developed in Study 1 (Chapter 3), after which a new version of the instrument was developed in Study 3 (Chapter 4). The new version was developed to make the instrument more generic and applicable with different sensemaking tasks, because the original version had some statements that can be used when the sensemaking task creates a narrative. The developed questionnaire proved to be valid and reliable to measure what is believed to be perceived sensemaking. Such an instrument can be used in future studies that investigate sensemaking and studies that evaluate tools that support sensemaking. The questionnaire began with the root question, *To what extent do you think conducting the given task under this condition helped you?* Below this question, 13 sub-questions were included in the instrument. The questionnaire is divided into six sub-scales and each item is scored on a visual analogue scale, ranging from 1 (to a small extent) to 11 (to a large extent). The questionnaire can be used in studies that measure perceived sensemaking, such as evaluating new tools that support sensemaking.

6.3.3 A reliable metric to measure to measure structuredness

A third methodological contribution introduced by this doctoral research involves a metric to measure structuredness of user-generated external representations during sensemaking. The development and validation of the metric are reported in Chapter 4. During sensemaking, sensemakers perform different sub-tasks, such as externalising their thinking in user-generated external representations in different forms, e.g. creating a timeline, themed grouping relations, and taking notes of the information they have encountered during the sensemaking. The developed metric can be used to measure structuredness of such external representations. To use the developed metric, researches can follow the following steps:

- Create a parse tree of the external representations by using the approach developed by Okoro (2014) and Okoro and Attfield (2016). (The application of the approach is discussed in detail in Chapter 4). User-generated representations can be visually represented as parse trees, where relation and sub-relations, such as timeline and themed grouping relations, and primitives, such as source files and notes embodied within each-others. A parse tree of representations has a high-level relation (parent node) and a low-level relation (child node) and primitives (leaf node).

- The representations, represented by the parse tree, are a single relation that consists of sub-relations that can be higher level relations connected other sub-relation and lower relations that connect primitives. The calculation of structuredness starts from the top of the parse tee to the bottom and then up again. In other words, the structuredness of the overall representations is based on the structuredness of the high-level relation. The structuredness of the high-level relation is based on its relation type, the number of its primitives and structuredness of its lower level relations. The structuredness of lower level relations is, in turn, based on the number of its primitives and its relation type. Variable types of any relation, whether high-level relation or low-level relation, are multiplied by its number of branches.

The developed metric provides a way of quantitatively measuring the changes in sensemaking, which can be studied in relation to changes on other parts of sensemaking the process.

6.3.4 Empirical results of the effect of user-generated representation during sensemaking

Some of the previous research emphasises the importance of using external representations, while some research shows that external representations may hinder the process in some cases. This research provides empirical evidence of the effect of creating user-generated external representations in the process of sensemaking. Studies 1 and 4 in this doctoral research provide empirical findings based on quantitative analysis (Chapters 3 and 5), clarifying the effects of creating user-generated external representations on key variables in the sensemaking process, specifically perceived sensemaking, keyword novelty and perceived uncertainty.

Creating user-generated external representations in a narrative form during sensemaking helps to increase perceived sensemaking and to reduce perceived uncertainty.

6.3.5 Empirical results of the relationship between levels of structuring of external representations and other key variables

This research shows other empirical findings (Chapter 5) that clarify the relationship between key variables during sensemaking process – in particular structuredness, perceived sensemaking, keyword novelty and perceived uncertainty.

The developed metric to measure structuredness (the third contribution) makes this empirical contribution possible. It was found that the increase in structuredness of external representations does not correlate with the increase in the tendency of creating new search terms, the decrease in levels of perceived uncertainty and at some certain levels of structuredness with which it correlates.

6.3.5 A theoretical explanation of the effect of user-generated representations on some of the sensemaking process subtasks (keyword novelty)

The frequent significance of external representations during sensemaking has been explicitly recognised by some of the sensemaking models. In their notional model of sensemaking, Pirolli and Card (2005) emphasise the centrality of representation to the “schematise” stage of the sensemaking process, when the analyst structures the collected information into a representation designed to guide the analysis process. According to Pirolli and Card (2005), the process of sensemaking is not limited to the gathering of information: instead, it is accomplished through the manipulation of a created representation by means of which sensemakers can build insight, create further knowledge, or take action.

In their learning loop complex model, Russell et al. (1993) claim that, during the sensemaking process, sensemakers engage in three activities: the generation loop, the representational shift loop and the data coverage loop. Sensemakers establish the process of sensemaking by searching for a good representation within the generation loop. The generated representation is then filled by data in the data coverage loop. The representation may shift and change in the representational shift loop, when the sensemaker may find data that does not fit into the first generated representation.

In their data frame model, Klein et al. (2007) describe sensemaking as an interactive process between two entities: data and frame. During the process of sensemaking, people fit new situations (data) into a representation (frame), in order to make sense of them. The frame is later used to define what is considered as relevant data to the situation. However, finding new data may lead the sensemaker to discard the frame and search for a frame that can be anchored in the new data.

Similar to these models, the proposed process model in Figure1.2 (presented in Chapter1) represents sensemaking as an iterative process that consists of sub-tasks of sensemaking, where creating external representations is an essential sub-task of the process. The results from Study4 – through the manipulation of user-generated representation – showed that, when sensemakers created external representations, they tend to generate more novel search terms than when they did not create external representations. These results extend the previous models of sensemaking by shedding light on some of the effects of external representations in sensemaking – in particular on how the effects of creating user-generated external representations on cognition propagate around that process. The results suggest that creating external representations changes the way sensemakers think of search terms.

One possibility is to understand this distinction in terms of a psychological theory, such as the model of level of processing of Craik & Lockhart (1972). They investigated the relation between levels of processing, shallow or deep, and memory recall. Deep processing includes semantic processing and elaboration, which involves more thinking and association, while shallow processing tends to focus on surface-level aspects of stimuli, such as structural and phonetic features. The results of this study suggest that the use of external representations may support participants in deeper semantic processing of the domain of which sense is being made, thereby allowing them to derive search terms based on semantic relationships than when they do not use of external representations.

The results may also be described in light of the spreading activation theory of Collins and Loftus (1975). According to their theory, "knowledge" is stored in a conceptual semantic network in memory, where nodes (concepts) are connected with links that differ in their numbers and lengths, based on the strength of the relation between them: the closer the closer the connection between concepts (nodes), the more and shorter the links between them. When a concept is triggered, activation spreads in the network to activate all relevant concepts – i.e. user-generated external representations may allow participants to activate greater semantic networks within the mind, which leads them to generate more new search terms than when they do not create external representations.

6.4 Research limitations and generalisability

The first study in Chapter 3 had limitations regarding keyword constructions. During the study, only four participants created search terms. However, these limitations were addressed in the fourth study (reported in detail in Chapter 5). Although an example of how to answer the questions was provided at the beginning of the sensemaking questionnaire in the third study (reported in Chapter 4), six out of 120 questionnaires were eliminated, as participants did not answer the questions as requested. For example, instead of crossing on the vertical lines of the visual analogue scale, they crossed the area between the lines. In future, it may be considered to provide two examples at the beginning of the questionnaire: one example showing the correct way of using the questionnaire (cross one of the vertical lines of the visual analogue scale) and another example showing the incorrect way (crossing the line between the vertical lines of the visual analogue scale).

The developed metric to measure structuredness can only be applied to external representations with a hierarchy structure, such as mind maps or timelines. In future, the metric can be developed further to include other types of external representations by accounting for others factors that explain the constraints that are imposed by external representations, such dimensionality, e.g. maps have two dimensions (2D), while an ordinal timeline has one dimension (1D).

The work in this doctoral research does have a number of boundaries. The focus is on individual sensemaking, which may differ in other sensemaking settings, such as collaborative sensemaking. The tasks for participants in both Studies 1 and 4 were to create narrative representations: participants were asked to create user-generated external representations to build a story of the domain. Other types of representations, e.g. argument/s, may have different effects on the sensemaking process.

6.5 Future work

This section provides brief examples of the directions for future studies that originate in this doctoral thesis.

- The experimental paradigm can be applied to evaluate and investigate the effect of new sensemaking tools through experimental manipulation. For example, the new tool can be provided to participants under one condition, and under the other condition, participants do not use a sensemaking tool or a tool that lacks the new features of the new, evaluated sensemaking tool. Moreover, the context of this doctoral research is individual sensemaking settings. The paradigm can be applied in different sensemaking settings, such as the investigation of the effects of externalising thinking during collaborative sensemaking. The context of this doctoral research is narrative sensemaking, where participants' tasks were to externalise their thinking in a narrative form of representation. Therefore, the designed paradigm can be used to investigate other types of representations, such as argument representations.
- In this doctoral research, the changes that occur when using external representations were measured on keyword novelty, perceived sensemaking and perceived uncertainty. Future studies may look into changes in other sub-tasks of the sensemaking process.

- The developed quantitative measures may be used as indicators to sensemaking, e.g. the increase in perceived sensemaking and keywords novelty, and the decrease in perceived uncertainty can be considered when evaluating tools that support sensemaking measuring.
- The developed metric to measure structuredness of user-generated external representations can be used in further studies to find the relationships between this variable and other sub-tasks of the sensemaking process. Structuredness of external representations can be also investigated in experimental settings, e.g. in an experiment with two conditions, where under one condition participants externalise their thinking in user-generated representations of low structuredness only, creating two a folder type of representations, and, in another condition, they can create representations with more embodied relations, such creating timelines within themes. Such studies can lead to empirical results of the effect of structuredness.
- Moreover, the results of this these show no correlation between structuredness measured by the developed metric, which leads to new a research direction as to what other ways of measurements of constraints imposed by external representations can be developed.
- In relation to the theoretical contribution, further analysis of the thinking allowed protocol will be conducted to understand the sources of search terms developed by participants during Study 4, and to determine wither the type of representations created by participants have relation to those.

6.6 Conclusion

Through the development of an experimental paradigm, this doctoral research has contributed to the field of human computer interaction in general and to research on the effect of external representations during sensemaking in electronic environment in particular. This research also provides two other methodological contributions: a questionnaire to measure perceived sensemaking and a metric to measure structuredness of user-generated external representations. Moreover, it provides quantitative empirical evidence that clarifies the effects of creating user-generated external representations on key variables in the sensemaking process –particularly perceived sensemaking; keyword novelty and perceived uncertainty – as well as a theoretical explanation of the effect of user-generated representations on some of the sensemaking process subtasks (keyword novelty).

The main research question RQ1 was answered through four studies. Studies 1, 2 and 4 helped to answer the sub-questions by building and testing sets of hypotheses, while Studies 2 and 3 helped to developed quantitative measures of some of the sensemaking sub-tasks and final products.

Finally, this doctoral thesis makes suggestions of future research in terms of the quantitative study of the notion of external representation in relation to the sensemaking process. These suggestions include the use of the developed paradigm and the developed sensemaking questionnaire and the metric to measure structuredness of user-generated external representations.

References

Abraham, A., Petre, M., & Sharp, H. (2007). Information seeking and sensemaking for 'personal fit'. In *Exploratory search and HCI: Designing and evaluating interfaces to support exploratory search interaction.* Proceedings of the ACM SIGCHI 2007 Workshop (pp. 1–4).

Ahearn, E. P. (1997). The use of visual analog scales in mood disorders: A critical review. *Journal of Psychiatric Research*, *31*(5), 569–579.

Alsufiani, K., Attfield, S., & Zhang, L. (2017, July). Towards an instrument for measuring sensemaking and an assessment of its theoretical features. In Proceedings of the 31st British Computer Society Human Computer Interaction Conference (p. 86). Swindon, United Kingdom: BCS Learning & Development.

Alsufiani, K., & Attfield, S. (2018, July). An exploratory study of computer supported sensemaking: relating representational structure to triage. In Proceedings of the 32nd International BCS Human Computer Interaction Conference (p. 155). Swindon, United Kingdom: BCS Learning & Development.

Anderson, T. D. (2006). Uncertainty in action: Observing information seeking within the creative processes of scholarly research. *Information Research*, 12(1).

Attfield, S., & Baber, C. (2017). *Elaborating the frames of data-frame theory*. In Proceedings of the 13th International Naturalistic Decision Making Conference, Bath, UK (pp. 25–32).

Attfield, S., & Blandford, A. (2009). Improving the cost structure of sensemaking tasks: Analysing user concepts to inform information system design. In *INTERACT '09.* Proceedings of the 12th IFIP International Conference on Human-Computer Interaction. Part 1 (pp. 532–545). Berlin: Springer.

Attfield, S., & Blandford, A. (2011). Making sense of digital footprints in team-based legal investigations: The acquisition of focus. *Human-Computer Interaction*, *26*(1–2), 38–71.

Attfield, S., Fields, B., & Baber, C. (2018). A resources model for distributed sensemaking. *Cognition, Technology & Work*, *20*(4), 651–664.

Attfield, S., Fields, B., Wheat, A., Hutton, R., Nixon, J., Leggatt, A., & Blackford, H. (2015, June 9–12). *Distributed sensemaking: A case study of military analysis*. In Proceedings of the 12th International Conference on Naturalistic Decision Making, McLean, VA (pp. 9–12).

Baber, C., Conway, G., Attfield, S., Rooney, C., Kodagoda, N., & Walker, R. (2015). *How military intelligence personnel collaborate on a sense-making exercise*. In Proceedings of the 12th International Naturalistic Decision Making Conference, McLean, VA.

Baber, C., Attfield, S., Conway, G., Rooney, C., & Kodagoda, N. (2016). Collaborative sense-making during simulated intelligence analysis exercises. *International Journal of Human-Computer Studies*, *86*, 94–108.

Belkin, N. J. (1980). Anomalous states of knowledge as a basis for information retrieval. *Canadian Journal of Information Science*, *5*(1), 133–143.

Bex, F. J., Van Koppen, P. J., Prakken, H., & Verheij, B. (2010). A hybrid formal theory of arguments, stories and criminal evidence. *Artificial Intelligence and Law*, *18*(2), 123–152.

Bex, F., & Verheij, B. (2012). Solving a murder case by asking critical questions: An approach to fact-finding in terms of argumentation and story schemes. *Argumentation*, *26*(3), 325–353.

Bhangaonkar, S., Chu, S. L. & Quek, F. (2016, May). *Thinking in stories*. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA. (pp. 2782–2789). New York: ACM Press.

Blandford, A., & Attfield, S. (2010). *Interacting with information*. Synthesis Lectures on Human-Centered Informatics. San Rafael, CA: Morgan& Claypool.

Blandford, A. E. (2013) Semi-structured qualitative studies. In M. Soegaard & R. Dam, R (Eds.), ***The encyclopedia of human-computer interaction*. Denmark:** Interaction Design Foundation.

Brade, M., Sehl, A., & Groh, R. (2016, May). *Between the Lines: A comparative study of freeform-based knowledge-map-creation with paper and tablet*. In Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA. (pp. 3006–3012). New York ACM Press.

Broder, A. (2002, September). *A taxonomy of web search*. ACM SIGIR Forum 36(2), 3–10.

Bruner, J. S. (2003). *Making stories: Law, literature, life*. Cambridge, MA: Harvard University Press.

Buchanan, G., & Loizides, F. (2007, September). Investigating document triage on paper and electronic media. In International Conference on Theory and Practice of Digital Libraries (pp. 416– 427). Berlin: Springer.

Çakan Akkaş, B. N., Sönmez E., & Kabataş Memiş. (2018). Step-by-step argument map in learning environment: Example of optic. *Online Fen Eğitimi Dergisi*, *3*(2), 15–25.

Cerutti, F., Norman, T., & Toniolo, A. (2018). *A tool to highlight weaknesses and strengthen cases*. Retrieved from https://pdfs.semanticscholar.org/d302/d86e9694f68631c4215a86004d0328c71a71.pdf

Chapin, L., Attfield, S., & Okoro, E. M. (2013). Predictive coding, storytelling and god: narrative understanding in e-discovery. *British Journal of Industrial Relations*.

Chen, P. Y., & Popovich, P. M. (2002). *Correlation: Parametric and nonparametric measures*. Thousand Oaks, CA: SAGE.

Chin, G., Kuchar, O. A., & Wolf, K. E. (2009, April 6). *Exploring the analytical processes of intelligence analysts*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA *(*pp. 11–20).

Choudhury, S. T., Brierley, C., Rooney, C., Xu, K., Chen, R., Wong, B. L., & Atwell, E. (2011, October 23–28). *Middlesex University's Invisque visual analytics tool: Supported by text analytics techniques from the University of Leeds*. In IEEE VAST Challenge, Providence, Rhode Island, USA.

Collins, A.M. and Loftus, E.F., (1975). A spreading-activation theory of semantic processing. Psychological review, 82(6), (p.407).

Cool, C., Belkin, N., Frieder, O., & Kantor, P. (1993, August). *Characteristics of text affecting relevance judgments*. In National Online Meeting. Vol. 14 (pp. 77–77).

Cook, K., Grinstein, G., & Whiting, M. (2014). The VAST challenge: History, scope, and outcomes: An introduction to the special issue. *Information Visualization, 13*(4), 301–312.

Corbin, J., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology*, *13*(1), 3–21.

Cox, R., & Brna, P. (2015). Twenty Years on: Reflections on “Supporting the use of external representations in problem solving”. *International Journal of Artificial Intelligence in Education, 26*(1), 193–204.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684.

D'Ambra, J., & Wilson, C. S. (2004). Use of the World Wide Web for international travel: Integrating the construct of uncertainty in information seeking and the task-technology fit (TTF) model. *Journal of the American Society for Information Science and Technology, 55*(8), 731–742.

De Vries, E., & Masclet, C. (2013). A framework for the study of external representations in collaborative design settings. *International Journal of Human-Computer Studies*, *71*(1), 46–58.

Dervin, B. (1983, May). *An overview of sense-making research: Concepts, methods, and results to date.* Paper presented at the annual meeting of the International Communication Association, Dallas, TX.

Dervin, B. (1992). *From the mind's eye of the user: The sense-making qualitative-quantitative methodology*. Retrieved from https://www.semanticscholar.org/paper/From-the-mind%E2%80%99s-eye-of-the-user%3A-The-sense-making-Dervin/117927016793d5d79305c0ed04f5655a0c4c9558

Dervin, B. (1998). Sense-making theory and practice: an overview of user interests in knowledge seeking and use. *Journal of Knowledge Management*, *2*(2), 36–46.

Dervin, B., & Foreman-Wernet, L. (2013). Sense-making methodology as an approach to understanding and designing for campaign audiences: A turn to communicating communicatively. In R. E. Rice, & C. A. Atkin (Eds.), *Public communication campaigns* (4th ed., pp.147–162). Thousand Oaks, CA: SAGE.

Dix, A., & Ellis, G. (1998, May). *Starting simple: Adding value to static visualisation through simple interaction*. In Proceedings of the Working Conference on Advanced Visual Interfaces (pp. 124–134).
Duff, W. M., & Johnson, C. A. (2002). Accidentally found on purpose: Information-seeking behavior of historians in archives. *The Library Quarterly*, *72*(4), 472–496.

Duffy, T., Baber, C., & Stanton, N. A. (2013). *Measuring collaborative sensemaking*. In Proceedings of the 10th International ISCRAM Conference (pp. 561–565).

Eisenbach, M, & Eisenbach, A. (2003). jsSyntaxTree. Retrieved from http://www.ironcreek.net/syntaxtree/

Faily, S., Lyle, J., Paul, A., Atzeni, A., Blomme, D., Desruelle, H., & Bangalore, K. (2012, October). *Requirements sensemaking using concept maps*. In 4th International Conference on Human-Centred Software Engineering (HCSE), Toulouse, France (pp. 217–232).

Faisal, S., Attfield, S., & Blandford, A. (2009). *A classification of sensemaking representations*. In CHI 2009 Workshop on Sensemaking.

Field, A. (2009) Discovering statistics using SPSS. (3rd ed.). London: SAGE.

Fisher, K., Counts, S., & Kittur, A. (2012, May). *Distributed sensemaking: Improving sensemaking by leveraging the efforts of previous users*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 247–256).

Fisher, D., Hoff, A., Robertson, G., & Hurst, M. (2008, October 19–24). *Narratives: A visualization to track narrative events as they develop*. In Proceedings of the 2008 IEEE Symposium on Visual Analytics Science and Technology (pp. 115–122).

Garreau, L., Mouricou, P., & Grimand, A. (2015). Drawing on the map: An exploration of strategic sensemaking/giving practices using visual representations. *British Journal of Management*, *26*(4), 689–712.

Görg, C., Liu, Z., & Stasko, J. (2013). Reflections on the evolution of the Jigsaw visual analytics system. *Information Visualization*, *13*(4), 336–345.

Gotz, D. (2007, May 8–12). *The ScratchPad: Sensemaking support for the web*. In WWW ’07: Proceedings of the 16th International Conference on World Wide Web, Banff, Alberta, Canada (pp. 1329–1330).

Gotz, D., Zhou, M. X., & Wen, Z. (2006, January). *A study of information gathering and result processing in intelligence analysis*. In IUI 2006 Workshop on User Interface for Intelligence Analysis (p. 6).

Haggerty, J., Haggerty, S., & Taylor, M. (2014). Forensic triage of email network narratives through visualisation. *Information Management & Computer Security*, *22*(4), 358–370.

Haider, J. D., Seidler, P., Pohl, M., Kodagoda, N., Adderley, R., & Wong, B. W. (2017, September). *How analysts think: Sense-making strategies in the analysis of temporal evolution and criminal network structures and activities*. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Los Angeles, CA (pp. 193–197). Los Angeles, CA: SAGE.

Hearst, M. A., & Degler, D. (2013, October). *Sewing the seams of sensemaking: A practical interface for tagging and organizing saved search results*. In Proceedings of the Symposium on Human-Computer Interaction and Information Retrieval (p. 4).

Hedman, J., & Borell, A. (2005). Broadening information systems evaluation through narratives. *The Electronic Journal of Information Systems Evaluation, 8*(2), 115–122.

Hjermstad, M. J., Fayers, P. M., Haugen, D. F., Caraceni, A., Hanks, G. W., Loge, J. H., Fainsinger, R., Aass, N., & Kaasa, S. (2011). Studies comparing numerical rating scales, verbal rating scales and visual analogue scales for assessment of pain intensity in adults: A systematic literature review. *Journal of Pain and Symptom Management, 41*(6), 1073–1093.

Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science*, *19*(3), 265–288.

Hutchins, E., & Klausen, T. (1996). Distributed cognition in an airline cockpit. In Y. Engström, D. & Mddlelton (Eds.), *Cognition and communication at work* (pp. 15–34). Cambridge University Press.

Jaasma, P., Van Dijk, J., Frens, J., & Hummels, C. (2017, October). *On the role of external representations in designing for participatory sensemaking*. In Proceedings of the Conference on Design and Semantics of Form and Movement-Sense and Sensitivity, DeSForM. Retrieved from https://www.intechopen.com/books/proceedings-of-the-conference-on-design-and-semantics-of-form-and-movement-sense-and-sensitivity-desform-2017/on-the-role-of-external-representations-in-designing-for-participatory-sensemaking

Jonassen, D. (2003). Using cognitive tools to represent problems. *Journal of Research on Technology in Education, 35*(3), 362–381.

Jonathan, J. (2017). *Information journey in digital archives* (Doctoral thesis). University of York, United Kingdom.

Kang, R., Kane, A., & Kiesler, S. (2014, February). *Teammate inaccuracy blindness: When information sharing tools hinder collaborative analysis*. In Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing (pp. 797–806).

Keim, D., Andrienko, G., Fekete, J. D., Görg, C., Kohlhammer, J., & Melançon, G. (2008). Visual analytics: Definition, process and challenges. In Kerren A., Stasko J. T., Fekete J. D., & North, C. (Eds.), *Information visualization: Lecture Notes in Computer Science*. Vol. 4950. (pp. 154–175). Berlin: Springer.

Keim, E. D., Kohlhammer, J., Mansmann, G., & Ellis, G. (2010). *Mastering the Information Age: Solving problems with visual analytics*. Goslar, Germany: Eurographics Association.

Keim, D. A., Schneidewind, J., & Sips, M. (2004, May 25–28). *CircleView: A new approach for visualizing time-related multidimensional data sets*. In Proceedings of the Working Conference on Advanced Visual Interfaces (pp. 179–182).

Kessell, A. M., & Tversky, B. (2008, September 19–21). Cognitive methods for visualizing space, time and agents. In G. Stapleton., J. Howse, & J. Lee. (Eds.), *Diagrammatic representation and inference.* International Conference on Theory and Application of Diagrams, Herssching, Germany (pp. 382–384). Berlin: Springer.

Kirsh, D. (2009). *Interaction, external representation and sense making*. In Proceedings of the 31st Annual Conference of the Cognitive Science Society, Austin, TX (pp. 1103–1108).

Kirsh, D. (2010). Thinking with external representations. AI & SOCIETY, 25(4), 441–454.

Klein, G., Moon, B., & Hoffman, R. R. (2006a). Making sense of sensemaking 1: Alternative perspectives. *IEEE Intelligent Systems*, *21*(4), 70–73.

Klein, G., Moon, B., & Hoffman, R. R. (2006b). Making sense of sensemaking 2: A macrocognitive model. *IEEE Intelligent Systems, 2*1(5), 88–92.

Klein, G., Phillips, J. K., Rall, E. L., & Peluso, D. A. (2007). A data-frame theory of sensemaking. In R. R. Hoffman (Ed.), *Expertise out of context*. Proceedings of the Sixth International Conference on Naturalistic Decision Making, Pensacola Beach, FL (pp. 113–155). New York: Lawrence Erlbaum.

Klimek, L., Bergmann, K.C., Biedermann, T., Bousquet, J., Hellings, P., Jung, K., Merk, H., Olze, H., Schlenter, W., Stock, P., & Ring, J. (2017). Visual analogue scales (VAS): Measuring instruments for the documentation of symptoms and therapy monitoring in cases of allergic rhinitis in everyday health care. *Allergo Journal International, 26*(1), 16–24.

Kodagoda, N. (2012). *Interactive visualisation for low literacy users*. (Doctoral thesis, Middlesex University).

Kosara, R., Hauser, H., & Gresh, D. L. (2003). *An interaction view on information visualization*. Proceedings of EUROGRAPHICS 2 (pp. 123–137). Granada: Blackwell.

Krishnamurthy, Y., Pham, K., Santos, A., & Freire, J. (2016). *Interactive exploration for domain discovery on the web*. ACM KDD Workshop on Interactive Data Exploration and Analytics (pp. 64–71).

Kuhlthau, C. C. (1991). Inside the search process: Information seeking from the user's perspective. *Journal of the American Society for Information Science, 42*(5), 361–371.

Kuhlthau, C. C. (1993a). *Seeking meaning: A process approach to library and information services*. Norwood, NJ: Ablex.

Kuhlthau, C. C. (1993b). A principle of uncertainty for information seeking. *Journal of Documentation, 49*(4), 339–355.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, *11*(1), 65–100.

Laurel, B., Bates, J., Don, A., & Strickland, R. (1991, April). *Interface and narrative arts: Contributions from narrative, drama, and film*. In CHI '91: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New Orleans (pp. 381–383).

Linder, R., Lupfer, N., Kerne, A., Webb, A. M., Hill, C., Qu, Y., Keith, K., Carrasco, M., & Kellogg, E. (2015, June). *Beyond slideware: How a free-form presentation medium stimulates free-form thinking in the classroom*. In Proceedings of the 2015 ACM SIGCHI Conference on Creativity and Cognition (pp. 285–294).

Liu, Z., Görg, C., Kihm, J., Lee, H., Choo, J., Park, H., & Stasko, J. (2010, October). *Data ingestion and evidence marshalling in Jigsaw.* In IEEE Symposium on Visual Analytics Science and Technology (pp. 271–272).

Liu, Z., Nersessian, N., & Stasko, J. (2008). Distributed cognition as a theoretical framework for information visualization. *IEEE Transactions on Visualization and Computer Graphics*, *14*(6), 1173–1180.

Loizides, F., & Buchanan, G. (2009, September). *An empirical study of user navigation during document triage*. In International Conference on Theory and Practice of Digital Libraries (pp. 138–149). Berlin: Springer.

Louis, M. R. (1980). Surprise and sense making: What newcomers experience in entering unfamiliar organizational settings. *Administrative Science Quarterly*, 226–251.

MacIntyre, A. (1981). A*fter virtue: A study in moral theory*. University of Notre Dame Press.

Mandel, D. R., Karvetski, C. W., & Dhami, M. K. (2018). Boosting intelligence analysts' judgment accuracy: What works, what fails? *Judgment and Decision Making, 13*(6), 607–621.

Marchionini, G. (1992). Interfaces for end-user information seeking. *Journal of the American Society for Information Science*, *3*(2), 156–163.

Marchionini, G. (1997). *Information seeking in electronic environments*. Cambridge: Cambridge University Press.

Marchionini, G., & White, R. (2007). Find what you need, understand what you find. *International Journal of Human Computer Interaction, 23*(3), 205–237.

Microsoft. 2020. *Basic tasks in OneNote 2010.* Retrieved from https://support.microsoft.com/en-us/office/basic-tasks-in-onenote-2010-29a50122-eb92-4eaf-8a39-ae5f01094ddc?ocmsassetid=ha101829998&correlationid=1167e92d-3f16-410e-b3f6-782efc5d484a&ui=en-us&rs=en-us&ad=us#_

Mohammad, A., Amini, S., Sadatmoosavi, A., & Ahmadi, N. J. (2018). Evaluation and analysis of uncertainty in the information seeking behvior of post-graduate students. *Journal of Research in Medical and Dental Sciences, 6*(3), 24–32.

Munzner, T. (2014). *Visualization analysis and design*. Boca Raton, FL: CRC Press.

Neuberger, L., & Silk, K. J. (2016). Uncertainty and information-seeking patterns: A test of competing hypotheses in the context of health care reform. *Health Communication*, *31*(7), 892–902.

Newman, I., & Benz, C. R. (1998). *Qualitative-quantitative research methodology: Exploring the interactive continuum*. Carbondale, IL: Southern Illinois University Press.

Nguyen, P. H. (2017). *Visualization of analytic provenance for sensemaking.* (PhD thesis, Middlesex University).

Niebuhr, S., & Pinkwart, N. (2012, June). *Usability requirements for exploratory learning environments: the case of educational argumentation systems*. In Proceedings of the Workshop on Intelligent Support for Exploratory Environments at the 11th International Conference on Intelligent Tutoring Systems (pp. 64–72).

Norman, D. A. (1993). Cognition in the head and in the world: An introduction to the special issue on situated action. *Cognitive Science, 17*(1), 1–6.

Novak, J. D., & Cañas, A. J. (2006). *The theory underlying concept maps and how to construct them*. Retrieved from https://web.stanford.edu/dept/SUSE/projects/ireport/articles/concept_maps/The%20Theory%20Underlying%20Concept%20Maps.pdf

Nunnally, J., & Bernstein, I. (1994). Psychometric theory (3rd ed.). New York: McGraw-Hill.

Okoro, E. M. (2014.) *A study of different representation conventions during investigatory sensemaking.* (Master's dissertation, Middlesex University).

Okoro, E., & Attfield, S. (2016, July 11–15). Towards an approach for analysing external representations created during sensemaking using generative grammar. In *Fusion.* 30th International BCS Human Computer Interaction Conference, Bournemouth, UK (p. 31).

Padilla, S., Methven, T. S., Robb, D.A., & Chantler, M. J. (2017, May). *Understanding concept maps: A closer look at how people organise ideas*. Proceedings of the *2017 ACM SIGCHI Conference on Human Factors in Computing Systems* (pp. 815–827).

Passmore, P. J., Attfield, S., Kodagoda, N., Groenewald, C., & Wong, B. W. (2015, September). *Supporting the externalisation of thinking in criminal intelligence analysis*. European Intelligence and Security Informatics Conference (pp. 16–23).

Pennington, N., & Hastie, R. (1991). *A cognitive theory of juror decision making: The story model*. Retrieved from https://heinonline.org/HOL/LandingPage?handle=hein.journals/cdozo13&div=30&id=&page=

Pioch, N. J., & Everett, J. O. (2006, November). *POLESTAR: Collaborative knowledge management and sensemaking tools for intelligence analysts*. CIKM '06: Proceedings of the 15th ACM International Conference on Information and Knowledge Management (pp. 513–521).

Pirolli, P., & Card, S. (2005, May). *The sensemaking process and leverage points for analyst technology as identified through cognitive task analysis*. Proceedings of International Conference on Intelligence Analysis. Vol. 5 (pp. 2–4).

Pirolli, P., & Russell, D. (2011). Introduction to this special issue on sensemaking. *Human-Computer Interaction*, *26*(1), 1–8.

Pontis, S., & Blandford, A. (2016). Understanding "influence": An empirical test of the data-frame theory of sensemaking. *Journal of the Association for Information Science and Technology, 67*(4), 841–858.

Pugh, J. J. (2017). *Information journey in digital archives* (Doctoral thesis, The University of York).

Qu, C., & Furnas, G. W. (2005). *Sources of structure in sensemaking*. CHI '05: Extended Abstracts on Human Factors in Computing Systems (pp. 1978–1992).

Qu, Y., & Hansen, D. (2008, April). *Building shared understanding in collaborative sensemaking*. In 2008 CHI Workshop on Sensemaking, Florence, Italy.

Ramirez, A., Walther, J. B., Burgoon, J. K., & Sunnafrank, M. (2002). Information-seeking strategies, uncertainty and computer-mediated communication: Toward a conceptual model. *Human Communication Research, 28*(2), 213–228.

Rau, M. A., Aleven, V., Rummel, N., & Rohrbach, S. (2012, June). Sense making alone doesn't do it: Fluency matters too! ITS support for robust learning with multiple representations. In S. A. Cerri, W. J. Clancey, G. P. Papaoudrakis, & K. Panourgia. (Eds.), *ITS 2012* (pp. 174–184). Berlin: Springer.

Ravasio, P., Guttormsen-Schar, S., & Tscherte, V. (2004). The qualitative experiment in HCI: Definition, occurrences, value and use. *Transactions on Computer-Human Interaction*, *5*, 1–24.

Rooney, C., Attfield, S., Wong, B., & Choudhury, S. (2014). INVISQUE as a Tool for Intelligence Analysis: the construction of explanatory narratives. International Journal of Human-Computer Interaction, 30(9), 703–717.

Rumelhart, D. (1980). Schemata: The building blocks of cognition. In R. Spiro, B. Bruce, & W. Brewer (Eds.), *Theoretical issues in reading comprehension* (pp. 33–58). Mayway: Erlbaum Associates.

Russell, D. M., Jeffries, R., & Irani, L. (2008, August). *Sensemaking for the rest of us*. In 2008 CHI Workshop on Sensemaking, Florence, Italy.

Russell, D. M., Stefik, M. J., Pirolli, P., & Card, S.K. (1993, May). *The cost structure of sensemaking*. In Proceedings of the INTERACT'93 and CHI'93 Conference on Human Factors in Computing Systems (pp. 269–276).

Ryder, B., & Anderson, T. (2009, November 23–27). 'Coalesce': a web-based tool for sensemaking. In J. Kjeldskov, J. Paay, & S. Willer. *OZCHI 2009: Conference Proceedings* (pp. 289–292). Melbourne, Australia

Ryder, B., & Anderson, T. (2010, October). Lightweight personal sensemaking tools for the web. In *NodiCHI 2020: Extending Boundaries*. Proceedings of the 6th Nordic Conference on Human-Computer Interaction: (pp. 413–421).

Salton, G. (1989). *Automatic text processing: The transformation, analysis and retrieval of information by computer*. Boston, MA: Addison-Wesley Longman.

Sanchiz, M., Chin, J., Chevalier, A., Fu, W.T., Amadieu, F., & He, J. (2017). Searching for information on the web: Impact of cognitive aging, prior domain knowledge and complexity of the search problems. *Information Processing & Management*, *53*(1), 281–294.

Savolainen, R. (2015). Cognitive barriers to information seeking: A conceptual analysis. *Journal of Information Science, 41*(5), 613–623.

Scaife, M., & Rogers, Y. (1996). External cognition: How do graphical representations work? *International Journal of Human-Computer Studies, 45*(2), 185–213.

Scholtz, J. (2008, April). *Progress and challenges in evaluating tools for sensemaking*. In 2008 CHI Workshop on Sensemaking, Florence, Italy.

Segel, E., & Heer, J. (2010). Narrative visualization: Telling stories with data. *IEEE Transactions on Visualization and Computer Graphics*, 16(6), 1139–1148.

Selvaraj, N., Attfield, S., Passmore, P., & Wong, B. W. (2016, August). *How analysts think: think-steps as a tool for structuring sensemaking in criminal intelligence analysis*. In 2016 European Intelligence and Security Informatics Conference (pp. 68–75).

Sharma, N. (2006). Sensemaking: Bringing theories and tools together. *Proceedings of the American Society for Information Science and Technology*, 43(1), 1–8.

Sharma, N. (2010). *Sensemaking handoff: When and how?* (PhD thesis). University of Michigan, United States of America.

Sharma, N. (2011, May). *Role of available and provided resources in sensemaking*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 1807–1816).

Shaughnessy, J., Zechmeister, E., & Zechmeister, J. (2011). *Research methods in Psychology*. New York: McGraw-Hill.

Shrinivasan, Y. B., & Van Wijk, J. J. (2008, April). *Supporting the analytical reasoning process in information visualization*. In Proceedings of the SIGCHI Conference on Human Factors In Computing Systems (pp. 1237–1246).

Siegel, S., & Castellan, N. J. (1988*). Nonparametric statistics for the behavioral sciences*. New York: McGraw-Hill.

Starbuck, W. H., & Milliken, F. J. (1988). Executives' perceptual filters: What they notice and how they make sense. In D. Hambrick (Ed.), *Executive effect: concepts and methods for studying top managers* (pp. 35–65). Greenwich, CT: JAI Press.

Stasko, J., Görg, C., & Liu, Z. (2008). Jigsaw: Supporting investigative analysis through interactive visualization. *Information Visualization*, *7*(2), 118–132.

Stenning, K., & Oberlander, J. (1995). A cognitive theory of graphical and linguistic reasoning: Logic and implementation. *Cognitive Science, 19*(1), 97–140.

Tang, R., & Solomon, P. (1998). Toward an understanding of the dynamics of relevance judgment: An analysis of one person's search behavior. *Information Processing & Management*, *34*(2–3), 237–256.

Thomas, J., & Cook, K. (2005). *Illuminating the path*. Los Alamitos, CA: IEEE Computer Society.

Tobin, P. (2007). Teaching IT through storytelling. *South African Computer Journal 38*, 51–61.

Toniolo, A., Norman, T. J., Etuk, A., Cerutti, F., Ouyang, R. W., Srivastava, M., Oren, N., Dropps, T., Allen, J. A., & Sullivan, P. (2015, May). *Supporting reasoning with different types of evidence in intelligence analysis*. In Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems (pp. 781–789).

Trafton, J. G., & Trickett, S. B. (2001). Note-taking for self-explanation and problem solving. *Human-Computer Interaction, 16*(1), 1–38.

Tversky, B. (2010). Visualizing thought. *Topics in Cognitive Science, 3*(3), 499–535.

Uren, V., Shum, S. B., Bachler, M., & Li, G. (2006). Sensemaking tools for understanding research literatures: Design, implementation and user evaluation. *International Journal of Human-Computer Studies*, *64*(5), 420–445.

Vakkari, P. (2001). A theory of the task-based information retrieval process: A summary and generalisation of a longitudinal study. *Journal of Documentation, 57*(1), 44–60.

Vakkari, P., & Hakala, N. (2000). Changes in relevance criteria and problem stages in task performance. *Journal of Documentation*, *56*(5), 540–562.

Vakkari, P., Pennanen, M., & Serola, S. (2003). Changes of search terms and tactics while writing a research proposal: A longitudinal case study. *Information Processing & Management, 39*(3), 445–463.

Walny, J., Huron, S., & Carpendale, S. (2015, June). An exploratory study of data sketching for visual representation. *Computer Graphics Forum, 34*(3), 231–240.

Wagenaar, W. A., Van Koppen, P. J., & Crombag, H. F. (1993). *Anchored narratives: The psychology of criminal evidence*. St Martin's Press.

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*(6), 1063.

Weick, K. E. (1995). *Sensemaking in organizations.* Thousand Oaks, CA: SAGE.

Weick, K. (1988). Enacted sensemaking in crisis situations. *Journal of Management Studies, 25*(4), 305–317.

Weick, K. E., Sutcliffe, K. M., & Obstfeld, D. (2005). Organizing and the process of sensemaking. *Organization Science*, *16*(4), 409–421.

Wheat, A., Attfield, S., & Fields, B. (2016, February). Developing a model of distributed sensemaking: A case study of military analysis. *Informatics, 3*(1), 1–16.

Wilkinson, L. (2005). *The grammar of graphics* (2nd ed.). New York: Springer.

Wilson, M. J., & Wilson, M. L. (2013). A comparison of techniques for measuring sensemaking and learning within participant-generated summaries. *Journal of the American Society for Information Science and Technology*, *64*(2), 291–306.

Wilson, T. D. (1999). Models in information behaviour research. *Journal of Documentation*, *55*(3), 249–270.

Wissbrock, F. (2004). *Information need assessment in information retrieval: Beyond lists and queries*. In Proceedings of the 27th German Conference on Artificial Intelligence.

Wong, W., Chen, R., Kodagoda, N., Rooney, C., & Xu, K. (2011, May 7–12). *INVISQUE: Intuitive information exploration through interactive visualization*. In The ACM CHI Conference on Human Factors in Computing Systems, Vancouver, Canada (pp. 311–316).

Wright, P. C., Fields, B., & Harrison, M. D. (1996, September). *Distributed information resources: A new approach to interaction modelling*. In Proceedings of Eighth European Conference on Cognitive Ergonomics (pp. 10–13).

Wright, P. C., Fields, R. E., & Harrison, M. D. (2000). Analyzing human-computer interaction as distributed cognition: The resources model. *Human-Computer Interaction*, *15*(1), 1–41.

Wright, W., Schroh, D., Proulx, P., Skaburskis, A., & Cort, B. (2006, April). *The Sandbox for analysis: Concepts and methods*. In CHI '06: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 801–810).

Yang-Turner, F., Lau, L., & Dimitrova, V. (2012, December). *A model-driven prototype evaluation to elicit requirements for a sensemaking support tool*. In 19th Asia-Pacific Software Engineering Conference. Vol. 1 (pp. 380–385).

Yi, J. S., Kang, Y.-A., Stasko, J. T., & Jacko, J. A. (2008). *Understanding and characterizing insights*. Proceedings of the 2008 Conference on BEyond Time and Errors: Novel EvaLuation Methods for Information Visualization.

Zhang, J. (1997). The nature of external representations in problem solving. *Cognitive Science, 21*(2), 179–217.

Zhang, J., & Norman, D. A. (1994). Representations in distributed cognitive tasks. *Cognitive Science*, *18*(1), 87–122.

Zhang, P., & Soergel, D. (2009). *Examining a comprehensive sensemaking model with user studies of computer-assisted sensemaking*. In Sensemaking Workshop at CHI. Vol. 2009.

Zhang, P., & Soergel, D. (2014). Towards a comprehensive model of the cognitive process and mechanisms of individual sensemaking. *Journal of the Association for Information Science and Technology, 65*(9), 1733–1756.

Zhang, P., & Soergel, D. (2016). Process patterns and conceptual changes in knowledge representations during information seeking and sensemaking: A qualitative user study. *Journal of Information Science, 42*(1), 59–78.

Zhang, X., Qu, Y., Giles, C. L., & Song, P. (2008, April 5–10). *CiteSense: Supporting sensemaking of research literature*. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Florence, Italy (pp. 677–680).

Appendix A: First Study (CH3)

Appendix A.1: Study 1: Participant Information Sheet

MIDDLESEX UNIVERSITY

PARTICIPANT SHEET (PIS)

Participant ID Code:…………………………………………

1. Study title

A new way (paradigm) of measuring sense-making.

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

3. What is the purpose of the study?

The aim of this study is to establish a new way (paradigm) of measuring sense-making. The study will investigate the impact of information structuring on both the performance of the document triage process and the quality of the user's queries, as proxies for sensemaking

4. Why have I been chosen?

It is important that we assess as many participants as possible, and you have indicated that you are interested in taking part in this study. The main criteria of the invited participants are to be a postgraduate student, as postgraduate students have enough experience with information seeking and documents triage.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. If you do decide to withdraw from the study then please inform the researcher as soon as possible, and they will facilitate your withdrawal. If, for any reason, you wish to withdraw your data please contact the researcher within a month of your participation. After this data it may not be possible to withdraw your individual data as the results may have already been published. However, as all data are anonymised, your individual data will not be identifiable in any way.

6. What will I have to do?

The task is to perform a mock investigation using a collection of documents. The task will involve constructing queries over a data set, searching for documents, and reviewing the results to decide on individual document relevance (document triage). There is a single independent variable (structure) with two levels (structuring vs non-structuring). You will be either structure the documents using OneNote software (structuring condition, time-based) or simply put the documents into a folder (non-structuring condition)

Please note that in order to ensure quality assurance and equity this project may be selected for audit by a designated member of the committee. This means that the designated member can request to see signed consent forms. However, if this is the case your signed consent form will only be accessed by the designated auditor or member of the audit team.

7. What are the possible disadvantages and risks of taking part?

Appropriate risk assessments for all procedures have been conducted, and will be followed throughout the duration of the study.

8. What are the possible benefits of taking part?

We hope that participating in the study will help you. However, this cannot be guaranteed. The information we get from this study may help us to investigate the impact of information structuring on both the performance of the document triage process, user engagement and the quality of the user's queries, as proxies for sensemaking. Where there is no intended benefit to the participant from taking part in the study.

9. Will my taking part in this study be kept confidential?

The research team has put a number of procedures in place to protect the confidentiality of participants. You will be allocated a participant code that will always be used to identify any data you provide. Your name or other personal details will not be associated with your data, for example, the consent form that you sign will be kept separate from your data. All paper records will be stored in a locked filing cabinet, accessible only to the research team, and all electronic data will be stored on a password protected computer. All information you provide will be treated in accordance with the UK Data Protection Act.

10. What will happen to the results of the research study?

The results of the research study will be used as part of a Postgraduate dissertation. The results may also be presented at conferences or in journal articles. However, the data will only be used by members of the research team and at no point will your personal information or data be revealed.

11. Who has reviewed the study?

The study has received full ethical clearance from the Research ethics committee who reviewed the study.

12. Contact for further information

If you require further information, have any questions or would like to withdraw your data then please contact:

Kholod Alsufiani

K.Alsufiani@mdx.ac.uk

Thank you for taking part in this study. You should keep this participant information sheet as it contains your participant code, important information and the research teams contact details

Appendix A.2: Study 1: Consent Form

Title of Project: A new way (paradigm) of measuring sense-making.

Name of Researcher: Kholod Alsufiani

1. I confirm that I have read and understand the information sheet dated ....……………..…for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

3. I agree that this form that bears my name and signature may be seen by a designated auditor.

4. I agree that my non-identifiable research data may be stored in National Archives and be used anonymously by others for future research. I am assured that the confidentiality of my data will be upheld through the removal of any personal identifiers.

5. I understand that my interview may be taped and subsequently transcribed.

7. I agree to take part in the above study.

Name of participant	Date	Signature
Name of person taking consent (if different from researcher)	Date	Signature
Researcher	Date	Signature
Name of parent/guardian (if appropriate)	Date	Signature

1 copy for participant; 1 copy for researcher;

Appendix A.3: Study 1: Sensemaking Questionnaire (Version 1)

To what extent do you think conducting the given task under this condition helped you to perform the following process successfully?

1. Construct understanding from the available information

To a small extent To a large extent

2. Gain insight from the available information

To a small extent To a large extent

3.Make sense of the available information

To a small extent To a large extent

4. Draw a link between the conflict you read about and similar previous conflict

To a small extent To a large extent

5. Draw a link between the story you read about and similar previous stories

To a small extent To a large extent

6. Develop a coherent representation of the information

To a small extent To a large extent

7. Find a structure in the information

To a small extent To a large extent

8. Find a way to organise the information

To a small extent To a large extent

9. Understand connections between people (countries)

To a small extent To a large extent

10. Understand connections between places

To a small extent To a large extent

11. Understand connections between events

To a small extent — To a large extent

12. Discover where the gaps in your information about the given task

To a small extent — To a large extent

13. Bridge gaps in your information about the given task

To a small extent — To a large extent

14. Reduce confusion

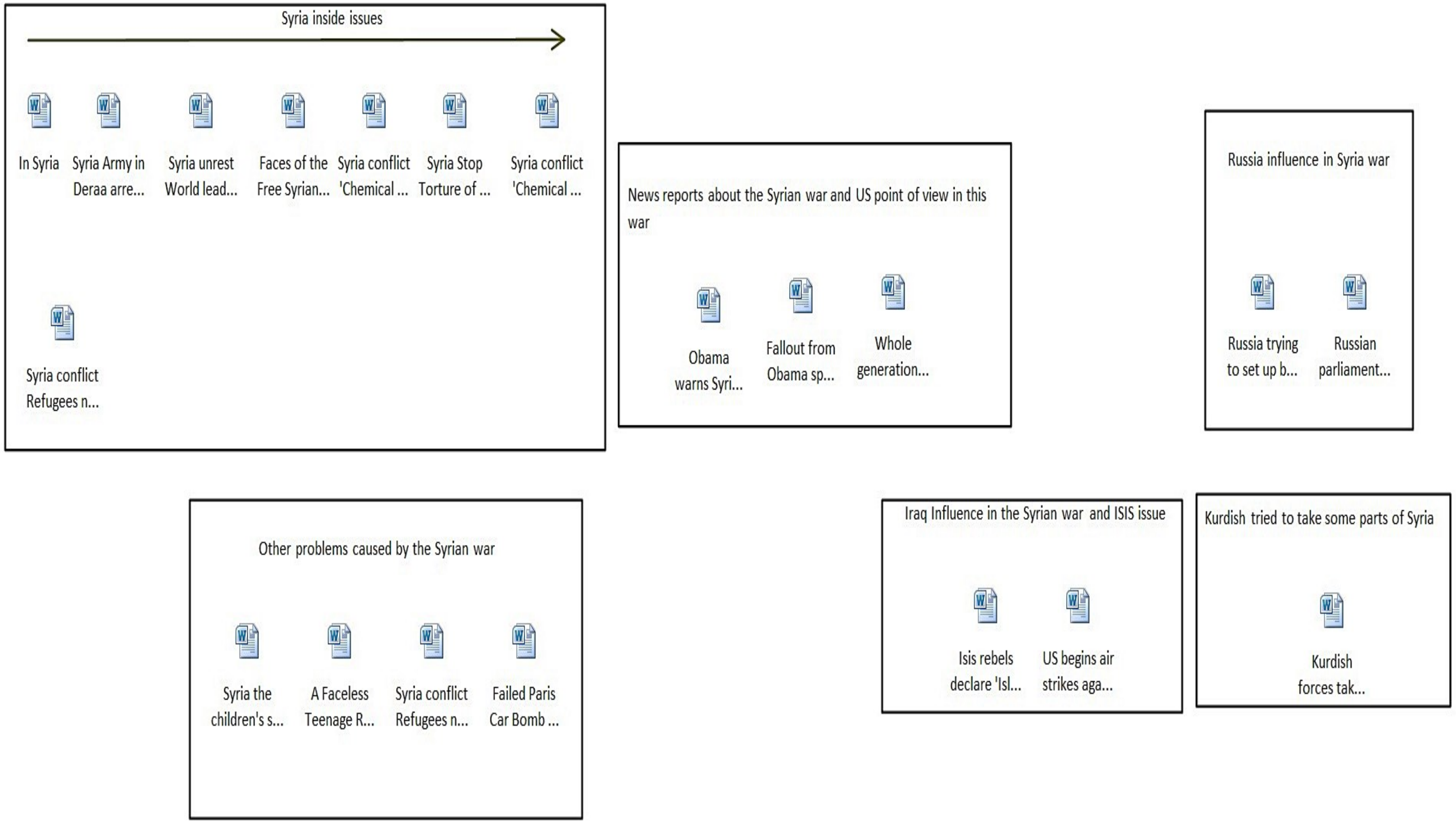
To a small extent — To a large extent

15. Reduce ambiguity

To a small extent — To a large extent

Appendix A.4: Study 1: Participants' representations

P1



P2

March 2011

Middle East unrest Thr...

At least three protesters have been shot dead in the south Syrian city of Deraa as security forces clamped down on a protest rally.They were killed by security forces as protesters demanded political freedom and an end to corruption, eyewitnesses and activists told foreign media.

President Bashar al-Assad, whose Baath party has dominated politics for nearly 50 years, tolerates no dissent.

Washington strongly condemned the use of force against demonstrators.

White House national security council spokesman Tommy Vietor said the US was calling on the Syrian government to "allow demonstrations to take place peacefully".

2012

US recognises...

The building, in the village of Aqrab, had been under siege from the Free Syrian Army and, according to the boy, as many as 300 civilians were killed,

There has been no word so far from the Syrian government and it is impossible to verify the activists' account.

More than half a million people have now fled the conflict in Syria to neighbouring countries, according to the UN's refugee agency.

Fab 2013

A Faceless Teenage R...

-by teenage rebellion against authority
-challenge to President Bashar al-Assad, a trained ophthalmologist, about the spreading national revolts.

2015

Russian parliament...

Vladimir Putin has received permission from parliament for Russian forces to take place in bombing raids in Syria, two days after the Russian leader spoke to the UN and called for an international coalition against terrorism to fight Islamic State.

Kurdish forces tak...

peshmerga were dispatched to assist Syrian Kurds, after the US had urged the reluctant Turkish government to let them join the fight against Isis.

feb 2016

Russia PM warns of

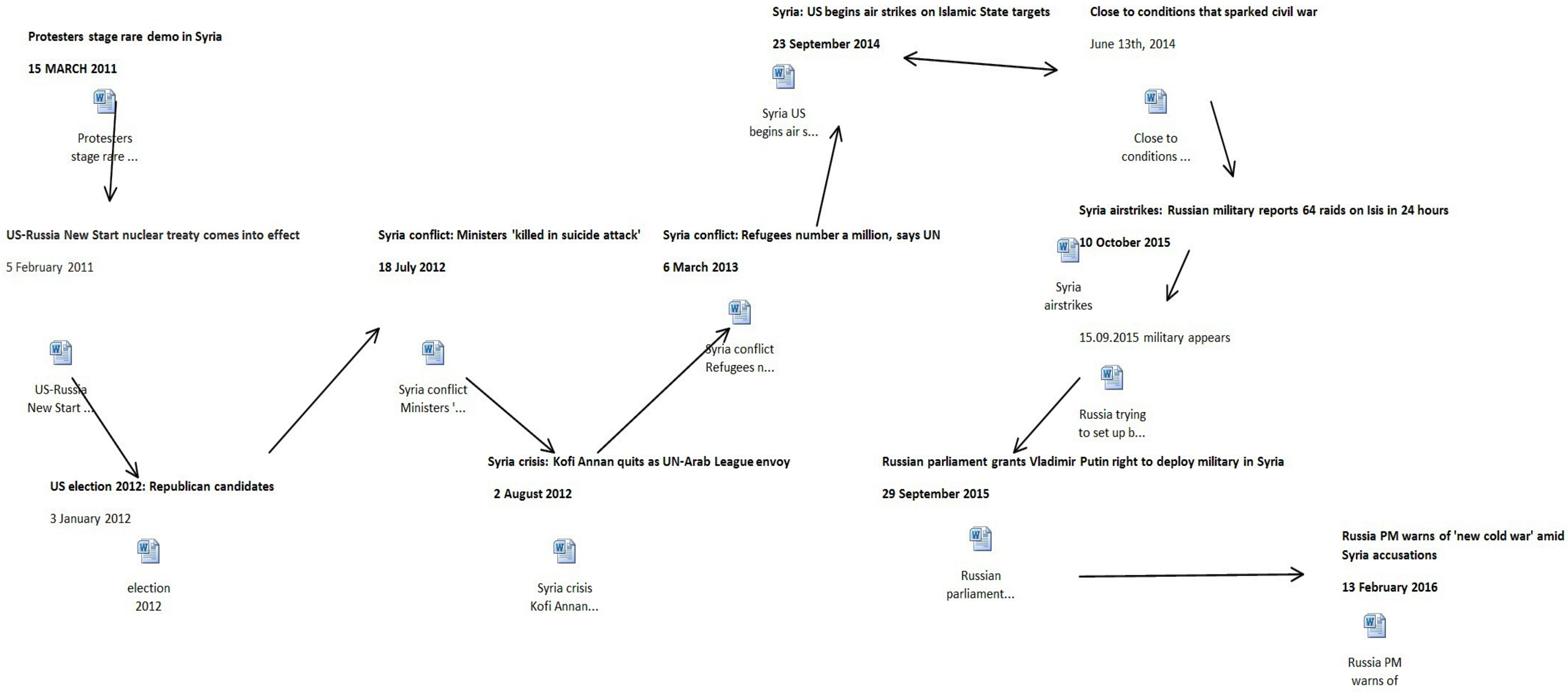
Dmitry Medvedev rejected the widely held belief that Russian planes had hit civilian targets in Syria.

"There is no evidence of our bombing civilians, even though everyone is accusing us of this," he said on Saturday. "Russia is not trying to achieve some secret goals in Syria. We are simply trying to protect our national interests ...

"Creating trust is hard ... but we have to start. Our positions differ, but they do not differ as much as 40 years ago when a wall was standing in Europe.

"You could say even more sharply: we have fallen into a new cold war,"

P3


Protesters stage rare demo in Syria
15 MARCH 2011
Protesters stage rare ...
US-Russia New Start nuclear treaty comes into effect
5 February 2011
US-Russia New Start ...
US election 2012: Republican candidates
3 January 2012
election 2012
Syria conflict: Ministers 'killed in suicide attack'
18 July 2012
Syria conflict Ministers '...
Syria crisis: Kofi Annan quits as UN-Arab League envoy
2 August 2012
Syria crisis Kofi Annan...
Syria conflict: Refugees number a million, says UN
6 March 2013
Syria conflict Refugees n...
Syria: US begins air strikes on Islamic State targets
23 September 2014
Syria US begins air s...
Close to conditions that sparked civil war
June 13th, 2014
Close to conditions ...
Syria airstrikes: Russian military reports 64 raids on Isis in 24 hours
10 October 2015
Syria airstrikes
15.09.2015 military appears
Russia trying to set up b...
Russian parliament grants Vladimir Putin right to deploy military in Syria
29 September 2015
Russian parliament...
Russia PM warns of 'new cold war' amid Syria accusations
13 February 2016
Russia PM warns of

P4

2013

Sunni groups

Back to civil war

Rebel groups

Isis rebels declare 'Isl...

Refugees

Syria conflict Refugees n...

TIMELINE

2011

Syria unrest Bloodiest ...

the Syrian revolution

2011

In Syria

DAMASCUS, Syria — Protests broke out in four Syrian cities on Friday, the first large-scale demonstrations here since the pro-democracy uprisings began in the Arab world three months ago. Brutal police crackdowns followed, leaving six people dead and scores injured.

2011

Syria unrest World lead...

The leaders of the US, UK, France, Germany and the EU have all called for Syria's President Assad to step down over his suppression of protesters.

2012

Syria crisis Kofi Annan...

Activists estimate some 20,000 people have died since anti-government protests erupted against President Assad in March last year. Tens of thousands of people have also fled the country.

2012

US recognises...

US

2013

Syria rebels capture no...

2014

Syria US begins air s...

US begins air strikes aga...

US

2016

Vladimir Putin orde...

Russia

CONTEXT

Close to conditions ...

this is a few thousand fighters from ISIS who are up against a 600,000 or 700,000-man Iraqi Army – and they are winning. And the reason they are winning is because they have local support among disaffected Sunnis. So in the Shia-Sunni context, you have a Shia government in Iraq supported by a Shia government in Iran. And as you point out, elite guards from Iran are coming to support the Iraqi government. And the U.S. would be placed in the extremely awkward position of being the air force for essentially Iran's Revolutionary Guard and the Iraqi government. That's the dilemma.

Russia trying to set up b...

The complex Syrian conflict has raged for more than four years, taking the lives of more than 200,000 people.

Rebel groups have been trying to defeat al-Assad's forces, but he has been able to retain his grip on parts of the country with help from Iran and Russia.

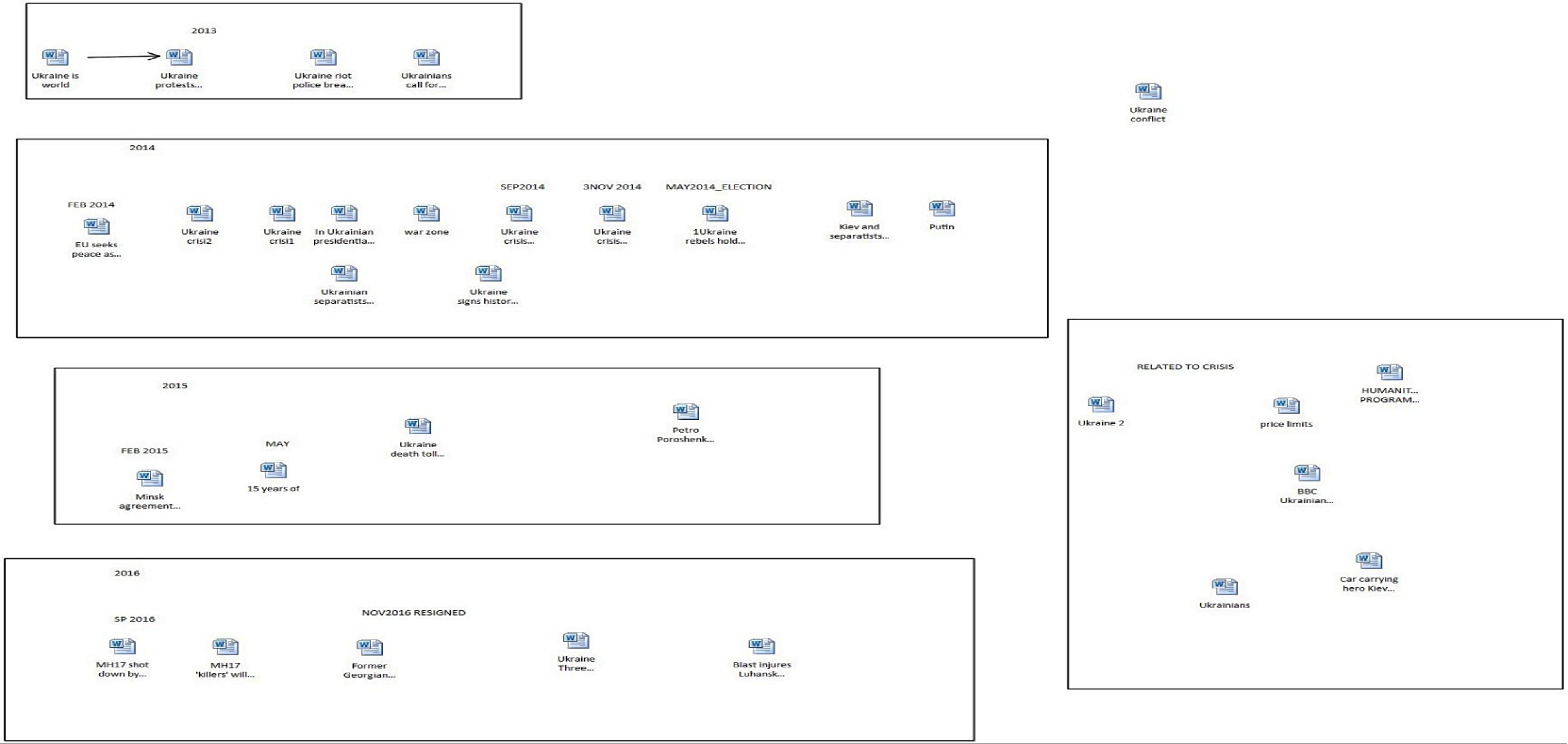
Both Moscow and Washington are opposed to ISIS, but their broader aims differ.

A U.S.-led coalition is conducting a bombing campaign against ISIS positions in Syria and Iraq.

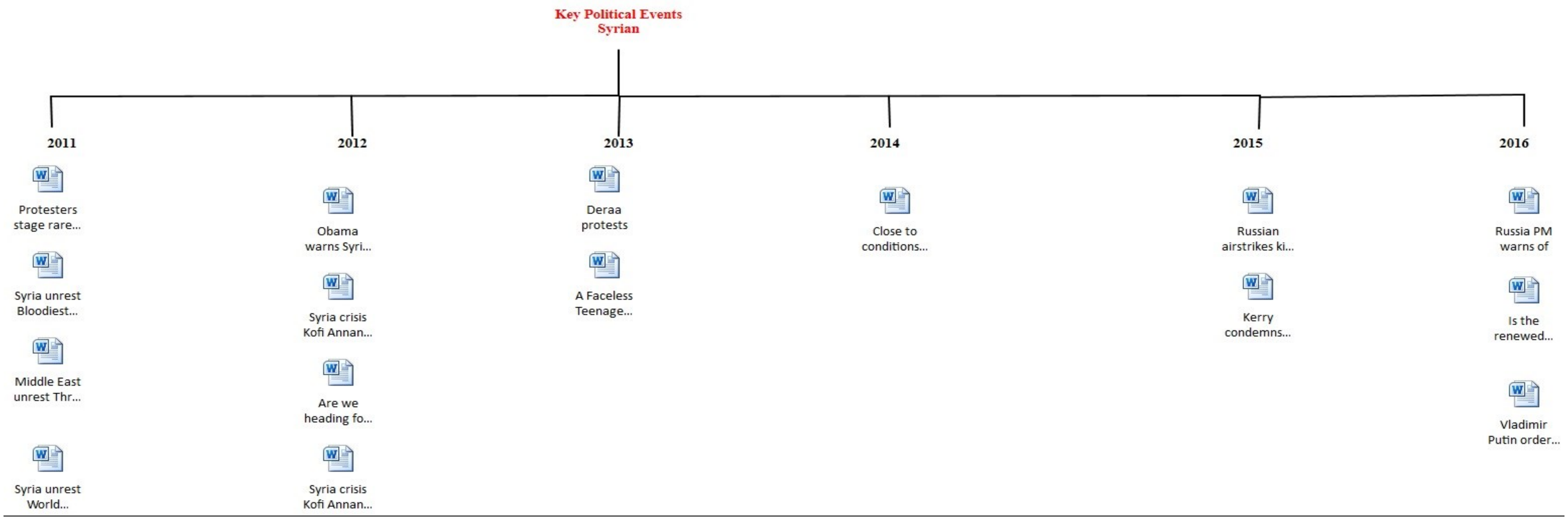
The United States has also been offering limited support to moderate Syrian rebels in the fight against ISIS. Those rebels, though, are also trying to drive out al-Assad, whom U.S. President Barack Obama has called on to step down.

Whole generation...

P5


2013
Ukraine is world
Ukraine protests...
Ukraine riot police brea...
Ukrainians call for...
Ukraine conflict
2014
FEB 2014
EU seeks peace as...
Ukraine crisi2
Ukraine crisi1
In Ukrainian presidentia...
war zone
SEP2014
Ukraine crisis...
3NOV 2014
Ukraine crisis...
MAY2014_ELECTION
1Ukraine rebels hold...
Kiev and separatists...
Putin
Ukrainian separatists...
Ukraine signs histor...
2015
FEB 2015
Minsk agreement...
MAY
15 years of
Ukraine death toll...
Petro Poroshenk...
RELATED TO CRISIS
Ukraine 2
price limits
HUMANIT... PROGRAM...
BBC Ukrainian...
Ukrainians
Car carrying hero Kiev...
2016
SP 2016
MH17 shot down by...
MH17 'killers' will...
NOV2016 RESIGNED
Former Georgian...
Ukraine Three...
Blast injures Luhansk...

P6


Key Political Events
Syrian
2011
2012
2013
2014
2015
2016
Protesters stage rare...
Syria unrest Bloodiest...
Middle East unrest Thr...
Syria unrest World...
Obama warns Syri...
Syria crisis Kofi Annan...
Are we heading fo...
Syria crisis Kofi Annan...
Deraa protests
A Faceless Teenage...
Close to conditions...
Russian airstrikes ki...
Kerry condemns...
Russia PM warns of
Is the renewed...
Vladimir Putin order...

P7

2011- Attack begins

US begins air strikes...

Syria unrest Bloodiest...

Syria unrest World...

Russian election...

MARCH 18, 2011

Middle East unrest Thr...

In Syria

3 May 2011

Syria Army in Deraa...

21 Aug 2011

Obama warns Syri...

Attacks and conflicts between US and ISIS

Isis rebels declare...

US begins air strikes...

Syria conflict Ministers...

Syria conflict 'Chemical...

Syria conflict 'Chemical...

Between 2012 to 2013- Children Attacks

Whole generation...

Syria the children's...

Syria Stop Torture of...

P8

Putin delays

1Ukraine
rebels hold...

Ukrainians
call for...

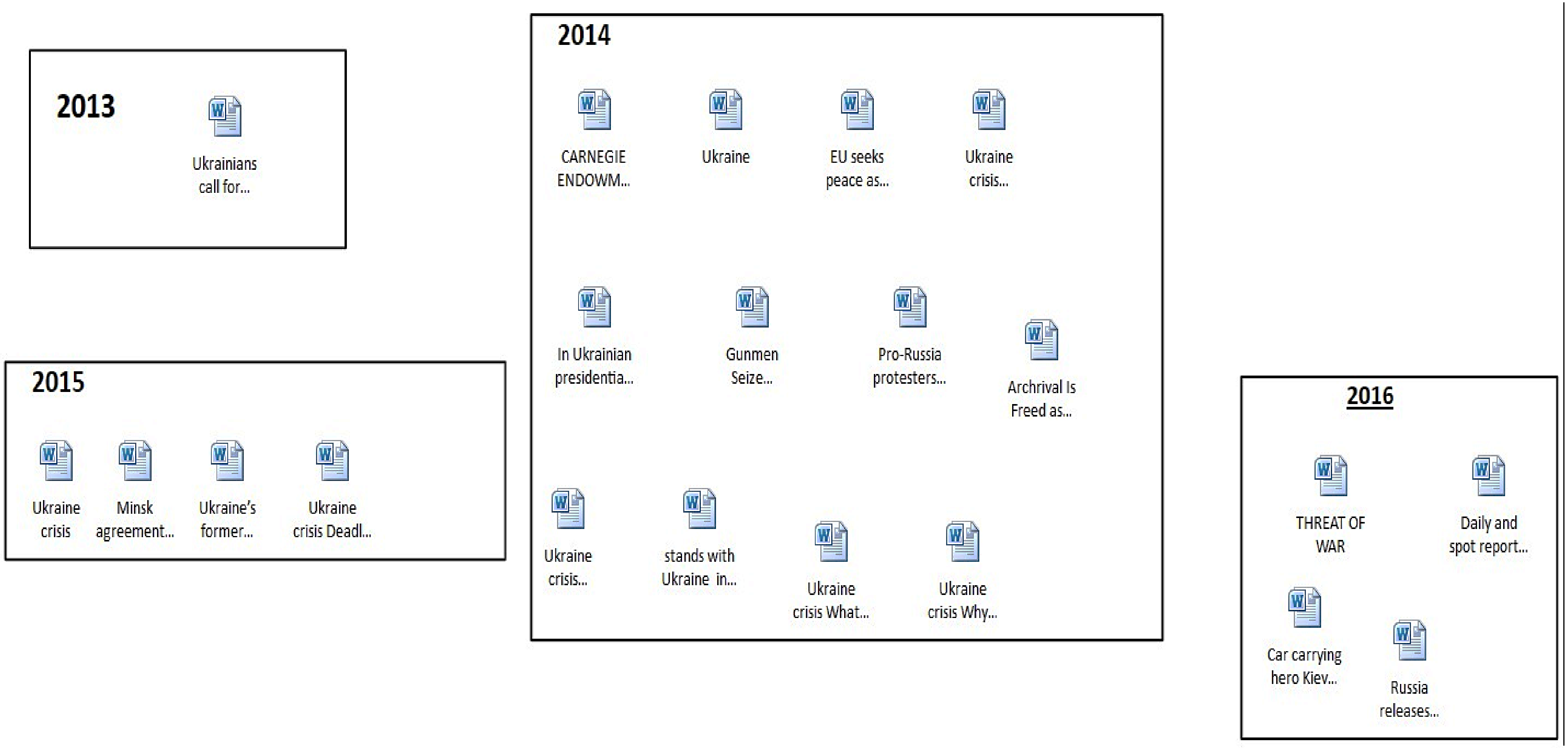
'reliable
partner'

Ukrainians

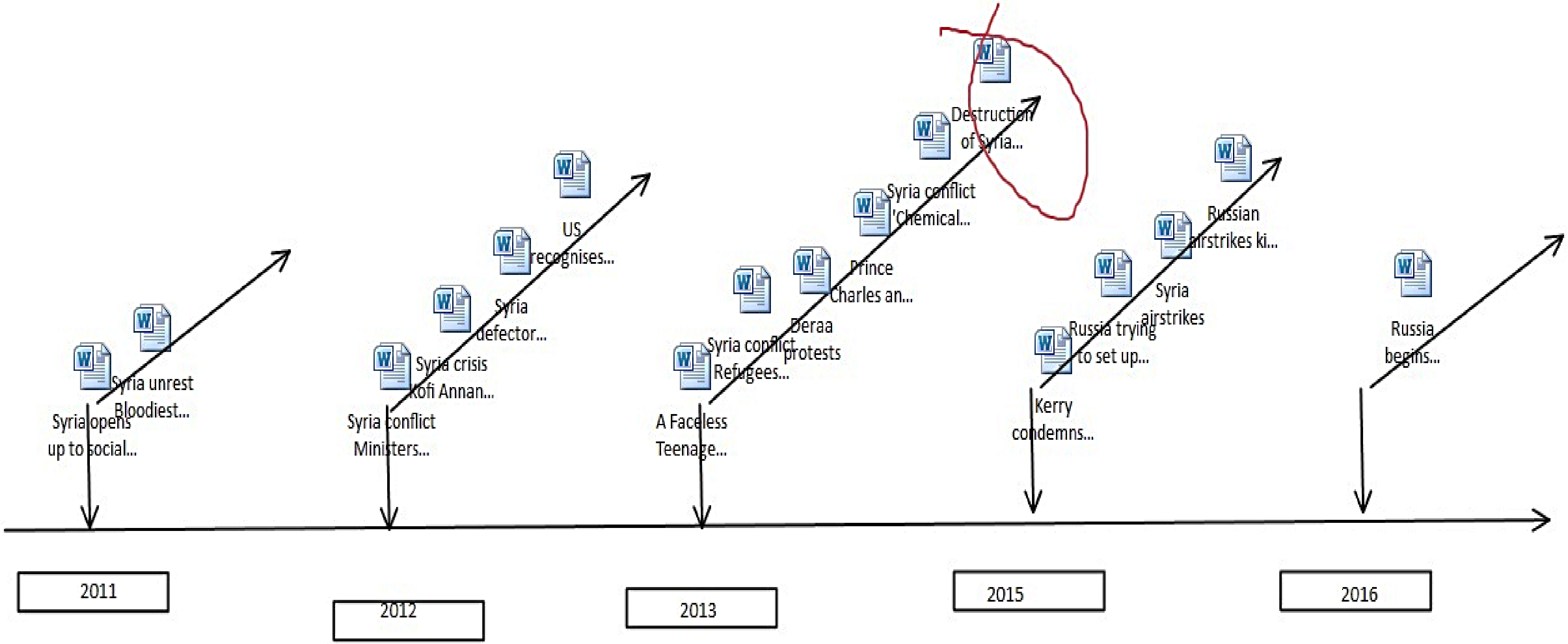
Ukraine
crisis Deadl...

ukriane

P9

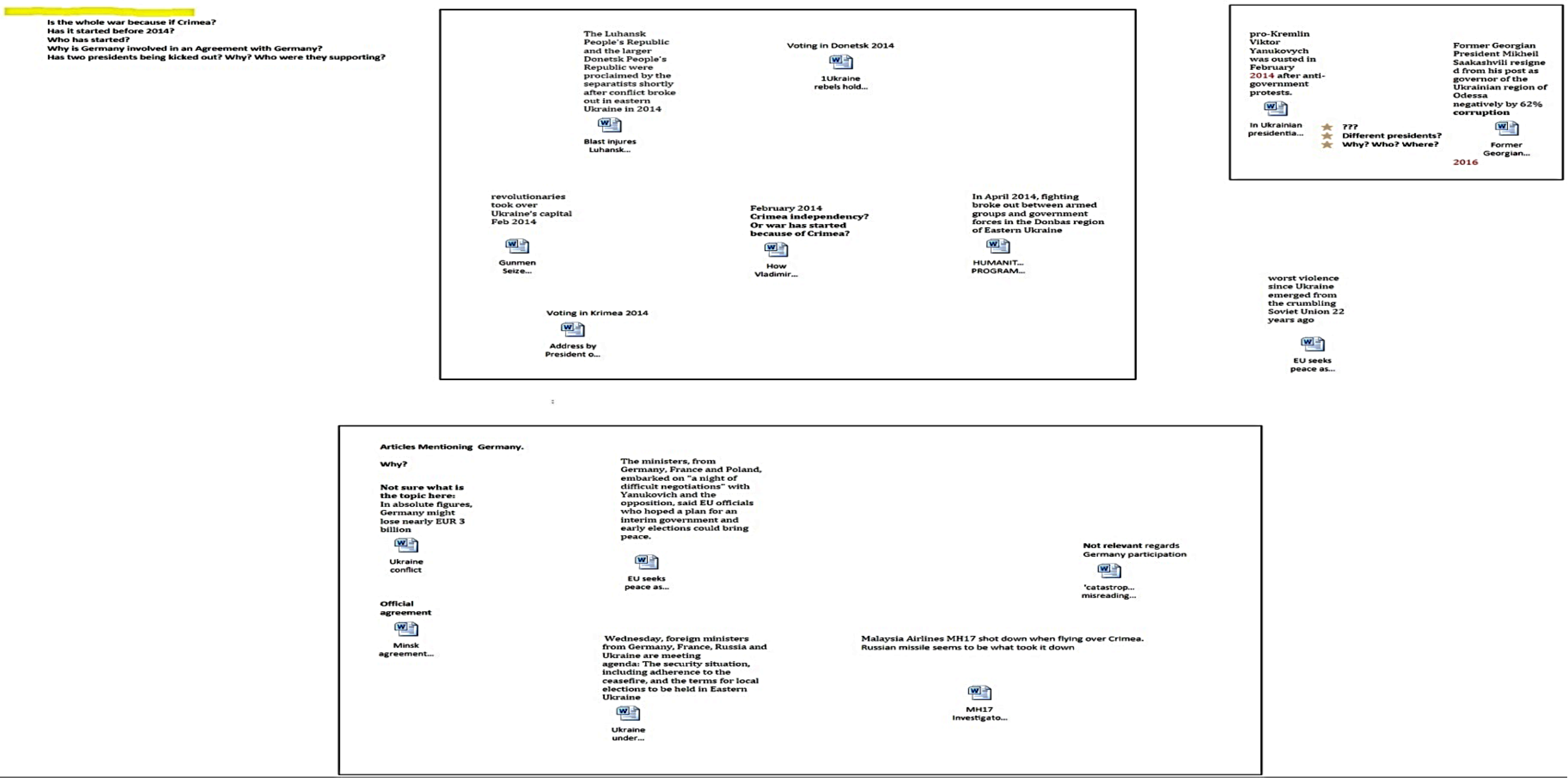

2013
Ukrainians call for...
2014
CARNEGIE ENDOWM...
Ukraine
EU seeks peace as...
Ukraine crisis...
In Ukrainian presidentia...
Gunmen Seize...
Pro-Russia protesters...
Archrival Is Freed as...
Ukraine crisis...
stands with Ukraine in...
Ukraine crisis What...
Ukraine crisis Why...
2015
Ukraine crisis
Minsk agreement...
Ukraine's former...
Ukraine crisis Deadl...
2016
THREAT OF WAR
Daily and spot report...
Car carrying hero Kiev...
Russia releases...

P10



Syria unrest Bloodiest...
Syria opens up to social...
US recognises...
Syria defector...
Syria crisis Kofi Annan...
Syria conflict Ministers...
Destruction of Syria...
Syria conflict 'Chemical...
Prince Charles an...
Deraa protests
Syria conflict Refugees...
A Faceless Teenage...
Russian airstrikes ki...
Syria airstrikes
Russia trying to set up...
Kerry condemns...
Russia begins...
2011
2012
2013
2015
2016

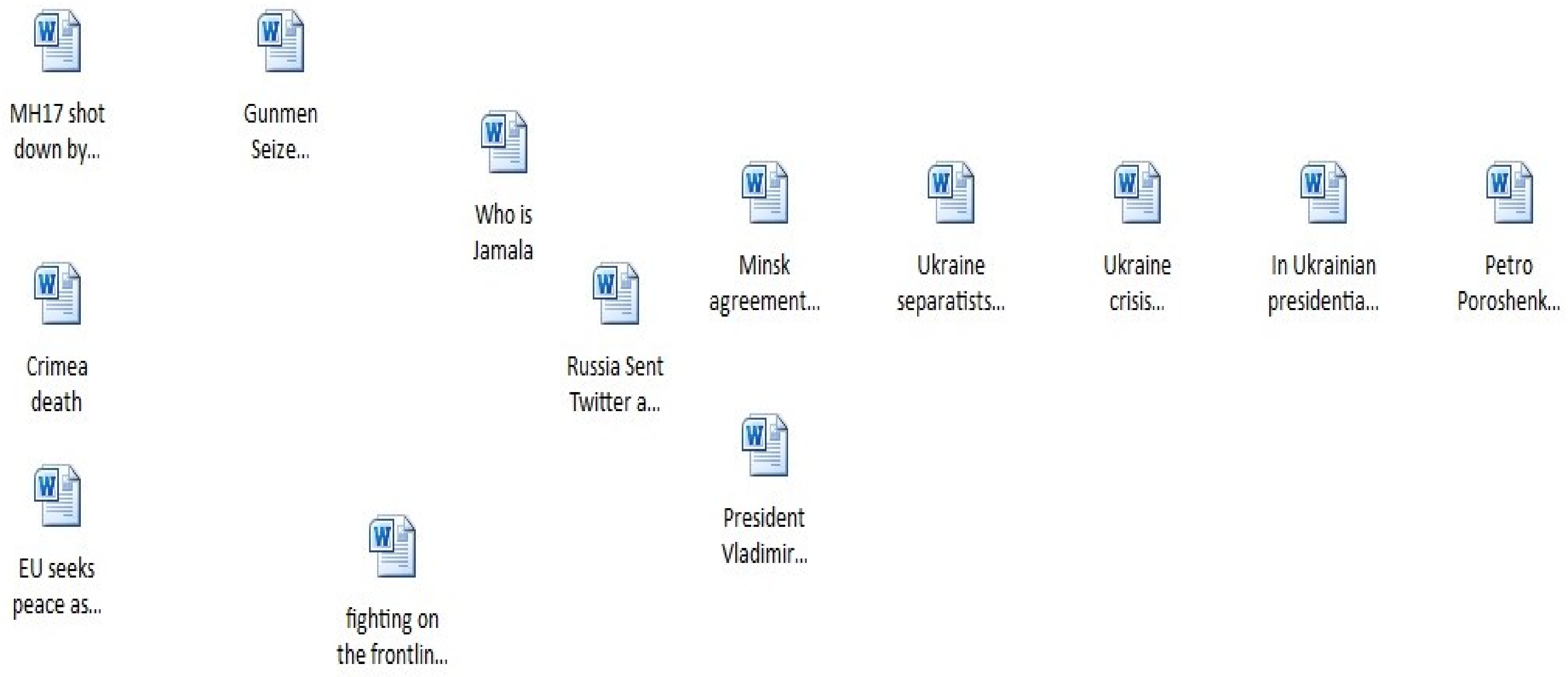
P11


Is the whole war because if Crimea?
Has it started before 2014?
Who has started?
Why is Germany involved in an Agreement with Germany?
Has two presidents being kicked out? Why? Who were they supporting?
The Luhansk People's Republic and the larger Donetsk People's Republic were proclaimed by the separatists shortly after conflict broke out in eastern Ukraine in 2014
Blast injures Luhansk...
Voting in Donetsk 2014
1Ukraine rebels hold...
revolutionaries took over Ukraine's capital Feb 2014
Gunmen Seize...
February 2014
Crimea independency? Or war has started because of Crimea?
How Vladimir...
In April 2014, fighting broke out between armed groups and government forces in the Donbas region of Eastern Ukraine
HUMANIT... PROGRAM...
Voting in Krimea 2014
Address by President o...
pro-Kremlin Viktor Yanukovych was ousted in February 2014 after anti-government protests.
In Ukrainian presidentia...
???
Different presidents?
Why? Who? Where?
Former Georgian President Mikheil Saakashvili resigne d from his post as governor of the Ukrainian region of Odessa negatively by 62% corruption
Former Georgian...
2016
worst violence since Ukraine emerged from the crumbling Soviet Union 22 years ago
EU seeks peace as...
Articles Mentioning Germany.
Why?
Not sure what is the topic here:
In absolute figures, Germany might lose nearly EUR 3 billion
Ukraine conflict
Official agreement
Minsk agreement...
The ministers, from Germany, France and Poland, embarked on "a night of difficult negotiations" with Yanukovich and the opposition, said EU officials who hoped a plan for an interim government and early elections could bring peace.
EU seeks peace as...
Wednesday, foreign ministers from Germany, France, Russia and Ukraine are meeting agenda: The security situation, including adherence to the ceasefire, and the terms for local elections to be held in Eastern Ukraine
Ukraine under...
Not relevant regards Germany participation
'catastrop... misreading...
Malaysia Airlines MH17 shot down when flying over Crimea. Russian missile seems to be what took it down
MH17 Investigato...

P12


Things between Ukranian and Russia
Kiev and separatists...
MH17 Investigato...
Pro-Russia separatists...
Car carrying hero Kiev...
MH17 shot down by...
External
EU seeks peace as...
Leading to the agreement
President Vladimir...
Ukraine crisis...
Russia releases...
Internal crisis
Ukraine protests...
Gunmen seize...
Crimea death
Ukraine conflict
Archrival Is Freed as...
crisis in Ukraine
Former Georgian...
Leading to the agreement
In Ukrainian presidentia...
Ukraine peace deal

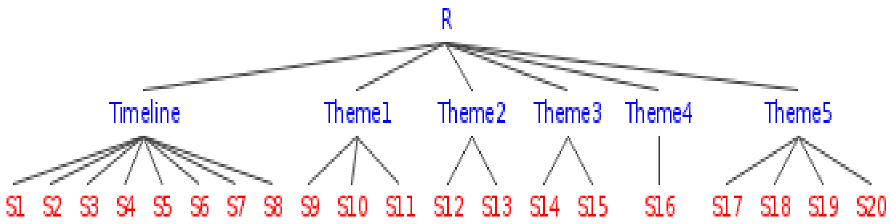
P13


MH17 shot down by...
Gunmen Seize...
Who is Jamala
Minsk agreement...
Ukraine separatists...
Ukraine crisis...
In Ukrainian presidentia...
Petro Poroshenk...
Crimea death
Russia Sent Twitter a...
President Vladimir...
EU seeks peace as...
fighting on the frontlin...

Appendix B: Second Study (CH4)

Appendix B.1: Study 2: Parse trees and grammar that describes the elements and combination of the parse trees of participants' representations.

P1

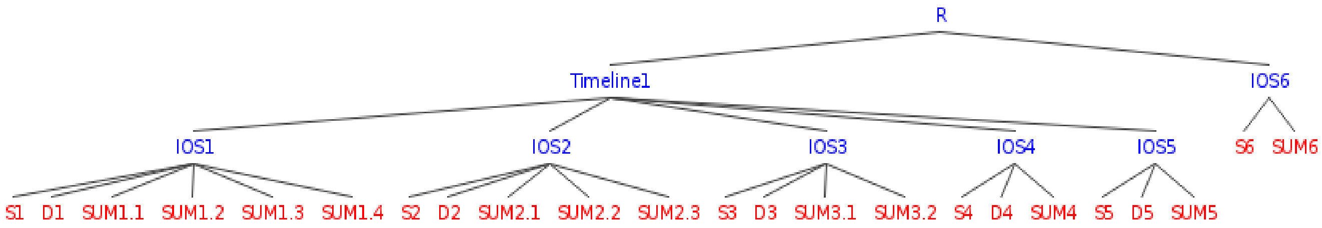


<Representation> $\longrightarrow$ *<Timeline> <Theme>*$_n$

<Timeline> $\longrightarrow$ *<Source>* $_n$

<Theme> $\longrightarrow$ *<Source>* $_n$

P2

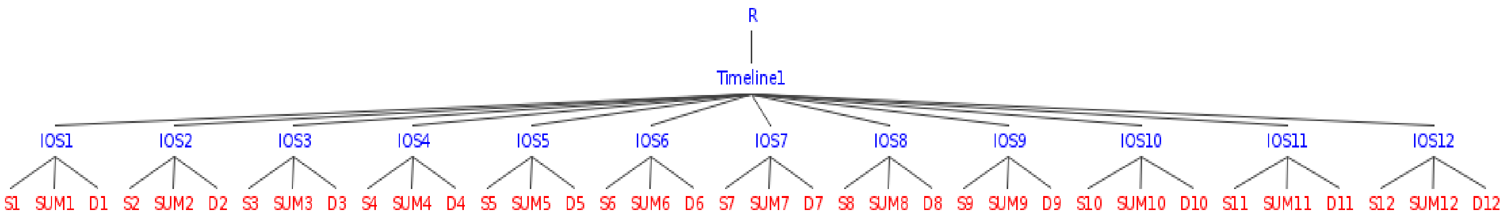


<Representation> ⟶ <Timeline> <Information Object Surrogate>

<Timeline> ⟶ <Information Object Surrogate> $_n$

<Information Object Surrogate> ⟶ <Source> $_n$ ***<Date> < Summary>*** $_n$ | ***<Source>*** $_n$ ***<Date>*** |
<Source> $_n$ ***<Date> < Summary>***

P3

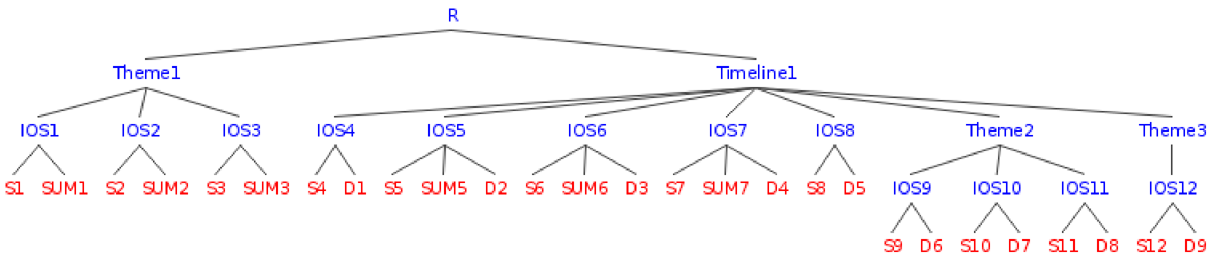


<Representation> $\longrightarrow$ *<Timeline>*

<Timeline> $\longrightarrow$ *<Information Object Surrogate>* $_n$

<Information Object Surrogate> $\longrightarrow$ *<Source><Date> < Summary>*

P4



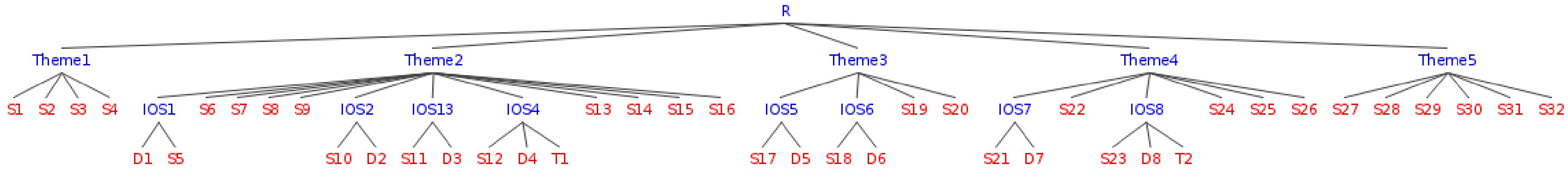
<Representation> $\longrightarrow$ *<Theme>*$_n$*<Timeline>*

<Theme> $\longrightarrow$ *<Information Object Surrogate>* $_n$ |*<Source>*

<Timeline> $\longrightarrow$ *<Information Object Surrogate>* $_n$

<Information Object Surrogate> $\longrightarrow$ *<Source> <Date> < Summary>* |*<Source> < Summary>*

P5

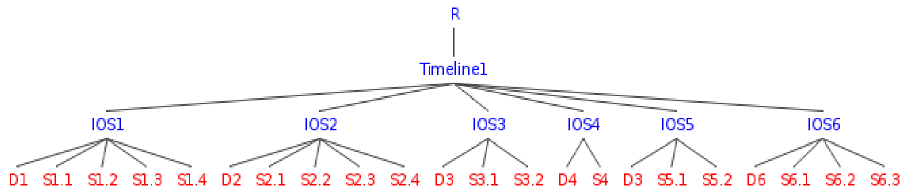


<Representation> → *<Theme>*$_n$

<Theme> → *<Information Object Surrogate>*$_n$ *<Source>*$_n$ | *<Source>*$_n$

<Information Object Surrogate> → *<Source> <Date>* | *<Source> <Date> <Title>*

P6

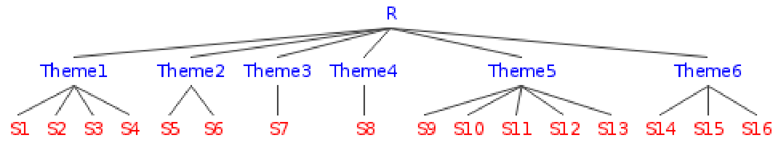


<Representation> $\longrightarrow$ *<Timeline>*

<Timeline> $\longrightarrow$ *<Information Object Surrogate>* $_n$

<Information Object Surrogate> $\longrightarrow$ *<Source> <Date>* | *<Source>* $_n$

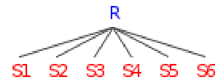
P7



<Representation> ⟶ *<Theme>*$_n$

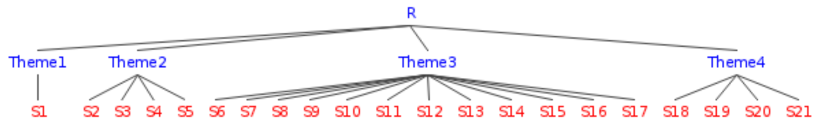
<Theme> ⟶ *<Source>*$_n$

P8



<Representation> ⟶ *<Source>*$_n$

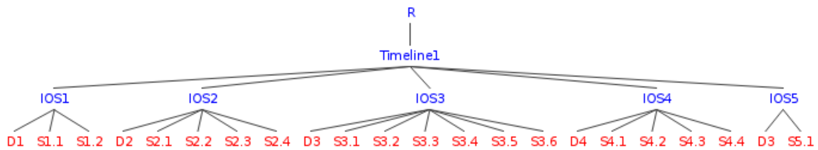
P9



<Representation> → *<Theme>*$_n$

<Theme> → *<Source>*$_n$

P10

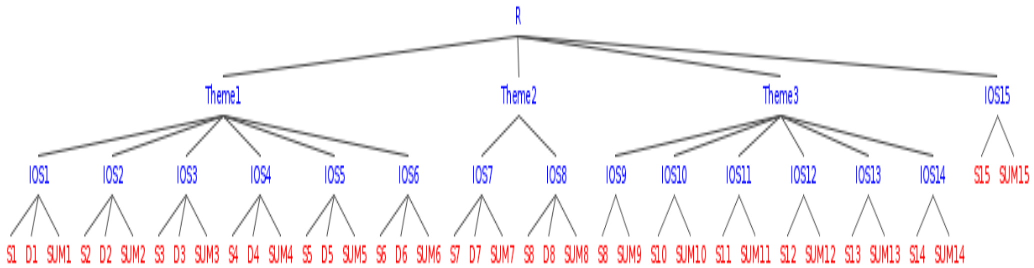


<Representation> ⟶ <Timeline>

<Timeline> ⟶ <Information Object Surrogate> $_n$

<Information Object Surrogate> ⟶ <Source> <Date> | <Date> <Source> $_n$

P11

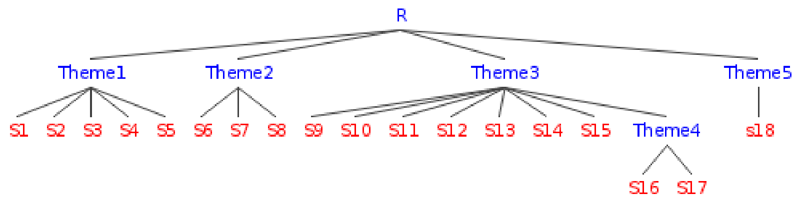


<Representation> ⟶ <Theme> $_n$ ***<Information Object Surrogate>***

<Theme> ⟶ <Information Object Surrogate> $_n$

<Information Object Surrogate> ⟶ <Source> <Summary> <Date> | <Summary><Source>

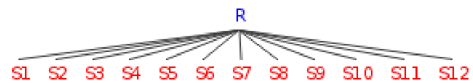
P12



$\langle \textit{Representation} \rangle \longrightarrow \langle \textit{Theme} \rangle_n$

$\langle \textit{Theme} \rangle \longrightarrow \langle \textit{Source} \rangle \mid \langle \textit{Source} \rangle_n$

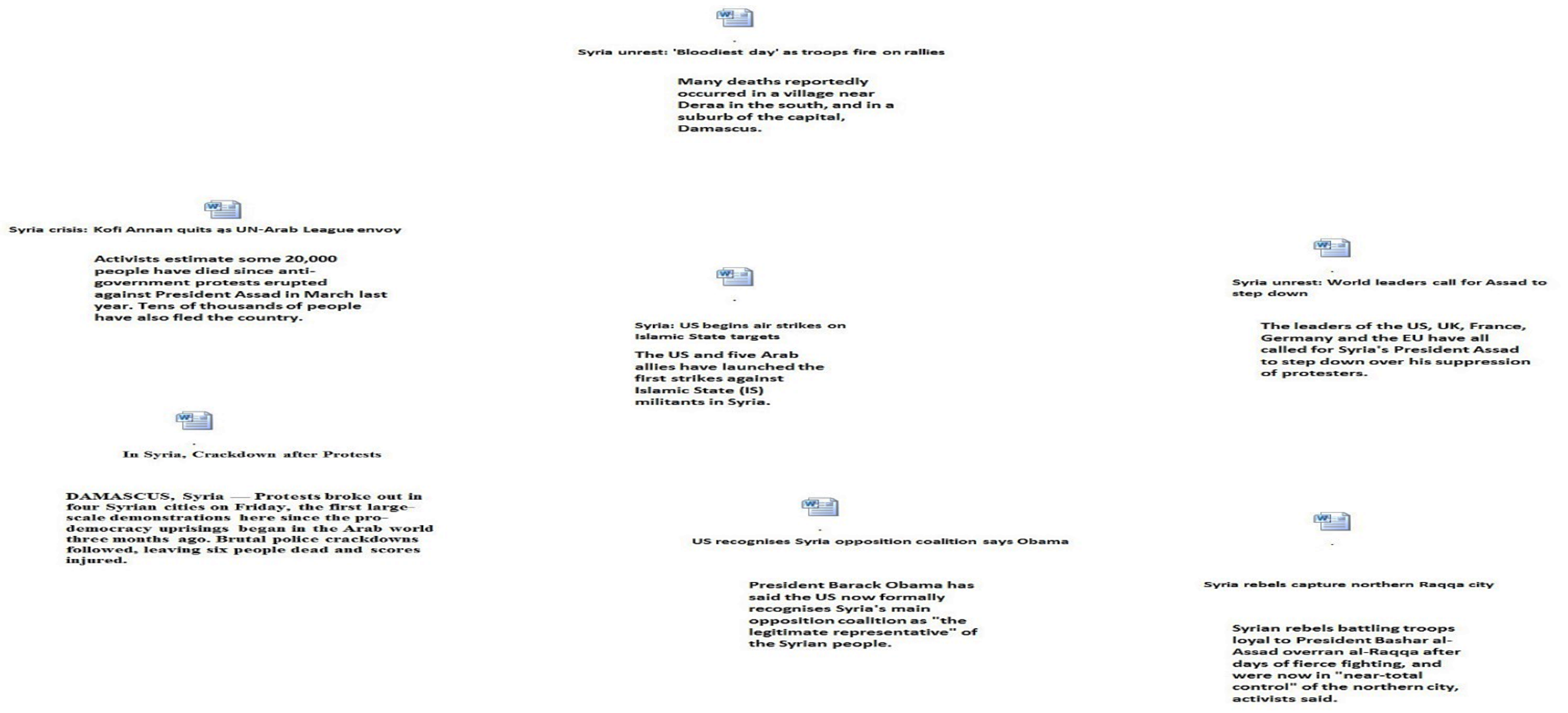
P13



$\langle \textit{Representation} \rangle \longrightarrow \langle \textit{Source} \rangle_n$

Appendix B.2: Study 2: Samples provided to participants during the validation study of the developed metric to measure structuredness

Folder relation



Themed grouping relation

Iraq Influence in the Syrian war and ISIS issue

Syria crisis: Kofi Annan quits as UN-Arab League envoy

Activists estimate some 20,000 people have died since anti-government protests erupted against President Assad in March last year. Tens of thousands of people have also fled the country.

Syria unrest: World leaders call for Assad to step down

The leaders of the US, UK, France, Germany and the EU have all called for Syria's President Assad to step down over his suppression of protesters.

Syria rebels capture northern Raqqa city

Syrian rebels battling troops loyal to President Bashar al-Assad overran al-Raqqa after days of fierce fighting, and were now in "near-total control" of the northern city, activists said.

US influence in Syria war

In Syria, Crackdown after Protests

DAMASCUS, Syria — Protests broke out in four Syrian cities on Friday, the first large-scale demonstrations here since the pro-democracy uprisings began in the Arab world three months ago. Brutal police crackdowns followed, leaving six people dead and scores injured.

US recognises Syria opposition coalition says Obama

President Barack Obama has said the US now formally recognises Syria's main opposition coalition as "the legitimate representative" of the Syrian people.

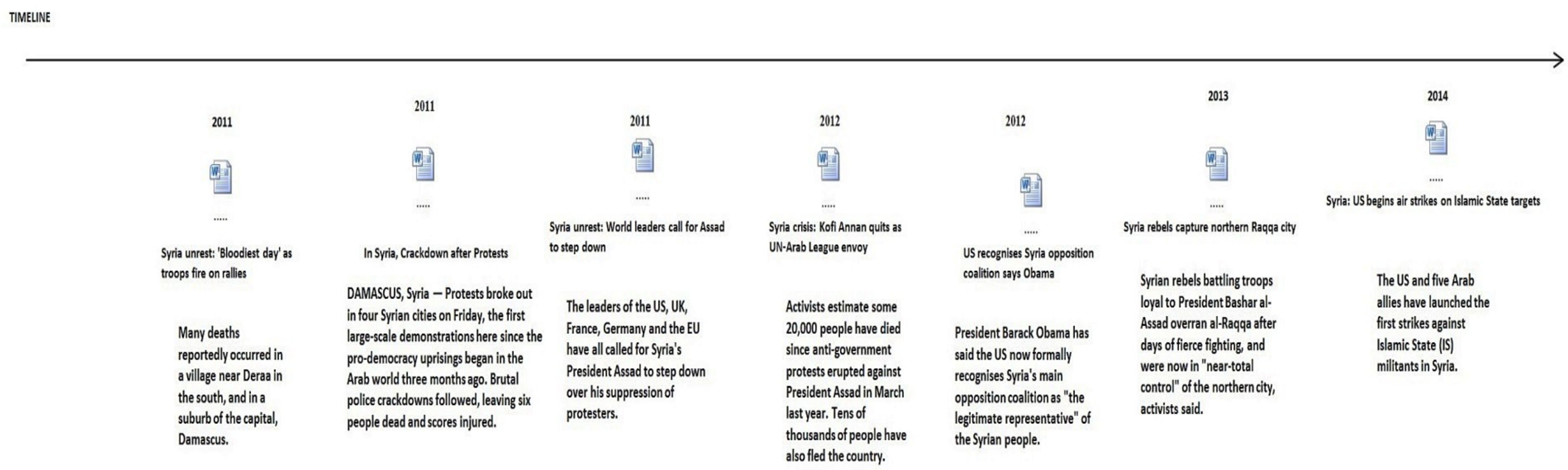
Syria unrest: 'Bloodiest day' as troops fire on rallies

Many deaths reportedly occurred in a village near Deraa in the south, and in a suburb of the capital, Damascus.

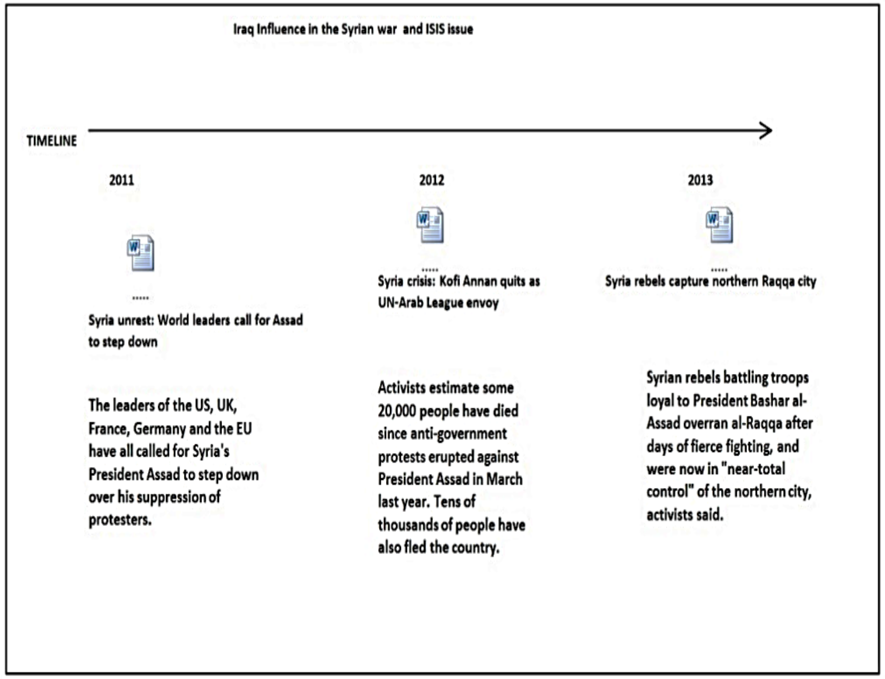
Syria: US begins air strikes on Islamic State targets

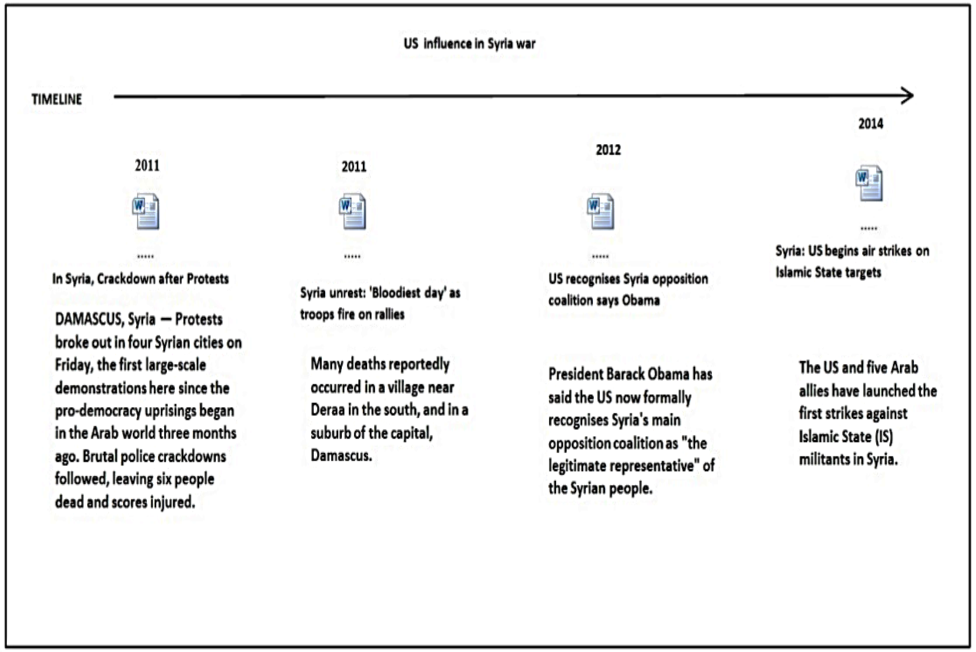
The US and five Arab allies have launched the first strikes against Islamic State (IS) militants in Syria.

Timeline relation

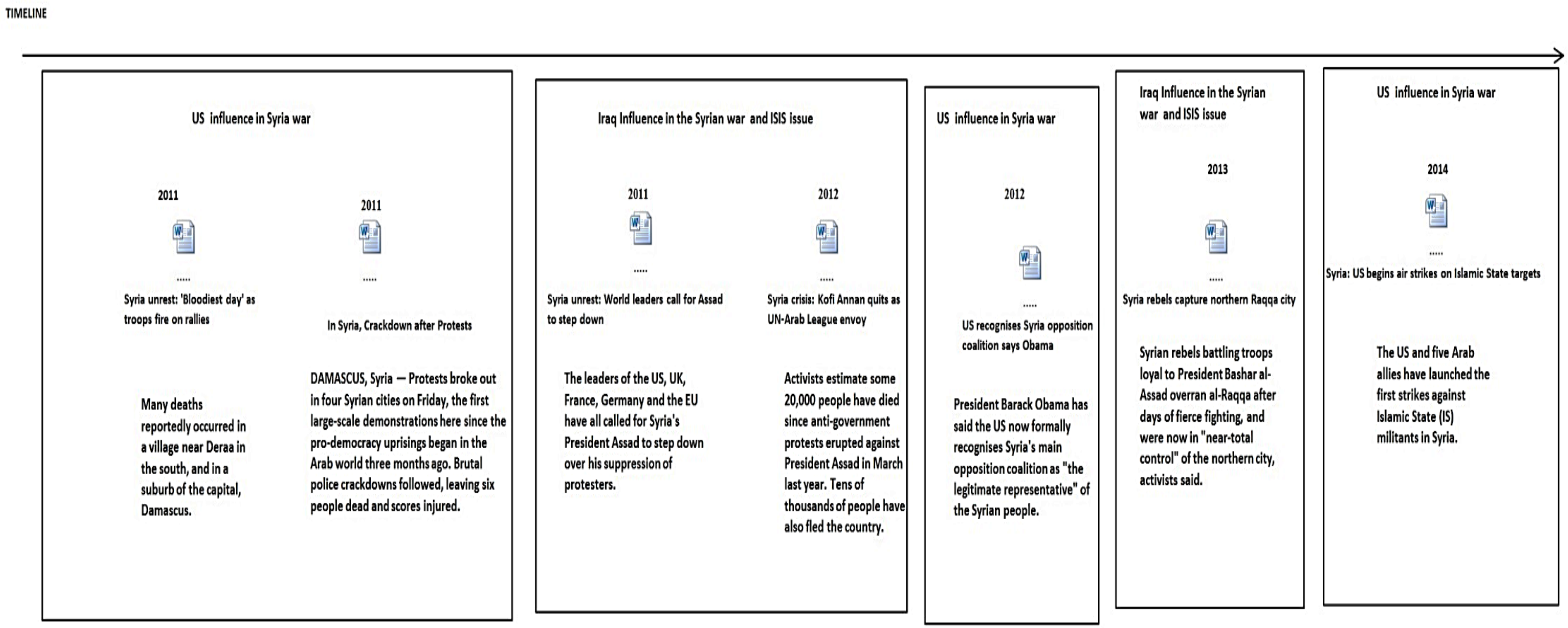


Timelines within themed groping relations



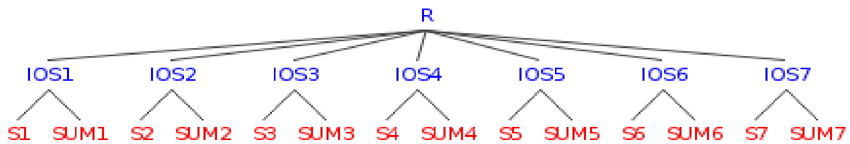


Themed groping within a timeline



Appendix B.3: Study 2: Parse trees of the samples provided to participants during the validation study of the developed metric to measure structuredness

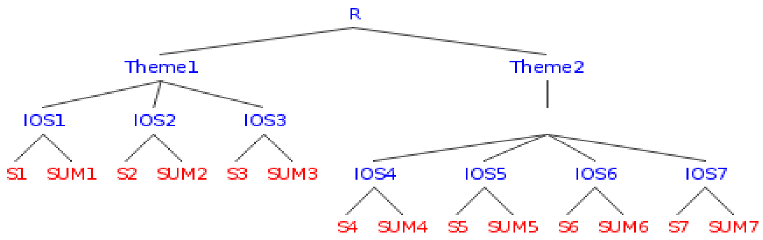
Parse tree of the folder representation



<Representation> → *<Information Object Surrogate>* $_n$

<Information Object Surrogate> → *<Source> <Summary>*

Parse tree of the themed grouping representation

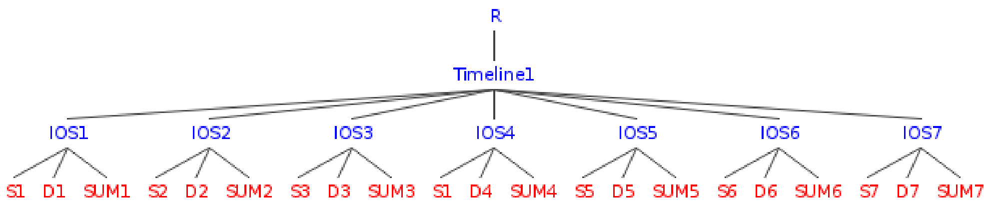


<Representation> → *<Theme>*$_n$

<Theme>$_n$ → *<Information Object Surrogate>* $_n$

<Information Object Surrogate> → *<Source> <Summary>*

Parse tree of the timeline represetnions

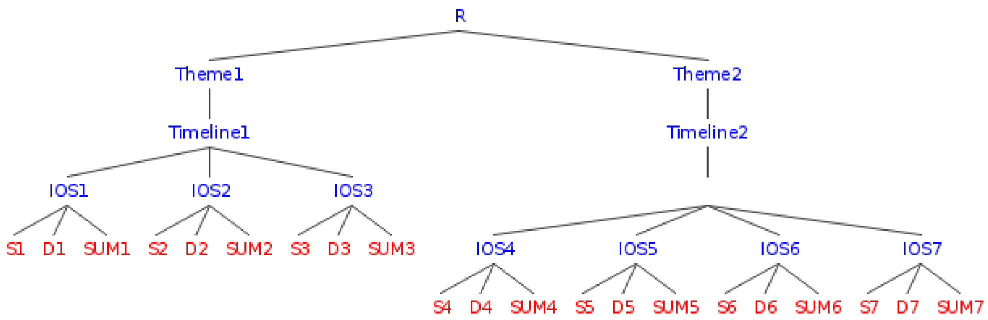


<Representation> ⟶ *<Timeline>*

<Timeline> ⟶ *<Information Object Surrogate>* $_n$

<Information Object Surrogate> ⟶ *<Source> <Summary> <Date>*

Parse tree of the timelines within themed grouping representation



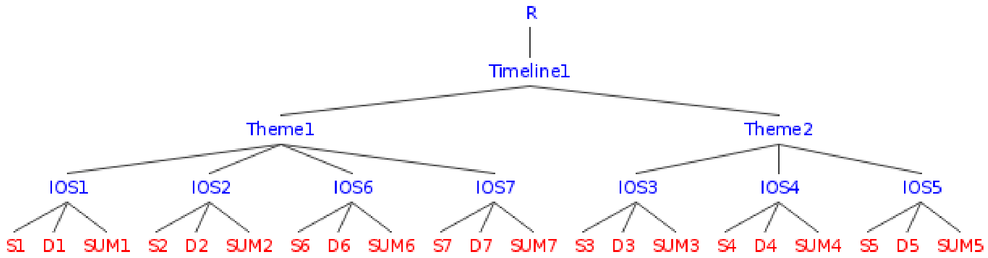
<Representation> ⟶ *<Theme>*$_n$

<Theme> ⟶ *<Timeline >*

<Timeline > ⟶ *<Information Object Surrogate>*$_n$

<Information Object Surrogate> ⟶ *<Source> <Summary> <Date>*

Parse tree of the themed grping realtion withing a timeline representation



<Representation> ⟶ <Timeline >

<Timeline > ⟶ <Theme>$_n$

<Theme> ⟶ <Information Object Surrogate>$_n$

<Information Object Surrogate> ⟶ <Source> <Summary> <Date>

Appendix C: Third Study (CH4)

Appendix C.1: Consent Form

MIDDLESEX UNIVERSITY

PARTICIPANT SHEET (PIS)

1. Study title

An Instrument for Measuring Sensemaking: Validation Study.

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

3. What is the purpose of the study?

The study measures participant's levels of understanding of certain activities subjectively.

4. Why have I been chosen?

You *have been chosen* because you are *performing a sensemaking activity (an activity that needs you to build an understating).*

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. If you do decide to withdraw from the study then please inform the researcher as soon as possible, and they will facilitate your withdrawal. If, for any reason, you wish to withdraw your data please contact the researcher within a month of your participation. After this data it may not be possible to withdraw your individual data as the results may have already been published. However, as all data are anonymised, your individual data will not be identifiable in any way

6. What will I have to do?

The task for you will be to fill out a questionnaire at the end of this session.

7. What are the possible disadvantages and risks of taking part?

Appropriate risk assessments for all procedures have been conducted, and will be followed throughout the duration of the study.

8. What are the possible benefits of taking part?

We hope that participating in the study will help you. However, this cannot be guaranteed.

9. Will my taking part in this study be kept confidential?

The research team has put a number of procedures in place to protect the confidentiality of participants. Your name or other personal details will not be associated with your data. All paper records will be stored in a locked filing cabinet, accessible only to the research team, and all electronic data will be stored on a password protected computer. All information you provide will be treated in accordance with the UK Data Protection Act.

10. What will happen to the results of the research study?

The results of the research study will be used as part of a Postgraduate thesis. The results may also be presented at conferences or in journal articles. However, the data will only be used by members of the research team and at no point will your personal information or data be revealed.

11. Who has reviewed the study?

The study has received full ethical clearance from the Research ethics committee who reviewed the study.

12. Contact for further information

If you require further information, have any questions or would like to withdraw your data then please contact:

Kholod Alsufiani
K.Alsufiani@mdx.ac.uk

Thank you for taking part in this study. You should keep this participant information sheet, as it contains your participant code, important information and the research teams contact data

Appendix C.2: Sensemaking Questionnaire: New version (CH4)

Please mark on one of the vertical lines bellow to indicate your answer.

To what extent do you think you were able to:

1. **Construct an understanding from the available information?**

To a small extent | | | | | | | | | | | To a large extent

2. **Gain insight from the available information**?

To a small extent | | | | | | | | | | | To a large extent

3. **Make sense of the available information?**

To a small extent | | | | | | | | | | | To a large extent

4. **Draw a link between the available information and things you were aware of already?**

To a small extent | | | | | | | | | | | To a large extent

5. **Draw a link between information you encountered and your prior knowledge?**

To a small extent | | | | | | | | | | | To a large extent

6. Develop a coherent view of the information?

To a small extent | | | | | | | | | | | To a large extent

7. Find structure in the information?

To a small extent | | | | | | | | | | | To a large extent

8. Find a way to (mentally or otherwise) organise the information?

To a small extent | | | | | | | | | | | To a large extent

9. Understand connections between things?

To a small extent | | | | | | | | | | | To a large extent

10. Discover where the gaps are in how you understand a situation?

To a small extent | | | | | | | | | | | To a large extent

11. Bridge gaps in your understanding of a situation?

To a small extent | | | | | | | | | | | To a large extent

12. Reduce any confusion?

To a small extent | To a large extent

13. Reduce any ambiguity?

To a small extent | To a large extent

Appendix D: Fourth Study (CH5)

Appendix D.1: Study 4: Participant Information Sheet

MIDDLESEX UNIVERSITY

PARTICIPANT SHEET (PIS)

Participant ID Code:……………………………………………

1. Study title

A new way (paradigm) of measuring sense-making.

2. Invitation paragraph

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

Thank you for reading this.

3. What is the purpose of the study?

The aim of this study is to establish a new way (paradigm) of measuring sense-making. The study will investigate the impact of information structuring on the performance of the quality of the user's queries, as proxies for sensemaking

4. Why have I been chosen?

It is important that we assess as many participants as possible, and you have indicated that you are interested in taking part in this study. The main criteria of the invited participants are to be a postgraduate student, as postgraduate students have enough experience with information seeking and documents triage.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason. If you do decide to withdraw from the study then please inform the researcher as soon as possible, and they will facilitate your withdrawal. If, for any reason, you wish to withdraw your data please contact the researcher within a month of your participation. After this data it may not be possible to withdraw your individual data as the results may have already been published. However, as all data are anonymised, your individual data will not be identifiable in any way.

6. What will I have to do?

The task is to perform a mock investigation using a collection of documents. The task will involve constructing queries over a data set, searching for documents, and reviewing the results to decide on individual document relevance (document triage). There is a single independent variable (structure) with two levels (structuring vs non-structuring). You will be either structure the documents using OneNote software (structuring condition, time-based) or simply put the documents into a folder (non-structuring condition)

Please note that in order to ensure quality assurance and equity this project may be selected for audit by a designated member of the committee. This means that the designated member can request to see signed consent forms. However, if this is the case your signed consent form will only be accessed by the designated auditor or member of the audit team.

7. What are the possible disadvantages and risks of taking part?

Appropriate risk assessments for all procedures have been conducted, and will be followed throughout the duration of the study.

8. What are the possible benefits of taking part?

We hope that participating in the study will help you. However, this cannot be guaranteed. The information we get from this study may help us to investigate the impact of information structuring on both the performance of the document triage process, user engagement and the quality of the user's queries, as proxies for sensemaking. Where there is no intended benefit to the participant from taking part in the study.

9. Will my taking part in this study be kept confidential?

The research team has put a number of procedures in place to protect the confidentiality of participants. You will be allocated a participant code that will always be used to identify any data you provide. Your name or other personal details will not be associated with your data, for example, the consent form that you sign will be kept separate from your data. All paper records will be stored in a locked filing cabinet, accessible only to the research team, and all electronic data will be stored on a password protected computer. All information you provide will be treated in accordance with the UK Data Protection Act.

10. What will happen to the results of the research study?

The results of the research study will be used as part of a Postgraduate dissertation. The results may also be presented at conferences or in journal articles. However, the data will only be used by members of the research team and at no point will your personal information or data be revealed.

11. Who has reviewed the study?

The study has received full ethical clearance from the Research ethics committee who reviewed the study.

12. Contact for further information

If you require further information, have any questions or would like to withdraw your data then please contact:

Kholod Alsufiani

K.Alsufiani@mdx.ac.uk

Thank you for taking part in this study. You should keep this participant information sheet as it contains your participant code, important information and the research teams contact details

Appendix D.2: Study 4: Uncertainty Questionnaire

Please mark on one of the vertical lines bellow to indicate your answer.

1- I felt I didn't know where to go next.

Strongly disagree Strongly agree

2- I felt I needed help.

Strongly disagree Strongly agree

3- Under this condition, the search results were difficult to understand.

Strongly disagree Strongly agree

4- I found myself going round in circles.

Strongly disagree Strongly agree

5- I found the search under this condition confusing.

Strongly disagree Strongly agree

6- I often felt lost during the session.

Strongly disagree Strongly agree

7- At the end of the search session I felt uncertain.

Strongly disagree Strongly agree

8- The way of organising documents under this condition didn't tell me enough to know if what I was seeing was really relevant.

Strongly disagree Strongly agree

9- I wasn't sure whether what I was looking for was in the collection or not.

Strongly disagree Strongly agree

10- I found it difficult to keep track of what I was finding.

Strongly disagree Strongly agree

11- By the end, I was running out of ideas for new queries.

Strongly disagree Strongly agree

12- I was frustrated because I knew what I wanted but I couldn't get to it.

Strongly disagree Strongly agree

13- I found it difficult to cope with the sheer volume of material I was looking through.

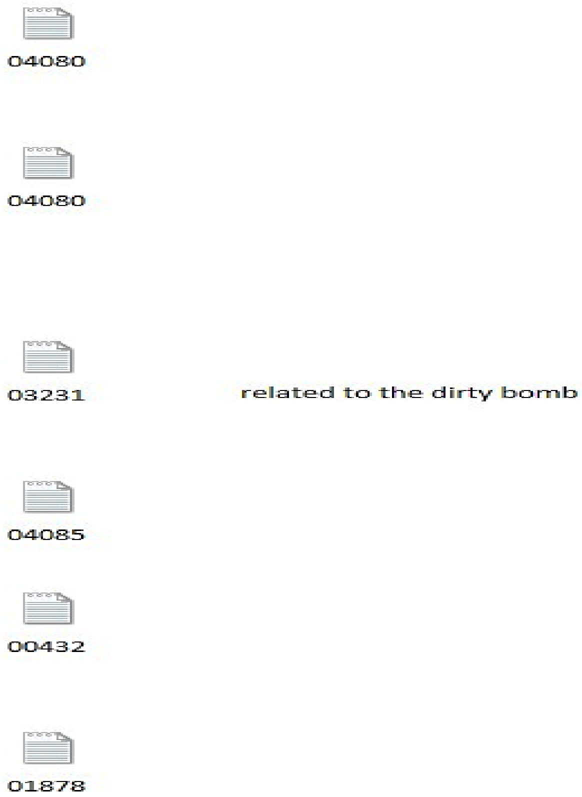
Strongly disagree Strongly agree

14- I knew what I wanted but I couldn't see how to get there.

Strongly disagree Strongly agree

Appendix D.3: Study 4: Participants' external representations

P1



P2

Animals Mass deaths

02385

April 1 2011
Mass deaths of livestock have been reported on farms a short distance outside of the Vastopolis metropolitan area

the investigation into the deaths is ongoing. ``The issue now is cleanup" he said. ``We also need to test the soil and feed for contamination.``

04080

April 14, 2011
Suspicions about the mass livestock deaths on April 1 have been raised today. Police detective Beatrice Brothers was investigating witness accounts that several suspicious individuals were trespassing at farms where the mass livestock deaths were reported. Brothers says that no trespassers have been identified yet. It seems very odd that so many trespassers were seen at these sites after the deaths. Multiple farmers were questioned if they had received any threats recently. All the farmers stated they knew of no one with ill will against them or their livestock.

Terror threat

04035

March 29, 2011
Vastopolis -- Mayor Douglas Lark ordered the creation of a commission to recommend laws and regulations to protect vital government and private systems against attacks by terrorists or computer hackers. On the national level, he described the effort as having the ``same level of urgency"

01088

April 10, 2011
The Police Commissioner said these exercises have become necessary in modern times. He stated that years ago there wasn't much to worry about with this kind of stuff, but with terrorist groups nowadays everyone needs to be prepared. Lucio said that schools would go through drills as well so the children would be ready, as the schools can be considered targets for terrorist groups.

Police Commissioner Jacob Lucio announced that Vastopolis would conduct dirty bomb training exercises in June. These exercises would include not just the police department, but also every emergency service.

04080

April 25, 2011
Jose Thom is a renowned author and terrorism expert. Today, he spoke out with a stern piece of advice to Vastopolis city officials.Thom's warning: the efforts of our officials to protect the residents against well-organized and well-funded terror groups are inadequate. Thom stated that we are potential victims of groups such as Paramurderers of Chaos, Network of Hate, and the Order of the Plague. An issue primarily lacking is the education necessary to prepare the residents for an event.

00432

May 09, 2011
Highly reliable sources report that city administration officials of Vastopolis were receiving threats now on a daily basis by a group of anti-government extremests calling themselves Anarchists for Freedom. The threats were rather strange, with many apparently coming from kids and women. Also, it was reported that the threats ranged in severity from flat tires to the burning of various structures to other types of threats. Our sources would not elaborate. It was learned that Special Agent Roy Wicker of the Federal Bureau of Investigation was assigned to investigate. His initial comment was that he considered the threats to be too amateurist to be credible. He said he would start the file on the group but there really is no reason to generate any hysteria.

01878

May 15, 2011
Officials from a food preparation plant in Vastopolis informed Vastpress that an individual was arrested for trespassing near the loading docks shortly after midnight.`Crocker stated that all he knew was that the individual was dressed like a gang member. The investigating officer stated that the colors represented the Paramurderers of Chaos which required intervention by the FBI. We then contacted Special Agent Roy Wicker about the matter. Wicker would only say that the FBI is conducting ongoing investigations of radical groups, like this one, that seem to be springing up in this area.

Flu

May 19, 2011
Vastpress hospital correspondent Janean Richardson has detected a swift increase in flu patients this year in Vastopolis. Local health official Nicole Barns was contacted for comment.

03295

P3

2-2-2002
To coincide with Luthor's announcement, he announced a private investment by the Washen Foundation of $1,000,000 to startup "Boynton Laboratories", to be named after the world-renowned biologist, Dr. Philip Boynton. Dr. Boynton, 85, arrived in Alderwood on Tuesday and stood with Luthor, mayor's aide Laurie Sulfate, council members John Torch, Jennie Angel, and Mayor Pro-tem George Greenway at the press conference in city hall. Luthor also announced $225,000 in matching funds from the state's new biotechnology initiative, and said he is working with the Washington State Legislature to secure an additional $300,000 for the lab, which is set to open this fall..
...wealthy City Attorney Bruce Rinz is heavily vested in this organization, however Rinz did not immediately return phone calls to confirm this.

110124333...

5 May 2002

Gov. Gary Locke joined Mayor Rex Luthor, Dr. Philip Boynton, and the Alderwood City Council in breaking ground for the $25 million Boynton Laboratories facility.

110116335...

4/12/2002
The idea to enter a new housing rehabilitation program came from Gene Weinmann of the Yakima Valley Conference of Governments (COG). COG is currently overseeing the Alderwood Up! housing rehabilitation program for the city.

110116340...

19-3-2003
de la Cruz informed the Council the police department had received a letter from the Federal Bureau of Investigations (FBI). de la Cruz said the Alderwood Police Department was instrumental in capturing a subject who has eluded the FBI since 1996.

110124318...

3/2/2004
Boynton Lab spokesperson Laurel Sulfate told a press conference today that a team of biophysicists at Boynton Laboratories in Alderwood, Washington have
developed a treatment for diseases such as Mad Cow and Kreutzfeldt-Jakob.

110116359...

10-7-2004
City Councilman John Torch exclaimed joyfully last night after the announcement that the Monson family had agreed to sell its 150-acre feedlot to the city.

110116268...

P4

Fredrick J. Partinl
Sulfa drug? What is it? Can it kill livestock?

Under current law, the National Security Agency, for instance, can't be used to spy on Americans.

03740 Suspicious people

03212 Keep an eye of the group that has been harassing Prof. Edward Patino.

00947 Security in Vastopolis airport

00062 Not through airport.

04073 Easy access to transports.

03040 The CDC believes that the food supply has the highest probability of being a bioterrorism target due to ease of dissemination. They say that targeting the food supply allows for widespread consumption by the populace that can be difficult to identify until it is too late.
"Check transportation of food supplies"

City Threat Level Increased

Department of Homeland Security has raised the threat level around the country, including Vastopolis. The press release confirms an increase threat of an attack on the city. Specifics were not given. At this time, this information is classified. In a related release, Mayor Douglas Lark is urging all residents of Vastopolis to report suspicious activity to authorities. He emphasized that citizens do not take matters into their own hands. ``It is too dangerous. These terrorists are specifically trained to protect their own objectives'', he stated.

THREAT LEVEL HAS BEEN RAISED IN VASTOPOLIS.

P5

Beatrice brothers - police detective

Department of Agriculture Official - Tony Grenier

Jose Thom - terrorism expert

Special Agent Roy Wicker - FBI

03785
Plane crash where?

02385

food shortage

need to test the soil and feed for contamination

03740

Witnesses: several suspicious individuals were trespassing at farms

No specific threats to farmers

10

04080

Terrorist Groups such as Paramurderers of Chaos, Network of Hate, and the Order of the Plague

03435

three people arrested, suspected to be part of a homegrown terror cell, Paramurderers of Chaos.

01878

One arrested for trespassing near the loading docks

Cornertown

Samuel Stansbury arrested

Network of Hate

02395

Flu out of control this year

03295

Anarchists for Freedom
too amateurist to be credible (FBI)

00432

P6

110124258...

Target:
The Washington Utilities and Transportation Commission staff and PacifiCorp agreed to a settlement of a $15.5 million annual revenue increase on Aug. 24, 2004.

Consequence:
Bill Douglas said that if the commission feels PacifiCorp should be allowed the increase or the settlement it would not be too much.
Douglas said rate increases have not kept up with inflation.

Analysts background

Reason:
Following record levels of growth, the "dotcom" industry collapsed. After the terrorist attacks of 9/11/2001, the teetering US economy entered a recession, heavily impacting the technology sector, raising unemployment levels in California, Oregon, and Washington to uncomfortably high levels. Tourism to many parts of the region dropped off severely.

110116388...

1. Alderwood voters are misrepresented in his paper due to his unethical, journalistic tactics of attempting to MAKE the news rather than report it.
2. Bob Story's policy of "front page editorials," where he unethically presents his opinion in hopes that it will be conceived by the public as fact, has unfortunately left the community of Alderwood with no credible local source of information regarding our local politics.

Person: Bob
Source: Front Page Editorials

P7

110116335...

Political wags in Alderwood are excitedly discussing the impact of steamy photos taken of Mayoral democratic candidate John Torch with an unidentified young brunette woman late one evening at a Tri-Cities Starbucks. Torch, married with 4 children, has not commented on the incriminating pictures. Hawk Press has obtained copies of these pictures, but following company policy, will not publish them.

Incumbent mayor Rex Luther characterized the scandal as "unfortunate". "Moral values are key to anyone wishing to assume a position of leadership and responsibility," he added.

Sources have identified the woman as an employee of Boynton Laboratories. Laurel Sulfate, spokeswoman for the laboratory, was unavailable for comment, currently vacationing in Switzerland. An assistant to Sulfate stated that she "will look into the matter upon her return."

110116294...

By comparison, challenger John Torch has raised only $33,000 and spent $10,634. Since the recent Starbucks scandal, Torch has all but disappeared from the mayor race.

Analysts background

A not-so-reliable source has stated that high-paying, high-tech employment is now "a sure thing" in Alderwood, and it's all supported by "the high-rolling big boys at City Hall". Another informant overheard that "if you support the bosses, the bosses will look after you."

110116397...

FDA cancels investigation

Story by: Mel Sacher

Date Published to Web: 6/19/2004

Boynton Laboratories spokesperson Laurel Sulfate announced today that the FDA has discontinued its investigation of the Alderwood institution. "The FDA informed us it was not pursuing its investigation of the laboratory, and that no operational modifications or impacts are imposed. We see this as a complete vote of confidence in the critical work Boynton is doing for the nation," said Sulfate.

Phone calls to Dr. Boynton, lab director, or Dr. VonRyker, chief scientist, were not returned. It is believed VonRyker is currenly in Paraguay performing experimental field tests on infected cattle in that country.

P8

02923

high pricings in feeding cattle (cows and other big animals)

Vastpress articles
tractor

04073

Agriculture

00699

subisdies

BSE in Europe. People worried for it to pass to lambs (5 april). Authorities says there`s no reason to panic .

02370

Beef crisis in march

Posilac - feeding for cows t

00055

o produce more milk
some say it is dangerous for humans.

Seems like Monsanto is not selling this hormone as much as they predicted. But, little farmers are worried about a loss in the price of milk

April 1: mass dea

02385

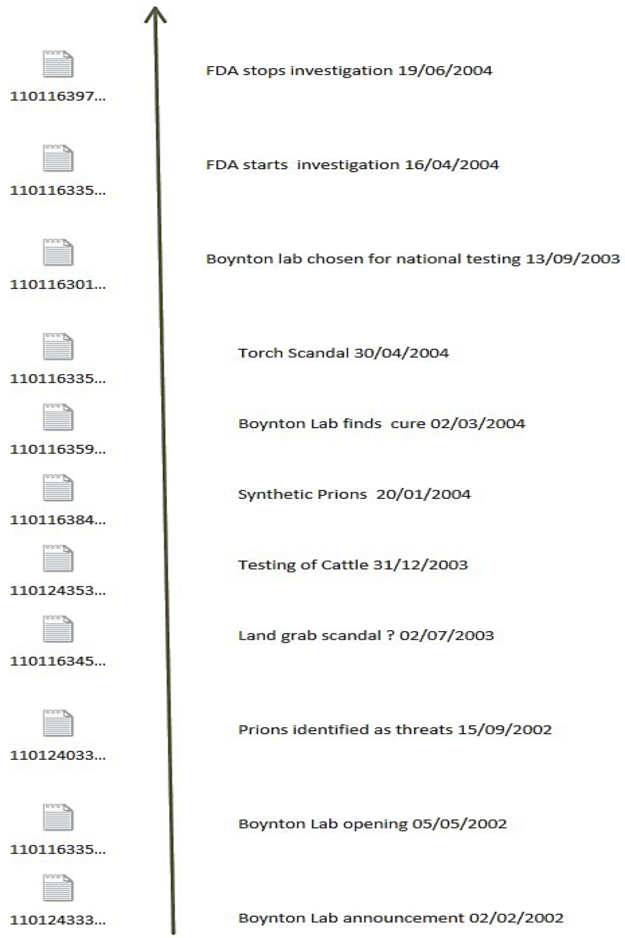
th reported. They also say they are investigating on 1) soil, 2) currently available food

April 14: witnesses says they have seen suspiscious guys trespassing their p
roperties after the deaths

03109

May 19: flu season out of control

P9


110116397...
FDA stops investigation 19/06/2004
110116335...
FDA starts investigation 16/04/2004
110116301...
Boynton lab chosen for national testing 13/09/2003
110116335...
Torch Scandal 30/04/2004
110116359...
Boynton Lab finds cure 02/03/2004
110116384...
Synthetic Prions 20/01/2004
110124353...
Testing of Cattle 31/12/2003
110116345...
Land grab scandal ? 02/07/2003
110124033...
Prions identified as threats 15/09/2002
110116335...
Boynton Lab opening 05/05/2002
110124333...
Boynton Lab announcement 02/02/2002

P10

Analysts background

Alderwood crisis
the FBI is tipped off to possible political shenanigans in the mid-sized vacation town of Alderwood, located on the banks of the Alderwood River in south-central Washington State. Alderwood was having problems resulting from the 'dot-com' crash: The usual vacationers and tourists, most of whom were dependant upon the technology industry for their (quite substantial) income, suffered economic setbacks from the dot-com crash, resulting in reduced vacationing and tourism for the Alderwood recreation industry. To make matters worse, routine testing at a local farm discovered bovine spongiform encephalitis (BSE, also known as 'mad cow disease") sending the remains of the local economy into a tailspin due from resulting beef import embargo imposed by the Food and Drug Administration (FDA), and several foreign nations. It's been a dismal scene.
Its fine water quality and lovely countryside is renown throughout the region. The rural area surrounding Alderwood was supported by the beef and dairy cattle industry. In addition to the tourism decline, a mad cow was discovered at a local ranch creating additional grief. The incident severely damaged beef sales, both nationally and internationally (with multiple foreign nations prohibiting US beef imports for the next seven years), resulting in a further depressed economy.

110116330...

Van Belle, who was selected as the Alderwood Chamber of Commerce's Outstanding Agri-business Person this past March, said his grandfather homesteaded the farm on Van Belle Road, located north of Alderwood. Van Belle was born in Alderwood and grew up in the Liberty area, near Granger. Cliff Van Belle can see the fruits of several generations of farmers who have tilled the land on property that has been in his family more than 80 years.

Analysts background

One piece of good news is the recent unexpected opening of a new private laboratory facility specializing in agri-business. A famous scientist has relocated to Alderwood to run it, and the residents hoped this could be the locus of a business renaissance.

03295

a sudden influx of young talented men and women relocating to Alderwood has caused a stir. A not-so-reliable source has stated that high-paying, high-tech employment is now "a sure thing" in Alderwood, and it's all supported by "the high-rolling big boys at City Hall". Another informant overheard that "if you support the bosses, the bosses will look after you."

110116260...

As one of the newest members of the Alderwood Noon Rotary Club, Rob Crum is learning his way around the group of Alderwood business owners and community professionals. Monday, the club members had an opportunity to learn a bit more about the third generation Eastern Oregonian, who is now the manager of the Alderwood branch of the Farm Credit Service. A recent graduate of Oregon State University, Crum has been in Alderwood for the past nine months, offering lines of credit to area farmers and agriculture-related businesses.

03295

. Crum said he sees his job as a way to help maintain the security of the nation's food supply. "We help to keep agriculture in America," Crum said. He said the Alderwood branch of the Farm Credit Service is part of the Northwest Farm Credit Service, which is one of five credit unions located throughout the United States. Crum said in addition to offering farmers low interest lines of credit for their farming operations, the Farm Credit Service also offers farm business classes for young farmers, incentives for staying in farming and low interest housing loans.

110116335...

Gov. Gary Locke joined Mayor Rex Luthor, Dr. Philip Boynton, and the Alderwood City Council in breaking ground for the $25 million Boynton Laboratories facility. More than 200 people attended the event, held on the site of the new building at the Boynton campus in Alderwood. "This remarkable facility is another example of our overall commitment to protect, preserve and restore the safety of our food and the health of Americans across the land," said Governor Locke. "Just imagine what this tremendous new facility will mean for Washington's future. We know the scientific breakthroughs that will be achieved here will further our understanding of fundamentals of biology and help us develop the necessary methods for curing mad cow disease."

110116301...

The government has chosen Boynton Laboratories to help test for mad cow disease.

Alderwood has one of five new laboratories authorized Tuesday by the U.S. Department of Agriculture Animal and Plant Health Inspection Service. The new labs will work with seven others approved in March.

"This further solidifies Boynton as a national and world leader in animal disease and research," said spokesperson Laurel Sulfate.

The labs will use rapid tests approved by Agriculture Department, which has a goal of testing 220,000 or more animals by the end of 2005.

"This approval will place us in the front line of the nation's war on animal disease and will be a key component in the constant surveillance to determine threats such as BSE," lab director Dr. Philip Boynton said.

110116384...

Scientists at Boynton Laboratories have produced a prion protein that can trigger the development of a neurological disorder in mice that is similar to "mad cow" disease, according to a new study announced by the Alderwood institute. The findings demonstrate that prions, an unusual class of infectious proteins, can make copies of themselves without the presence of viral DNA or RNA, damage brain tissue, and cause neurological diseases.

The breakthrough by Dr. Philip Boynton, and colleagues Dr. A. VonRyker and Dr. D. Sanderson, was announced by Boynton spokesperson Laurel Sulfate and is scheduled to be published in an first-tier publication.

For the study, Dr. Boynton and his colleagues produced prion protein fragments in bacteria, folded them into larger protein structures called amyloid fibrils, and then injected them into the brains of susceptible mice. The mice began exhibiting symptoms of disease in their central nervous systems.

The amyloid form of the prion protein, which is thought to cause prion disease, was also found in the brains of the diseased mice. The researchers then administered brain extracts from these animals to another group of mice, which subsequently developed similar symptoms 90 to 150 days later. The disorder seems to be distinct from that caused by other known strains of prions, suggesting that the synthetic prion didn't merely activate a pre-existing prion in these mice and that the synthesized prion protein itself is sufficient to make infectious and disease-causing prions.

110124353...

4 Under the newly announced slaughter regulations announced by U.S. Secretary of Agriculture Ann M. Veneman Tuesday, rapid testing will be used to test animals for bovine spongiform encephalopathy (BSE), commonly known as mad cow disease.

According to Dr. Ron DeHaven, Chief Veterinarian for the United States Department of Agriculture, they have already discussed using one of the several rapid tests available in Europe.

"Theoretically, the plan as we have developed it thus far would suggest that we would obtain the samples, whether they be at rendering plants or on the farm. Those samples then would be sent by overnight express to our laboratory to be received in the neighborhood of 10 a.m. the next morning," said DeHaven.

The samples would then be tested at Boynton Labs in Alderwood, with the results completed by the end of the day. He said if everything goes perfectly, assuming tests are negative, the results would be sent out the afternoon or early evening the day after they were first received.

DeHaven said that they are building in some flexibility in the scheduling. He said they expect that the test results will be back to slaughter houses within 36 to 48 hours.

"There's always the possibility that there could be complications in the laboratory," said DeHaven.

He added that for those animals that test positive, the carcasses would continue to be held pending further testing.

Animals testing positive would not be used in any fashion, including to make animal food or cosmetics, he said.

03740

When the US Food and Drug Administration (FDA) announced it was beginning an investigation of Alderwood's Boynton Laboratories, a pioneering prion research lab yesterday, the timing seemed a bit off.

British researchers had just identified a second case of variant Creutzfeldt-Jakob disease (vCJD) transmitted through a blood transfusion. The UK Medical Research Council is set to launch a trial of potential vCJD treatments, but there are no such trials in the US. A report released last winter by the National Academy of Sciences says the US research program on prion diseases is "small, aging, and inadequately funded, except with a possible shining star in new Boynton Laboratories..."

The FDA quickly responded that the lab's investigation is meant to address scientific concerns, not exacerbate political ones. Boynton Laboratories, founded in 2002, is focused on finding cures for prion diseases, says Laurel Sulfate, spokeswoman for the institution. Alderwood Mayor Rex Luthor called the investigation "outrageous" and called for the FDA to become "a partner in progress, not a bureaucratic impediment to the nation's health and well-being."

110116359...

Boynton Lab spokesperson Laurel Sulfate told a press conference today that a team of biophysicists at Boynton Laboratories in Alderwood, Washington have developed a treatment for diseases such as Mad Cow and Kreutzfeldt-Jakob.

Led by laboratory director Dr. Philip Boynton, and his chief scientists Drs. A. VonRyker and D. Sanderson, the scientists state that by exploiting a unique quality of these so-called "prion diseases"--that they do not infect all species equally--a prion inhibitor has been developed that stops the progress of the disease. The treatment has successfully been given to infected cattle in Brazil, where infections have been kept quiet until now.

110116397...

Boynton Laboratories spokesperson Laurel Sulfate announced today that the FDA has discontinued its investigation of the Alderwood institution. "The FDA informed us it was not pursuing its investigation of the laboratory, and that no operational modifications or impacts are imposed. We see this as a complete vote of confidence in the critical work Boynton is doing for the nation," said Sulfate.

Phone calls to Dr. Boynton, lab director, or Dr. VonRyker, chief scientist, were not returned. It is believed VonRyker is currenly in Paraguay performing experimental field tests on infected cattle in that country.

P11

May 1 2011
Department of Homeland Security Agent Samuel Turman

00383

Antiterrorist Plan Is Unveiled To Assure Safe Air Travel
May 19, 2011

00197

Although federal investigators haven't settled on a cause of the March 29, 2011 of a Antarctica Airlines jet over the Atlantic, the catastrophe sent the administration scurrying to improve aviation safety and security.

The commission also recommended that airports implement ``full baggage match'' programs to ship baggage only if the baggage's owner has boarded the flight. While this policy is basically in place on international flights it hasn't been fully implemented and sometimes misses bags that are transferred between airlines

00790

President's Speech : codi
May 12, 2011

SECURITY PLAN

Flu Season Hits Hard
May 19, 2011
Vastpress hospital correspondent Janean Richardson has detected a swift increase in flu patients this year in Vastopolis.

03295

Livestock Art Is Trendy Again: Maybe a Cow Over the Couch?
May 19, 2011

More livestock art will be on display at the San Francisco Fall Antiques Show opening July 06, 2011 Peers

Lonodn art dealer Ira Josephine

04139

Mass Animal Deaths
April 1, 2011
Mass deaths of livestock have been reported on farms a short distance outside of the Vastopolis metropolitan area. Officials are unsure of the cause at this time.
According to Department of Agriculture Official Tony Grenier, the investigation into the deaths is ongoing. ``The issue now is cleanup'' he said. ``We also need to test the soil and feed for contamination.`

02385

May news

Animal Deaths in City Caused by Microbes
April 20, 2011

The city has received a report from the Department of Agriculture on the deaths of farm animals outside Vastopolis. These animals were autopsied for cause. The report from the department's official Roxanne Faison further shows that a spore-forming microbe was the problem. She emphasizes that the discovered variant is not a threat to humans, asserting: ``We have seen this before and are proceeding with cleanup efforts on the farms affected as an extra precaution''.

04085

Update on Animal Deaths
April 14, 2011

Police detective Beatrice Brothers was investigating witness accounts that several suspicious individuals were trespassing at farms where the mass livestock deaths were reported.

One nearby resident commented that they may just be sick individuals who wanted to see the carnage.

03740

P12

Alderwood - town
Mayor Rex Luthor
Scientist relocated to run it - Dr. Philip Boynton

02/02/2002 - new biotechnology laboratory - Boynton Laboratories

January 2003 - possible political dishonest activities

NEW LABORATORY:

private investment by the **Washen Foundation** of $1,000,000

Luthor, mayor's aide **Laurie Sulfate**, council members **John Torch**, **Jennie Angel**, and Mayor Pro-tem **George Greenway** at the press conference in city hall.

Set to open on **fall**

110124333... 8

May 2002

Gov. **Gary Locke** joined

110116335... 1

15/09/2002

Laboratory founded

110124033... 2

07/02/2003

rumors suggest Swiss developers have expressed acute interest in the new waterfront Alderwood properties

110116345... 5

11/02/2004

Grandview fake checks

110124247... 5

3/2/2004

Breakthrough in mad cow disease

110116359... 1

16/04/2004

FDA starts investigation of Boynton
Mayor Rex Luthor against it

110116335... 5

30/04/2004

John Torch and Laurel Sulfate scandal

Laurel Sulfate vac. In Switzerland

110116335... 7

19/06/2004

FDA cancels investigation

Dr. VonRyker?

110116397... 5

24/08/2004

Republican booster (50,000) to Rex Luthor campaign,

John Torch also running - raised 33,000 , spent 10,634

110116294... 6

P13

02385 Initial report on the livestock deaths 5
The consequent effects on the economy and farmers

03740 Police are aware of the situation but no suspects as of yet 8

00129 VastPress receives threats possible from terrorists 9

04035 Mayor of Vastopolis trying to defend his state against terrorism in the future 8

03895 Discussion of terrorist attacks in Saudi Arabia 4

03667 Accusations of money being spent on terrorism 1

03262 Maoist Shining Path guerrillas 1

03229 Hijacking used to be a common threat 1

02967 Dangerous encryption software could be used against the government 9

02902 Vietnamese intruders causing harm after breaking into a property 4

03295 Reports of flu season in Vastopolis 5

04299 Bombings between Bosnia, Croatia and Serbia 1

04085 Animals dying from microbes 9

02370 Concern of a new mad sheep disease 6

P14

Alderwood Fire Chief Jim Stanton reported to the City Council this past Monday night on the status of the city's new fire truck.

Stanton reported that the city should have access to the fire truck purchased in partnership with Alderwood County by the end of April.

110124318...

When Kara Kondo was a young girl she was taken from her home, forced to give up nearly all of her possessions and was escorted to a train by armed soldiers for a long trek to a concentration camp she would call home.
The only crime she committed was living on the west coast of the United States

"It was a small community within a larger community," she said.

Japanese immigrants couldn't speak English,

110116296...

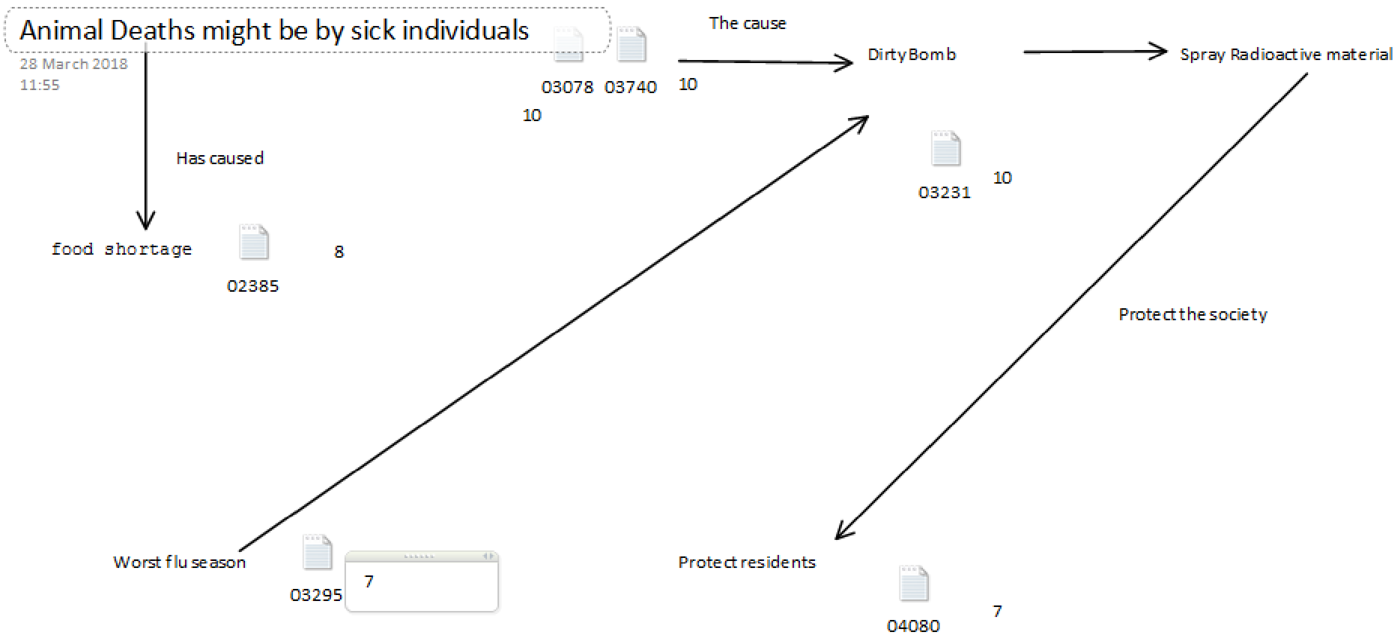
This is especially important for low income and minority students, too many of whom have fallen through the cracks in our public education system over the years.

110116250...

"We want people to remember one thing - never leave a child unattended in a car," said Joan Sharp, executive director of the Council.
Students shouldbe allowed to defend themselves

110116278...

P15



Animal Deaths might be by sick individuals
28 March 2018
11:55
03078
03740
10
The cause
10
DirtyBomb
Spray Radioactive material
03231
10
Has caused
food shortage
02385
8
Protect the society
Worst flu season
03295
7
Protect residents
04080
7

P16

110116250...

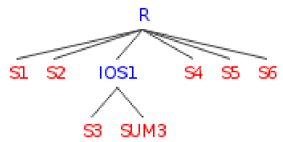
Gambling activity and money handling by non officials 102904

110124298...

Officials for the state's Unlicensed Practice Program said Esparza has been convicted of criminal impersonation. Maria L. Mendoza nursing asistant has been charged with unprofessional conduct on charges of possessing stolen property. . Tammy Trump Charges against Trump include diverting controlled substances for her own non-therapeutic use and showing signs of impairment at work. (50803.

Appendix D4: Study 4: Parse trees of participants' external representations

P1



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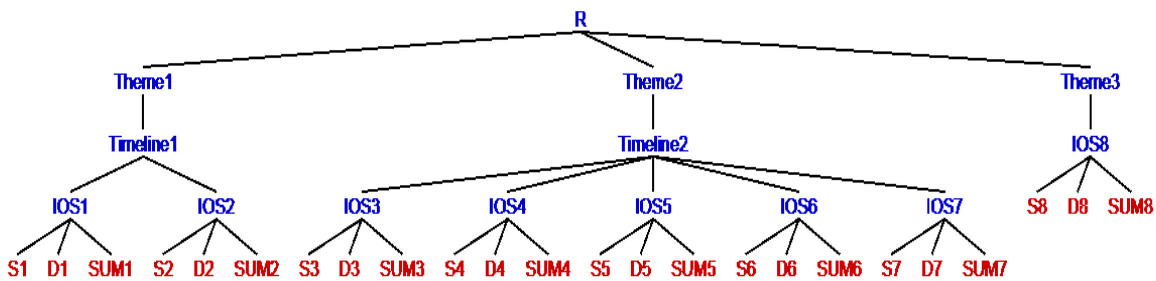

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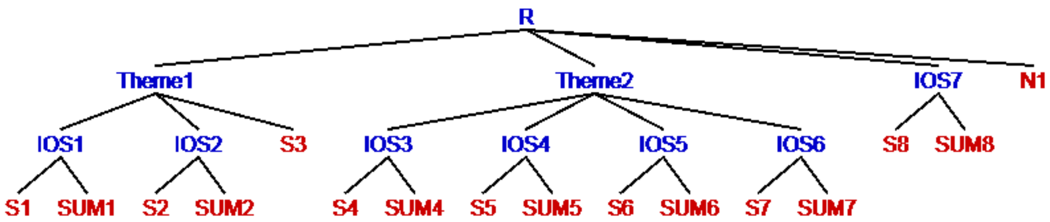

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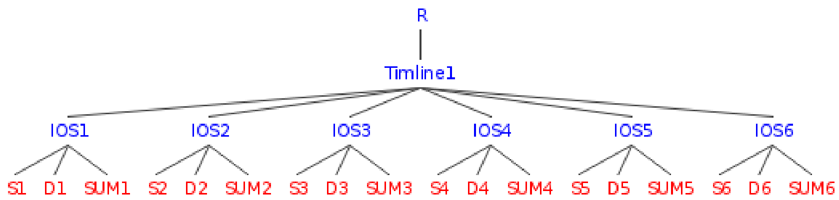

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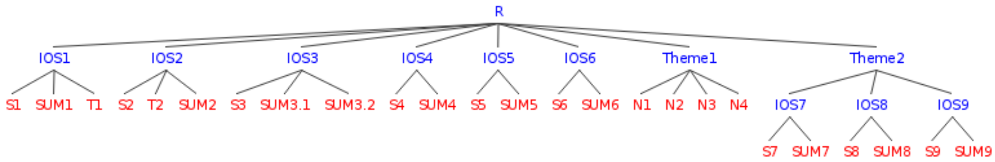

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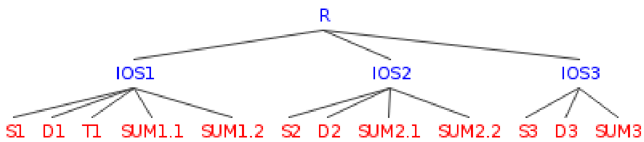

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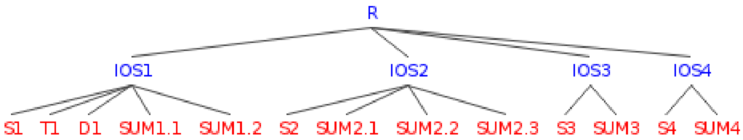

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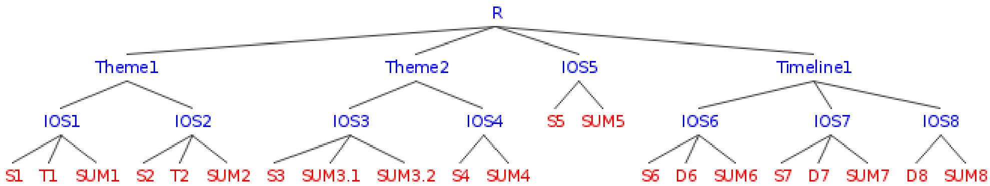

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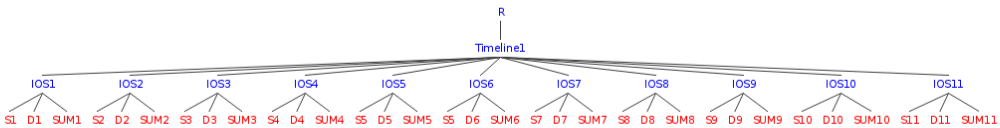

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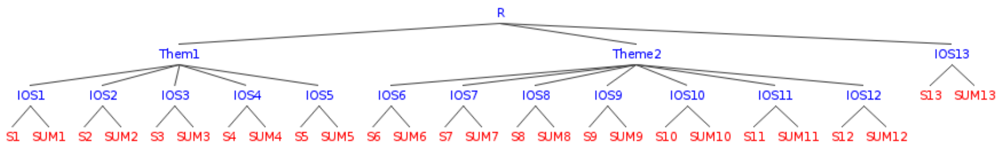

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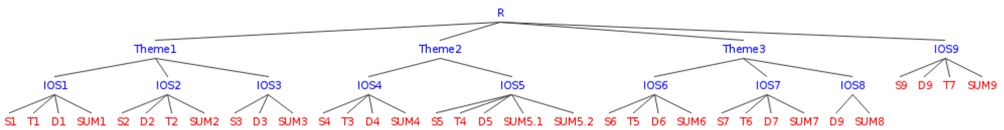

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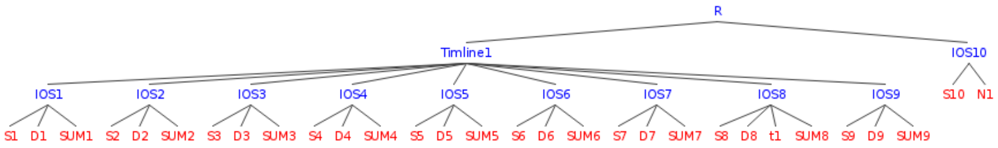

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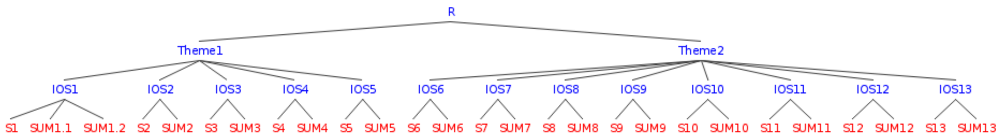

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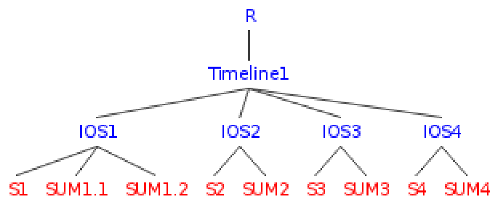

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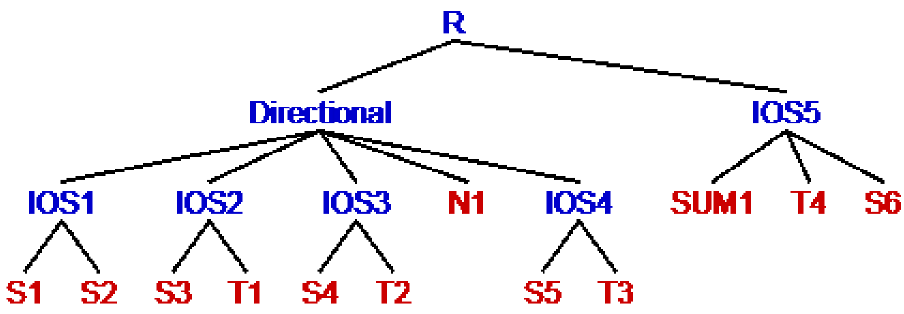

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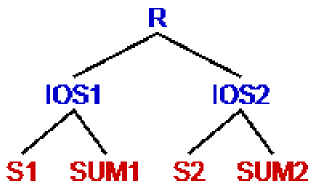

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Appendix E: Normality test

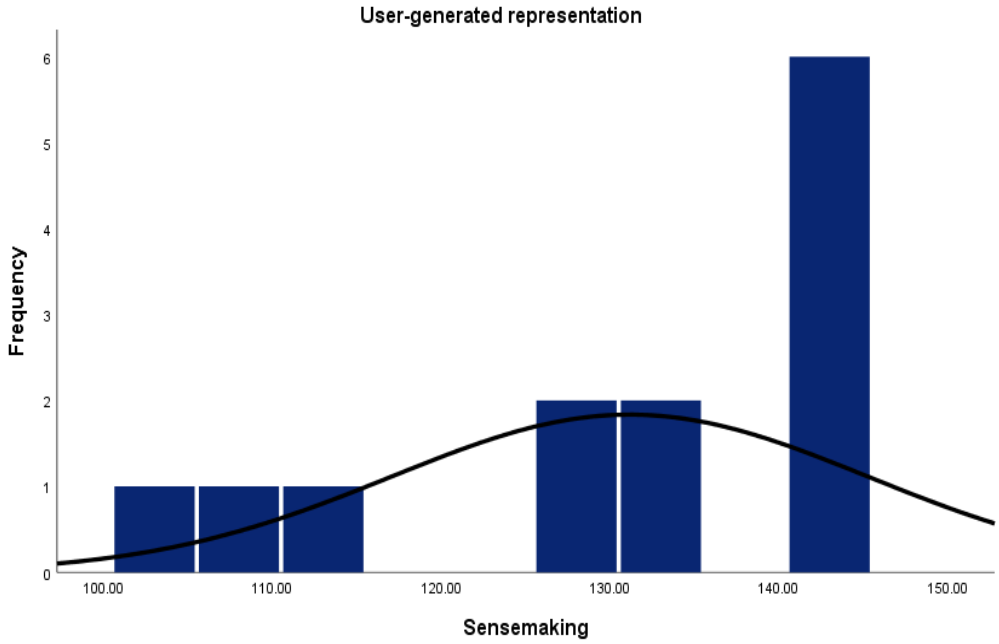
Appendix E.1: normality result from the first study CH3.

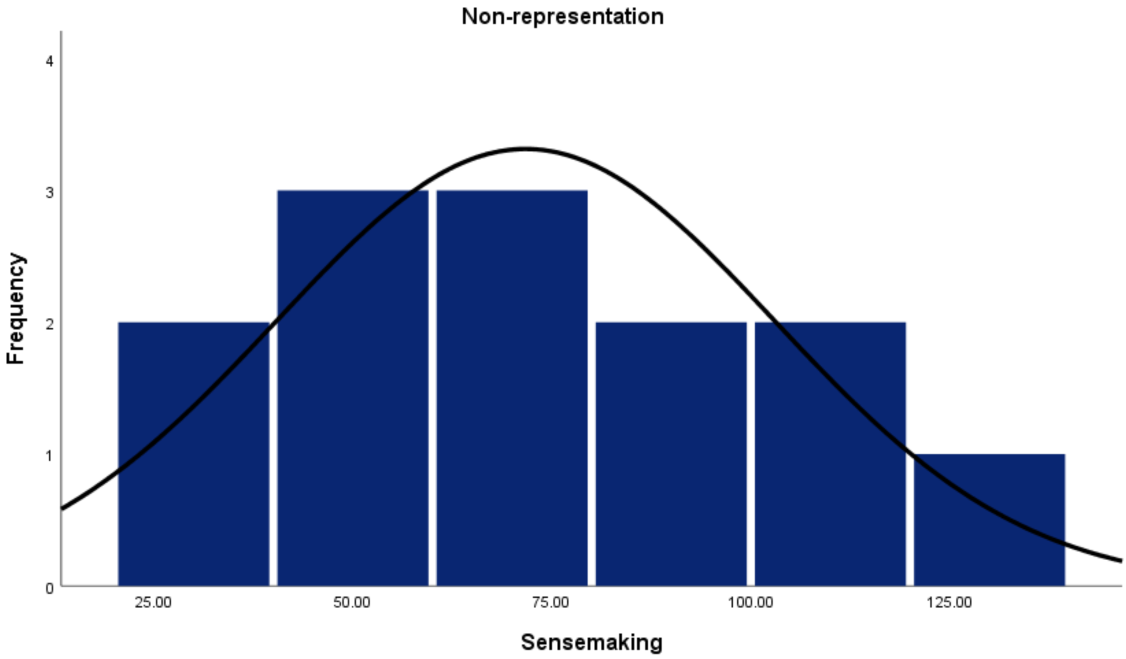
Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
User-generated representation	.240	13	.039	.850	13	.028
Non-representation	.111	13	.200*	.973	13	.923

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction





Descriptive Statistics

	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
User-generated representation	13	-.963	.616	-.271	1.191
Non-representation	13	.320	.616	-.759	1.191
	13				

Appendix E.2: normality result from the fourth study CH5.

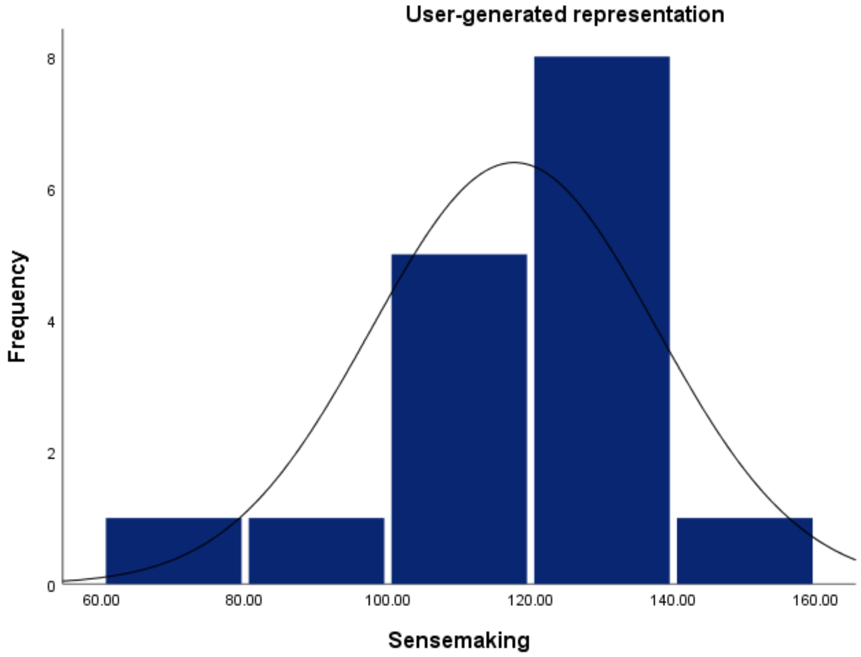
	N	Skewness		Kurtosis	
	Statistic	Statistic	Std. Error	Statistic	Std. Error
Sensemaking_ User-generated representation	16	-1.624	.564	3.010	1.091
Sensemaking_Non-representation	16	.485	.564	-.932	1.091
Uncertainty_ User-generated representation	16	.658	.564	.145	1.091
Uncertainty_Non-representation	16	-.921	.564	.111	1.091
Keyword-Novelty_User-generated representation	16	-.186	.564	-.593	1.091
Keyword-Novelty_Non-representation	16	.466	.564	-.979	1.091
Structuredness	16	1.284	.564	1.257	1.091
Valid N (listwise)	16				

Tests of Normality

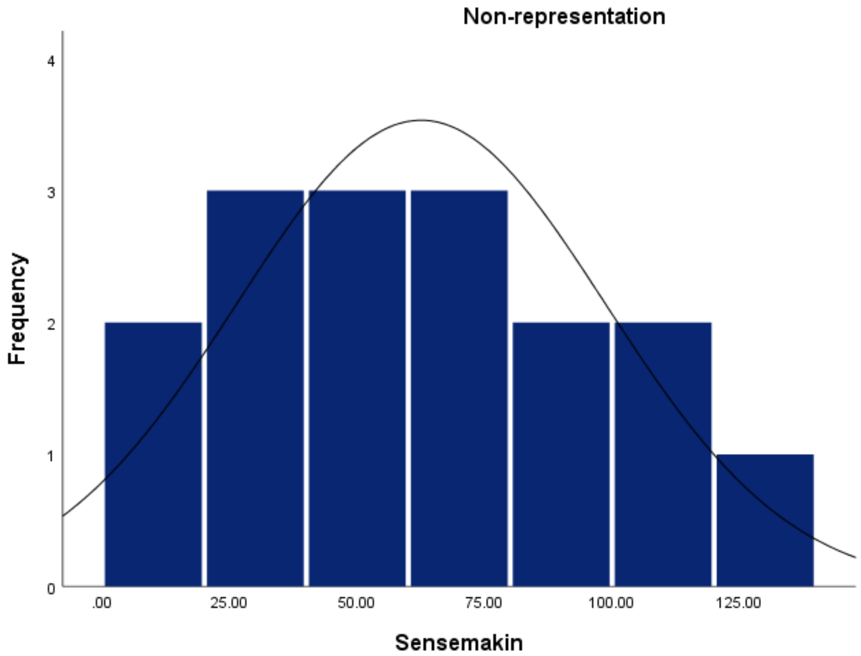
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Sensemaking_User-generated representation	.181	16	.167	.855	16	.016
Sensemaking_ Non-representation	.123	16	.200*	.931	16	.250
Uncertainty_User-generated representation	.177	16	.191	.936	16	.298
Uncertainty_ Non-representation	.196	16	.102	.886	16	.048
Keyword-Novelty_ User-generated representation	.167	16	.200*	.943	16	.383
Keyword-Novelty_Non-representation	.174	16	.200*	.898	16	.075
Structuredness	.178	16	.186	.873	16	.031

*. This is a lower bound of the true significance.

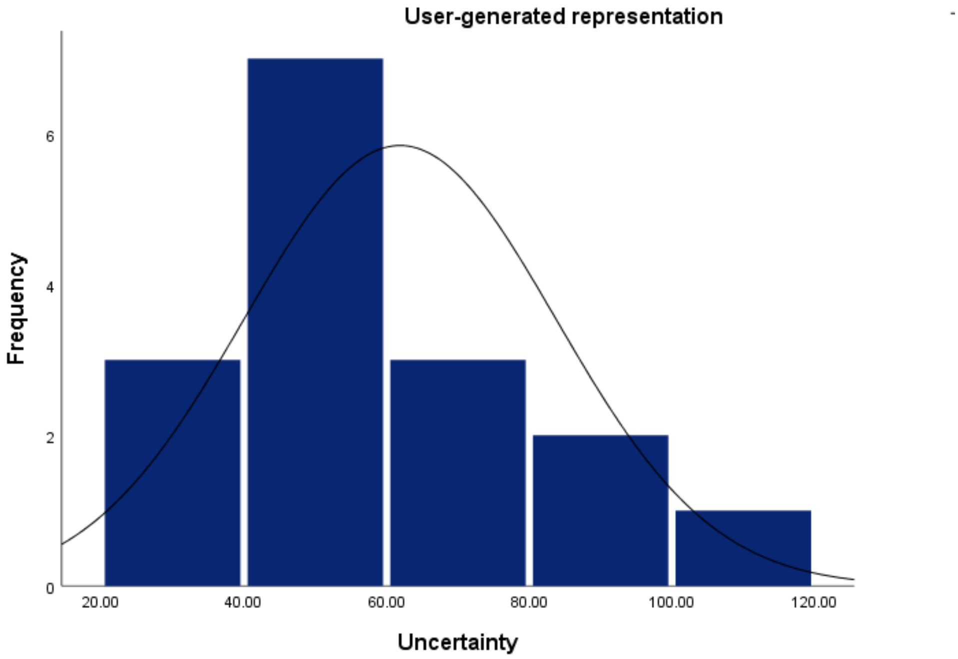
a. Lilliefors Significance Correction



[redacted]



[redacted]


User-generated representation
Frequency
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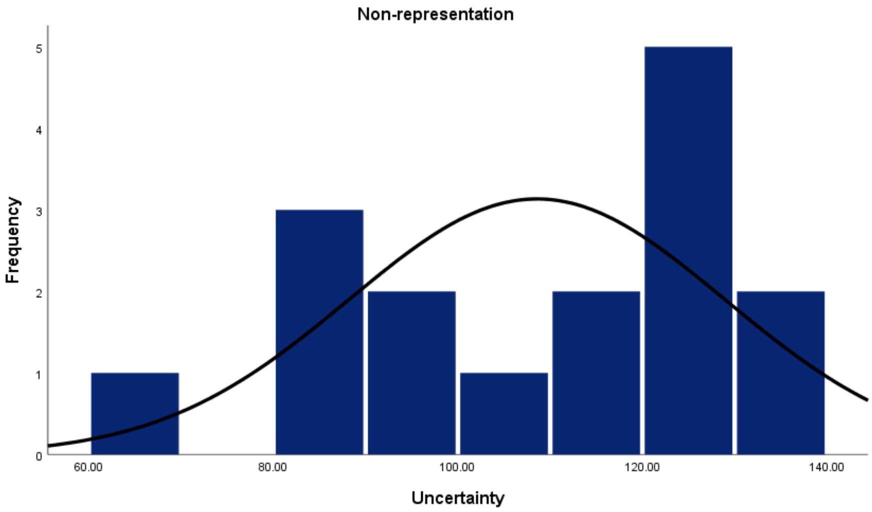
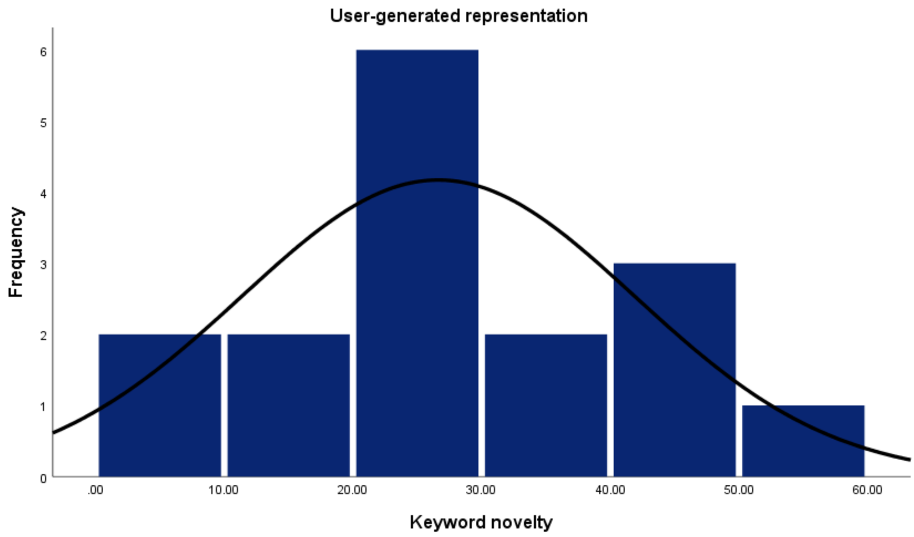
2
4
6
20.00
40.00
60.00
80.00
100.00
120.00
Uncertainty


Non-representation
Frequency
0
1
2
3
4
5
60.00
80.00
100.00
120.00
140.00
Uncertainty


User-generated representation
Frequency
6
5
4
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2
1
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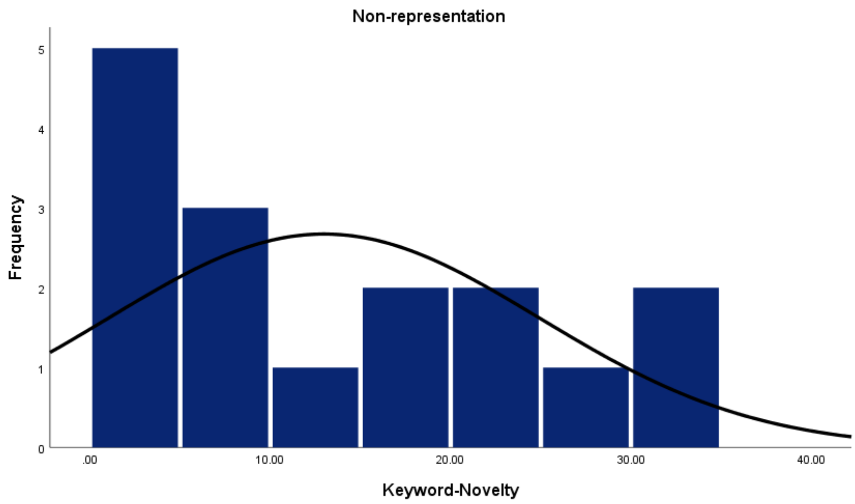
.00
10.00
20.00
30.00
40.00
50.00
60.00
Keyword novelty


Non-representation
Frequency
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4
3
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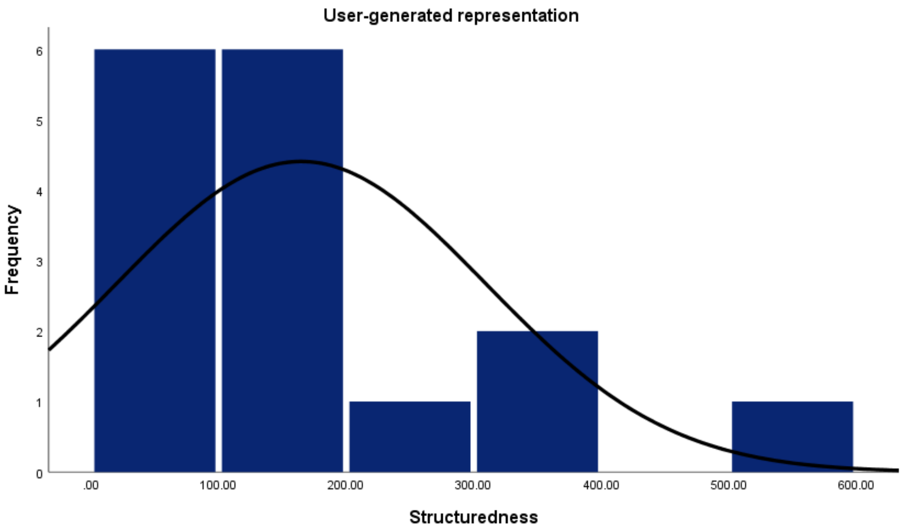
1
0
.00
10.00
20.00
30.00
40.00
Keyword-Novelty


User-generated representation
Frequency
6
5
4
3
2
1
0
.00
100.00
200.00
300.00
400.00
500.00
600.00
Structuredness