Searching for meaning: co-constructing ontologies with stakeholders for smarter search engines in agriculture

Abstract

A key challenge in agriculture, as in other disciplines, is taking a large body of research-based knowledge and making it meaningful to the user-audience. Computer aided search engines potentially can offer widespread access to large repositories with relevant reports and publications, however the usefulness of such systems for the practitioners who are dealing with multi-faceted and context-related issues is often limited. Building search engines with user-centered ontologies offer a means of resolving this as it provides a vocabulary common to different stakeholders and can optimise the interaction between practitioner users and the expert system.

The paper critically reflects on the methodology used to construct a user-centered ontology in the development of a search engine designed to help agricultural practitioners (farmers and advisers) find useful research outputs. This involved the iterative participation of domain experts, adviser practitioners and stakeholder communities in ten diverse case studies across Europe. Specifically it analyses the design, validation and evaluation phases of the ontology development drawing on qualitative data (reports, observations, interviews) from four case studies and asks: How effective is the process of co-constructing an ontology with experts, practitioners and other stakeholders in enabling the search for useful and meaningful knowledge? In doing this, it contributes to a deeper theoretical understanding of shared concepts and meanings in the context of digital communications in the agricultural arena by adapting Carlile's (2004) framework of syntactic, semantic and pragmatic capacities.

Key words: ontology; stakeholder; knowledge domain; search engine; digital tools; farmers

1. Introduction

Research is a key dimension of innovation and offers significant opportunities for making farming smarter, more competitive and sustainable. However, the challenge of turning good science into good practice has occupied many commentators (Top and Wigham, 2015). In particular a central issue for innovation in agriculture, as in other disciplines, is taking a large body of research-based knowledge and making it meaningful to the user-audience (Baumbusch et al., 2008, Müller et al., 2016). Although a lot of information exists in journals, repositories, databases and websites, this knowledge is not reaching practitioners due to its unstructured, incomplete, varied formats, use of different terminologies for the same concept, and lack of targeted delivery methods. Although the limitations of knowledge exchange between science and decision makers are known to go far beyond information and knowledge management (Cvitanovic et al., 2016), it is valid to consider how these sources can be utilised given the increasing corpus of data and information and the investment this entails (Müller et al., 2016, Pauleen and Wang, 2017).

There are opportunities throughout agricultural research now for providing and accessing data and information through digitisation along with the increasing availability of internet and mobile technologies in agricultural communities (EU, 2015). The proliferation of cheap decentralised computational power allows for collection, storage and dissemination on a large scale. This so-called 'basic e-science technology', in the form of web applications, networks and databases, makes the reach of the dissemination much greater (Top and Wigham, 2015). However, while a lot of valuable research outputs continue to be generated, and practitioners are increasingly accessing research networks, the systems to enable widespread access and utilisation of such outputs are not keeping pace (Antle et al., 2017, Sulaiman et al., 2012). The need for more effective tools, information systems, decision support systems (DSS), knowledge platforms and smart search engines has been identified, if agricultural science is to be made accessible to, and meaningful for, practitioners[1] (Sulaiman et al., 2012). As Dayde et al. (2016 p1) point out, "the issue of imbalance between the richness of available information and the ability of farmers to harness it in their decision-making process has received little attention so far". As a consequence, the proliferation of information and technology does not always result in more useful knowledge. This trend

[1] We understand 'researchers' as those using data and field knowledge, and producing expert knowledge, while 'practitioners' participate in experiments, contribute field knowledge, and access expert knowledge.

has led those working in knowledge management to question whether more information and data actually means more knowledge (Pauleen and Wang, 2017).

Computer aided search engines can potentially offer widespread and cheap access to large research repositories with relevant reports and publications (Top and Wigham, 2015, Azizan et al., 2018). In such systems the user usually enters a few search terms, the system returns a ranked list of documents and the user refines the search terms if needed. These systems rarely offer the chance for real or smart interrogation of the knowledge base, nor for any dialogue or interaction with the system. As such, they cannot substitute the expert-practitioner interaction that complex decision-making often requires for innovation in agriculture. This, Willems et al. (2015) argue, is because in standard solutions, background knowledge on the domain[2] is missing in the interaction between practitioner and system. Furthermore, often those designing and using search engines use different terminologies to express the same concept, and they do not always incorporate the expressive relationships among concepts which are required to represent knowledge, and to address context specific needs (Walisadeera et al., 2015, Willems et al., 2015). The problems of shared meanings and the need to bridge different modes of representation used by individuals to interpret them from one perspective into another are not being addressed in agricultural contexts.

User-centered ontologies offer a means of resolving this in Information Communication and Technology (ICT). A user-centred ontology can provide a vocabulary common to different stakeholders and thus optimise the interaction between practitioner users and the expert system (Miah et al., 2014, Basu, 2019). They potentially have a wide application in the classification of agricultural information, the construction of information and knowledge database, the research and development of intelligent search engines. They allow information and knowledge needs to be provided, not only in a structured and complete way, but also in a context specific manner. However, to date their potential has not been fully explored (Walisadeera et al., 2015). Whilst the importance of involving users in DSS development is well known (Lundström and Lindblom, 2018, Carberry et al., 2002, McCown, 2001), and some user-attributes are being considered in ontology development (Likavec et al., 2015), the role of users in the co-design of ontologies for agricultural search engines has been under-explored.

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[2] The term knowledge domain is variously defined, for example, Zheng Ye-lu et al. (2012 p701) note that "In knowledge representation, the domain knowledge is described as "the set that containing concepts, relations, concept hierarchy, relations between concepts, and axioms"; while others describe them as "thought worlds".

This paper describes the development of a search engine which has a user-centred ontology at its core. This search engine aims to help practitioners (farmers and advisers) in the field of agriculture and forestry[3] to find research outputs that respond to their specific queries. The paper critically reflects on the methodology used to construct the user-centered ontology, which involved the iterative participation of domain experts, adviser practitioners and stakeholder communities in ten diverse case studies across Europe. Specifically it analyses the design, validation and evaluation phases of the ontology development drawing on empirical qualitative data from project reports, observations, interviews; and asks: How effective is the process of co-constructing an ontology with experts, practitioners and other stakeholders in enabling the search for useful and meaningful knowledge? In doing this, it aims to contribute to a deeper theoretical understanding of shared concepts and meanings in the context of digital communications in the agricultural arena.

2. Relevant concepts for digital tool development

ICTs are more suited to transfer of highly codified and standardised knowledge, therefore developing a search engine that can mimic the socialisation and contextualisation of knowledge creation, and achieve co-presence without co-location, has been a challenge (Boisot, 2002, Roberts, 2000). The potential of user-centered ontologies in addressing this challenge are considered next.

2.1 Challenges of transferring knowledge in a search engine

For search engines it is assumed that the knowledge needed to provide answers is contained in a set of digital documents which comprise the document base. Such documents are sourced from, and represent some form of codified knowledge, that is, data and information. In agriculture these might range from scientific data, scientific papers and reports, to models, practical factsheets and technical recommendations where data and information have been translated[4] to different extents through analysis, interpretation, modelling, synthesis and summarising. Different types and modes of knowledge, for example, data, information, knowledge, wisdom, have been extensively described and classified in the literature (Joshi et al., 2007, Upadhyay and Kumbharana, 2018). Although these terms are often used

[3] Due to limitation in space this paper focuses on agriculture only, although the methodology described was also used to develop ontologies for forestry knowledge domains drawing on user input from forestry case studies.

[4] Here we use the term translation to describe the process whereby science becomes part of useful knowledge for decision making, in agriculture it is equivalent to turning knowledge into action (Valdiva et al., 2014; Ingram et al., 2018)

interchangeably, they represent concepts which are qualitatively different and this has implications when communicating from one to the other. While data and information are independent of context and can easily be transferred using digital tools and processing, they have to be contextualised in order to become relevant or provide useful knowledge for individuals to act on. This implies a process of translation and transformation of data or information into knowledge (Carlile, 2004, Pauleen and Wang, 2017).

Although conventional search engines can transfer information, they need to incorporate some interactive exchange and negotiation of meaning to replicate the true communication processes that enables this contextualisation (Sulaiman et al., 2012). According to those commentating on knowledge exchange or transferring knowledge, differences between the use and the supply of knowledge needs to be reconciled and a 'degree of resonance' found (Cvitanovic et al., 2016, McNie, 2007). Specifically for search engines this highlights the importance of enabling a form of dialogue between users and suppliers to allow effective communication and expression of questions and answers.

Understanding how practitioners, as potential users, ask questions, articulate issues, and define problems is an important element of any search or decision support tool. Researchers have highlighted the subtle differences in practitioner problem articulation and definition (Hansen et al., 2018) and the need for purposeful and understanding-oriented communication. Information seeking behavior, language and specificity of articulation and problem-framing changes depending on the purpose of the search, for example, whether it is for problem detection, problem solution, new practices, or opinions (Eastwood et al., 2017, Ingram et al., 2018, Willems et al., 2015, Allen et al., 2017, Solano et al., 2003). Although the study of query articulation in search engine development is well advanced (Patel and Jain, 2019, Willems et al., 2015), articulation of questions and problems for retrieving information specifically on agricultural topics has not been widely addressed. As Willems et al. (2016) point out, replicating the normal expert-practitioner interaction in a search engine is a challenge many current agricultural support systems are not up to.

In this respect of these two aspects, enabling contextualisation of knowledge exchange, and replicating a normal dialogue, there is a need to define terms to express the same concept.

2.2 Ontology – a common vocabulary

An ontology provides a structured view of domain knowledge and acts as a repository of concepts in the domain. This structured view is essential to facilitate knowledge sharing, knowledge aggregation, information retrieval and question answering (Miah et al., 2014, Gruber, 1995, Madin et al., 2008, Zheng et al., 2012, Basu, 2019).

Ontologies are often represented in semantic networks where concepts are linked to describe interconnections and hierarchy (Zheng et al., 2012, Basu, 2019, Brügger and Milligan, 2018). Multiple alternative names or synonyms can be attached to one concept, while different types of relations can also be defined. The network of relations determines the formal semantics of the associated concepts, allowing applications like search engines to act in an informed and intelligent way (Likavec et al., 2015). Such advanced e-science technology, or web semantic technologies, can greatly improve the findability of data (Top and Wigham, 2015, Patel and Jain, 2019, Vrana et al., 2018). However, the specificity of the ontology affects the retrieval outcomes, as does the construction and contextual basis (Müller et al., 2016, Straccia, 2006). Although ontologies exist in the domain of agriculture, these tend to have generic concepts (e.g. Agrovoc), to rely on experts to determine and structure the knowledge, and to address researchers' rather than practitioners' information needs in the local context (Walisadeera et al., 2015, Müller et al., 2016). As such, limitations have been noted such as "semantic ambiguity in definition and usage of vocabularies; lack of high level cross domain concepts and meaning of their relationships not being precisely defined" (Walisadeera et al., 2015 p142). Additionally, the judgements about whether the retrieved information meets an expressed need are always context dependent and subjective (Straccia, 2006).

An ontology co-created by multiple stakeholders for a specific domain can address these limitations. Haverkort and Top (2011 p121) define an ontology as "a controlled and shared vocabulary that describes concepts and the relations between them in a formal way, and has a grammar for using the vocabulary terms to express something meaningful within a specified domain of interest". According to this understanding, it can provide the basis for experts and practitioners to define a common language to express questions and answers and provide the platform for using the modelled domain knowledge (ontology) in such a way that allows an effective dialogue between user and digital system (Willems et al., 2015). The advantage of this is that all possible stakeholders are able to understand the data expressed by this ontology and that software applications can process them automatically (Haverkort and Top, 2011).

2.3 The importance of user-input in design

Digital developments, which utilise and interpret data, such as search engines, DSS and virtual platforms, often neglect understanding of users' information contexts and needs (referred to as domain specific knowledge), and their expectations and utilisation of them (Eastwood et al., 2017, Carberry et al., 2002, McCown, 2001).

User-involvement in ICT can range from traditional testing, feedback or consultation, for example, applying user-requirements analysis, to modern techniques of user-centered design, in which software is built in direct contact with the end-user in short iterations. In the latter approach, user-needs and requirements guide and modify the development in each iteration, although often the input and the architecture comes from experts rather than practitioners (Beguin et al., 2012, Patel and Jain, 2019, Poirier, 2017).

In agriculture, the importance of involving stakeholders in the development of digital tools is well understood, and there are many examples of participatory user-consultation in DSS development. However, this is often through soliciting user-feedback about tool performance and ease of use (Ingram et al., 2016, Rose et al., 2018) rather than engaging users in the core design processes. As Ditzler et al. (2018) point out, while the need for participatory approach is well rehearsed, how the design of systems analysis tools contributes to their usefulness in collaborative problem-solving processes remains largely unexplored. Some cases of participatory co-design approaches are reported, Cerf et al. (2012 p900), for example, sought to build a shared conception of the design problem through dialogue with stakeholders and to put “a model into use in a decision support system, but also to design the model itself”. However, genuine co-design in models and tools is still largely an aspiration (Berthet et al., 2018, Prost et al., 2012).

2.4 The role of ontologies in enabling common meanings: a framework for syntactic and semantic levels of communication

Representation is a means for organising and communicating information but translating information between domains can meet problems with semantics since different domains naturally generate interpretive differences (Lee and Jeong, 2012, Vrana et al., 2018). This has been conceptualised as boundaries between domains where different knowledge types and perspectives exist (Carlile, 2004). Achieving this shared understanding requires cognitive filtering and interpretation so that representations created in one domain of expertise can be meaningful in other domains (Lee and Jeong, 2012, Basu, 2019). The theoretical ideas behind bridging different modes of representation used by individuals to interpret them from one perspective into another have had some limited exploration in studies of tool co-design. These have, for example, described the diversity of ways of representing the agronomic problem (Cerf et al., 2012), and identified the importance of achieving some commonality in representation. Ditzler et al. (2018), in applying the theory of affordances[5] to systems analysis tool design, identified two affordance types which allow commonality. First 'naming' whereby system components are named using a common vocabulary. For example this was applied to artefacts and rules to establish a common vocabulary among participants in the development of serious games (Dolinska, 2017). Secondly 'framing' whereby a shared space of experience and system representation is created. Although common concepts have been theorised in this way, few studies in agricultural domains have explored how ontologies can provide a semantic capacity to allow a common meaning to be found between users and designers of search engines.

Carlile's (2004) framework, developed to examine the relational properties of knowledge at a boundary, has particular relevance to how shared meaning can be achieved and communicated across, and within, domains. Although developed to look at the boundaries that exist among specialised domains in a new product-development setting, and with reference to search engines capabilities at the time, it offers a framework for understanding the relationship between knowledge processes (transfer, translation), an ontology, and user-input, as discussed above. Carlile (2004) distinguished syntactic and semantic levels of communication complexity. At the syntactic level, the primary focus is on the storage and retrieval of knowledge, which relies on information processing. At the syntactic boundary, knowledge is transferred according to a common lexicon, and domain specific knowledge can be efficiently managed across the boundaries between actors (through the use of tools and search engines as boundary objects[6], for example). This has limitations, however, because "while a common lexicon is always necessary, it is not always a sufficient type of common knowledge to share and assess domain-specific knowledge" (Carlile,

[5] Affordance is defined here as a function provided by an object through an interaction with a user.

[6] Boundary objects are defined as ''an analytic concept of those scientific objects which both inhabit several intersecting social worlds and satisfy the informational requirements of both of them" (Star and Griesemer, 1989, p. 393).

2004 p558). He describes a transition from a syntactic to a semantic boundary, where interpretive differences in what a word, measurement, or outcome means, limits the effective management of knowledge between actors. A process of learning about and translating domain-specific knowledge is needed to establish common meanings to allow actors to share their knowledge. This is where the relevance of a user-centred ontology in providing and enhancing a semantic capacity, becomes apparent, as shown on Fig 1.

Advancements in semantic web technologies have enabled a shift, i.e. from synaptic to semantic, in search engine capabilities (Brügger and Milligan, 2018, Basu, 2019). Latent semantic analysis (LSA), a technique used to improve information retrieval systems and search engine query performance, for example, is used by search engines like Google to assess similarity in language and to discover how a term and content work together to mean the same thing (Vrana et al., 2018). However, the semantically-enhanced searches that these new techniques allow do not use domain and context specific ontologies (from experts and practitioners in agriculture) as a basis for ontology-based annotation (Vrana et al., 2018, Müller et al., 2016).

[Insert Fig. 1]

Fig 1. Framework showing how a user-centred ontology can improve semantic capacity

This paper examines the process of co-creating an ontology with domain experts, advisers and stakeholders, to build a search engine which aims to take the exchange of knowledge from the syntactic to the semantic level to optimise shared meaning and allow problem and question articulation.

3. Methodologies: constructing an ontology for the search engine

3.1 The project

The search engine was developed within a four year research project. The actors involved included: agricultural, forest and soil scientists, these acted as domain experts in six thematic domains: sustainable soil and water management, integrated pest management, recycling of biomass, supply chain optimisation, and ecosystem and social services from agriculture and forestry. Computer scientists developed and constructed the tool, while Case Study Partners who were advisers (agronomists, field and supply chain specialists) or other intermediaries, facilitated and coordinated the stakeholder community (potential users) in 10 case studies across Europe (Ingram et al., 2018). Social scientists coordinated the interaction between the Case Study Partners and the other project partners. The project team worked on the basis of open discussion, allowing space in meetings for reflection and debate to reconcile different viewpoints. Involving Case Study Partners as project partners was an important part of this process.

3.2 The ambition

The aim of the project was to construct a search engine which can help practitioners and advisers in the field of agriculture to find and share documents that respond to their specific queries. This involved constructing an ontology to: improve the structuring of knowledge for the specific agriculture domains according to the context of the users; create a shared vocabulary between experts and stakeholders to allow users to express questions and answers; annotate digital documents in a document base; and provide a semantic index so that best matching documents to answer a query could be found. This combines digital fingerprinting and automated annotation which have proven effective for the articulation of end-user innovation needs and for the retrieval of precisely matching information (Basu, 2019). Overall it builds on and refines recent developments in semantic technologies: query articulation, semantically enhanced searching, ontology-based annotation of documents, and Linked Open Data.

The ultimate ambition was to create a digital but knowledgeable ‘assistant-expert’ or ‘digital assistant’ which can serve as an intermediate between experts and practitioners, optimising the effectiveness of the interaction between them. An important challenge identified was to use the modelled domain knowledge (ontology) in such a way that the system is able to have an effective dialogue with the user. According to project partners “in such a dialogue, the initial question of a user (farmer, adviser) may be vague and broad, or very specific. If the idea of an assistant-expert is to work it needs to translate the users’ question into terms in which solutions are formulated, independent of a particular language, and help the user (farmer, adviser) to narrow down or broaden the questions, or suggest alternative lines of thinking” (Willems et al., 2015 p86). Given this ambition it was essential for the computer scientists and domain experts to work with potential users throughout the design and development of the tool.

3.3 Methodology for search engine development

The search engine was developed through progressive stages involving computer scientists, domain experts and potential users (Case Study Partners and case study stakeholders). This development involved three phases, each with user-input: design, validation and evaluation, together with a project team reflection conducted throughout (shown in Fig 2). The Case Study Partners played a critical role, not only providing their own technical and practical expertise, concepts and perspectives, but also coordinating their stakeholder communities in multiple participatory meetings. In this iterative process in the case studies, the search engine was first introduced in early meetings, concepts and terms were then harvested, and functionality progressively evaluated. The search engine development involved all the main elements described in Box 1 but the focus in this paper is the user-centred ontology.

[Insert Fig. 2]

Fig 2. The role of the ontology in search engine construction

3.3.1 Design

At the core of the search engine is the common ontology. The methods for co-constructing this are described next.

Expert and Case Study Partner input

Domain experts and Case Study Partners were asked to provide relevant concepts in the agronomic domains (for the six thematic domains of the project), place these concepts in a hierarchy using ROC+[7] and identify concepts that are related in another way (Koenderink et al., 2008). Domain experts can identify the range and scope of scientific concepts and information available, while Case Study Partners can identify the breadth of information required by practitioners. Case Study Partners initially used their personal vocabularies, they then collected context specific terms identified by stakeholders in case study meetings. Domain experts and Case Study Partners were trained and made their inputs in two workshop sessions (Table 1), at the beginning of the search engine development and then continued to add terms in small meetings or individually (remotely) throughout the project. Panels per thematic domain (experts and Case Study Partners) worked throughout the project to continue term collection and ontology expansion.

[7] Ontology construction is a lengthy process so a ROC+ (Rapid Ontology Construction) method was used to facilitate this activity. The ROC+-method consists of five steps: (i) entering of concepts into the ontology, (ii) identifying synonyms, (iii) use existing ontologies (such as Agrovoc, Eurovoc, DBPedia) to suggest other relevant concepts (iv) create the hierarchy between the concepts, (v) indicate relations between concepts. A Linked Open Data Infrastructure (LODI) is built by linking the partial ontologies from the case studies, the experts and existing ontologies into a single overall ontology.

Table 1: Workshop methods for collecting expert, Case Study Partner and stakeholder concepts and terms

EXPERT AND CASE STUDY PARTNER INPUT	
Ontology Workshop Session 1	**Activity**
Concepts and synonyms	Participants write down relevant terms of his/her domain. Groups comprised experts as well as Case Study Partners to provide scientific and practitioner terms In groups/pairs – they write down on paper all terms that came to mind concerning the theme to allow all to contribute equally to the initial ontology
ROC+ entry	Enter into ROC+
Identify synonyms	Experts identify synonyms for each term. ROC+ suggests synonyms for experts to accept or reject; or experts add new
Taxonomy/ Relations are created	"kind of" relations are indicated. These are relations that represent a hierarchical relation between concepts (e.g. "Elstar -- is a kind of -- Apple").
Taxonomy/ Relations are created	"related to" relations are indicated. These are relations that represent another type of relation between concepts (e.g. "Apple -- is related to -- Apple pie").
Ontology Workshop Session 2	
John and Mary stories and competency questions	The ROC+ input continued. To help the participants in setting the scope for the ontology, they were asked to create a 'John and Mary' story, in which John and Mary are farmers in their case study. The story described what kind of farm they run, what kind of issues or questions they have and what kind of information could help them. This helped to identify terms, also questions they would expect to be answered by a system. These are competency questions and they allow the most important concepts and relations between concepts to be found.
STAKEHOLDER INPUT	
Series of participatory meetings in case studies	**Activity**
Participatory activities	Case Study Partner facilitate stakeholder meetings to harvest concepts and terms for the ontology, identify innovation issues, generate competency questions

Stakeholder input

Following the ROC+ workshops, a series of participatory meetings were held with stakeholders in each case study (listed in Table 4) to harvest their concepts and terms for the ontology. This process collected terms directly from stakeholders through brainstorming approaches and indirectly through discussions. In the latter, participants were asked about their innovation needs (characterised as information from research) and potential solutions (see Ingram et al. (2018) for detailed description), either by inviting them to articulate questions or to contextualise such questions by telling 'John and Mary' stories. This generated several questions for each case study. These correspond to competency questions[8] which were

[8] A competency question is a natural language sentence that expresses a pattern for a type of questions people expect an ontology to answer. The answerability of competency questions hence becomes a functional requirement of the ontology.

used to identify major concepts, determine the scope and content of the ontology and to validate it (Table 2). These questions will serve as a 'litmus test' and are used to gauge whether the ontology contains enough information to answer them; and whether the answers require a particular level of detail or representation of a particular area. As Haverkort and Top (2011) note such competency questions are just a sketch and are not exhaustive.

The ontology was progressively developed using such methods, in line with the other elements and activities involved in building the search engine (Box 1 and Figure 2). The intention was to have three to four iterations, with each yielding further refined vocabularies, and using this (and stakeholder feedback) to develop better tailored retrieval, and better-tuned end-user information.

3.3.2 Validation and evaluation

Validation followed this design (ontology construction). This was carried out by domain experts, who worked in thematic domain panels, supported by Case Study Partners, to examine the correctness and relevance of the concepts and the relationships, using standardised criteria. They also manually checked the automatic annotation of documents (Box 1). Case Study Partners specifically validated the search engine with competency questions derived from the case studies (Table 2). As the search engine developed (by combining the elements in Box 1) a series of evaluation processes were carried out to collect Case Study Partner and stakeholder feedback about the functionality of different versions (see Table 2).

Table 2. Case Study Partner and stakeholder validation and evaluation activities

ACTORS AND METHOD	TOOL VERSION	ACTIVITY
Validation		
A series of small technical tests run by partners with Case Study Partners in between case study stakeholder meetings	All versions	These involved Case Study Partners completing a prepared structured questionnaire in project meetings, dedicated workshops, smaller tests in Skype mini-workshops and remote exercises facilitated by those constructing the search engine. Case Study Partners tested it with competency questions from the case studies. Case Study Partners and stakeholders could continue to suggest ontology terms when they discovered them missing.
Evaluation		
Three sets of technical demonstrations and tests were conducted in case studies facilitated by Case Study Partners who collected stakeholder feedback (according to standard protocols).	2,3 and 4	The tests involved users asking questions to test functionality. This was judged on usefulness of search outputs, performance of the query editor, the scope of document base and the type and language of the document. The evaluation methods were based on descriptive methods using a standardised template and reported in meeting reports.

Box 1 Key elements of the search engine

Box 1
At the core of the tool is the **ontology** (as described above), the other key elements are:

The **document base.** Domain experts and CSPs collected documents relevant to the 6 thematic domains and to the case studies. These documents were selected for their potential to help farmers/advisers to find the answers/innovations relevant to their problems and questions. They included scientific (articles) documents originating from scientific databases, reports from European projects, and practical documents (e.g. factsheets). They also linked to international and national repositories of advisory services, levy boards, NGOs (guided by CSPs).

Ontology based annotation of documents. A computer program automatically annotates documents in the document base, by identifying phrases in the documents that match concepts in the ontology (manually checked by the same domain experts). As such the ontology was used to take a 'fingerprint' (make a semantic index) of all documents in the document base. Annotation allows the user to find the best matching documents for a user query and relevant parts of text (fragments) within each document.

The **query editor.** The ontology assists users in query articulation. It helps the user (practitioner) to formulate a question as a formal query to the knowledge base. Through the ontology the query editor can suggest alternative directions to explore, and helps the user to zoom in or out of certain details or presents suggestions for expanding or narrowing the search, offering alternative search directions by showing slightly different concepts or synonyms or relations. This feature aims to act as a digital assistant.

(see Willems et al., (2015) for further details)

3.3.3 Data collection and analysis

All the activities described above generated qualitative data for analysis in the form of reports, notes and transcripts. In addition the authors collected insights from the Case Study Partners in a series of face to face reflective interviews at yearly intervals throughout the project (three times), and in discussions during project meetings or specially convened Case Study Partner group meetings. Collectively these data provide the empirical basis for the results presented here (Table 3). All reports, test templates and interviews schedules were standardised. The qualitative data were analysed using thematic coding referring to Carlisle's syntactic and semantic framework. The paper uses this analysis from four selected case studies (Table 4) to examine how effective the process of co-constructing an ontology is, with reference to the three phases of design, validation and evaluation, in creating a shared vocabulary and meeting the ambitions of the search engine development.

Table 3. Methods and data used for analysis

ACTIVITY	DATA ANALYSED
Workshop methods for collecting expert and CSP concepts and terms (ROC+)	Ontology terms, relations and architecture John and Mary stories Competency questions Observation notes and audio transcripts
Participatory meetings with case study stakeholders to harvest concepts and terms for the ontology	Case study meeting reports Ontology terms and relations Competency questions
Series of small technical tests with Case Study Partners	Completed questions Observation notes
Sets of technical demonstrations and tests with case study stakeholders	Test and demonstration reports and Case Study Partner feedback Observation notes
Case Study Partner interviews	Transcripts
Case Study Partner group meetings and skypes	Notes and audio transcripts
Project meeting participation and observation Case study validation and evaluation activities.	Minutes Observation notes and audio transcripts

Table 4. Selected Case Studies

NAME	TOPIC	STAKEHOLDERS
Improving milling wheat quality (Wheat supply chain)	Fertilisation, IPM and fungi control in sustainable milling wheat supply chain	Farmers, wheat-stocking cooperatives, seed companies, pesticide companies, wheat-buying companies
Sustainable potato supply chains (Potato supply chain)	Sustainable potato production for the French fry industry	Farmers, processing and exporting industry, suppliers of fertilizers and pesticides, experimental station and research
Innovative arable cropping (IAC)	Reducing herbicides use in arable crops	Technical institutes, agricultural chambers, farmers, research institutes, storage agencies
Catchment scale resource use efficiency (Catchment management)	Sustainable farming at landscape scale	Government agency, farmers union, NGOs, professional nutrient management group, agricultural sector levy boards

4. Results

4.1 Search engine development

Case Study Partners and stakeholders have progressively contributed to the ontology, and validated and evaluated each of the four versions of the search engine developed in the project period. In particular feedback about the language and format of the document base led to significant changes[9], whilst issues raised about functionality (searching and ranking) and presentation of results have been progressively addressed in each version. This paper focuses on the significance of the user contributions to the ontology and the impact of this on the search engine function overall.

4. 2 Design: Ontology

Whilst the expert and Case Study Partner ontology term collection was standardised according to the methods described above, Case Study Partners in case studies took different approaches to collecting terms for the ontology from their stakeholders, with implications for ontology construction and search engine functionality.

In the **Improving milling wheat quality case study** an exercise was carried out in the first stakeholder (all supply chain actors) meeting to identify innovation issues and research needs using a poster trail. After this, all content written on the posters were read and compared to the list that had been entered in the ROC+ system by the Case Study Partner earlier. Following this meeting, the Case Study Partner felt that it was not necessary to add any more terms, as the ontology was considered complete. The process was described as useful by the Case Study Partner who said that they found some connections that they had not thought about before such as: “fertilization” and “grain quality”; “monitor” and “wheat bugs”; and “NIR” (a form of analysis) and “guidelines”. The Case Study Partner reported that the recurrent terms of the stakeholder meetings were “supply-chain improvement”, “quality assessment” and “sorted storage” of the grain lots, which reflects the stakeholder group composition. The Case Study Partner found both these, and the specific terms referring to quality typologies of wheat varieties such as “Strong bread making varieties”; “Bread making varieties”; and “Biscuit making varieties”, difficult to assign to the

[9] The document base was expanded to provide access to non-scientific documents in six national languages, with an increase from 710 documents in Version 1 to 3,905 in Version 3 and the prospect of many tens of thousands through linked national repositories in Version 4. In turn this required an expansion of the ontology and a need for the CSP to translate the ontologies into native case study languages

ontology. Overall it was clear that the concepts and relations that concerned these stakeholders covered a broader area than those used for wheat agronomy identified by the domain experts, highlighting the significance of the supply chain context in which the stakeholders operate.

In the **Sustainable Potato Supply Chain case study** an exercise in small groups was carried out in early meetings, in which the stakeholders (all supply chain actors) listed "all terms that came into their minds". The Case Study Partner did not present the ontology made previously by the Case Study Partner and domain experts because, as he said, "I didn't want to lead them in a certain direction". Although this process expanded the terms, it did not offer relations. Furthermore, different stakeholders came with specific terms, related to their business. For example, suppliers of potato seeds had concerns about seed quality, identifying terms like "Rhizoctonia" and "Fusarium" (common diseases). On the other hand, representatives of the processing industry listed terms like "tuber shape"; "length"; and "disorder". Given that there is a connection between these terms, the Case Study Partner noted the benefit of having all stakeholders together to create all relevant terms and connections for the ontology. However, he noted the disparity with the expert ontological terms.

In the **Innovative Arable Cropping (IAC) case study** the stakeholders (mostly farmers) identified a number of innovation issues or questions which they progressively refined in the first participatory meeting. In this meeting, the farmers first identified key terms, then the linking processes that related to these terms, finally they refined these into a single question. This exercise was repeated for six topics (one topic is shown in Table 5). The key terms were added to the ontology. Figs 3 and 4 show how two selected terms, 'soil organic matter' and 'minimum tillage' appear in the ontology with synonyms and all relations. This exercise reveals the complexity of processes associated with each term, which needs to be captured in the ontology.

[Insert Fig 3 and Fig 4]

Fig 3: Example ontology from harvested terms and case study questions

Fig 4: Example ontology from harvested terms and case study questions

Table 5. Terms and questions from farmers in Innovative Arable Cropping case study

Key words and concepts identified:	Nitrogen / behavior of nitrogen / nitrogen cycle in the soil / + carbon / + soil organic matter / key nutrients cycle in the soil according to different cultural practices (minimum tillage, direct sowing, strip till, cultivation, tillage) or cropping system
Interim terms:	Seeking to break misconceptions on nutrients cycle (eg direct sowing increases the organic matter (OM) content of soil; OM can be found concentrated at the surface as mineralization occurs less easily). "What are the effects of direct sowing, covers, and soil tillage on the nitrogen cycle, its redistribution, and release (and the dynamics of the OM and carbon)?”
Final question:	"What are the effects of agricultural practices such as direct sowing, cover crops and soil tillage on the nitrogen and organic matter cycles and availability? “

In the **Catchment Scale Resource Use Efficiency case study** the Case Study Partner reported that “A specific session on collation of terms for ontology was not part of the agenda. Key terms were however collated by the two meeting facilitators and secretary.” These were collected in meetings by the facilitator who listed the terms used in meeting discussions with stakeholders (mainly farmers) but no relations were identified. The stakeholders also created brief stories in which to frame their innovation issues and questions as follows:

- [John is ..] An arable farmer on heavy clay soils has an increasing problem of blackgrass control using existing chemicals and Integrated Crop Management (ICM). He can only use combinable crops. What are the economic factors associated with using grassland in a rotation to control blackgrass? How efficient is grassland in controlling blackgrass?

- [Mary is] An arable farmer using zero-tillage cultivation techniques observed how snail numbers have increased on her high PH soil which is damaging her crop, even in late season and contaminating it, making harvesting difficult. Can she control snails economically without negatively impacting on the environment? What are the ICM solutions? What are the mechanical solutions?

- [John is..] are arable farmer on clay soils lying on moderate slopes is concerned about the implications surface run-off has for him. Are there any financial rewards offered for reducing surface run-off by the government? What are the economic implications of soil erosion via run-off for him? What are the best methods of controlling/preventing surface run-off? How much does each method cost to implement?

These demonstrate that, although there are agronomic questions about, for example, managing blackgrass weeds, or ICM, they are articulated in terms of the impact of management on economics and environment, suggesting that their meaning extended to much wider relationships than direct synonyms or relations used by domain experts.

These examples highlight some emerging issues in standardisation of collection methods, and the scope of terms and relations included. For example, in the Wheat and Potato supply chain case studies the terms were listed and collected directly, while in the Catchment management case study the terms were collected indirectly by facilitators in meetings, and in the IAC case study through expression of questions and identifying innovation issues or seeking solution to problems. Also for the former two supply chain case studies, the term collection were completed in one iteration and relations were sometimes omitted, while supply chain concepts were hard to capture in the ontology. For the latter two case studies, while the terms were expanded, the complexity of relationships and context expressed in questions is revealed.

4.3 Validation

As the project progressed the ontology expanded (from 1,746 to 6,253 terms overall) as the search engine developed from Version 1 to 4. This was largely due to continued efforts of domain experts, although Case Study Partners continued to access ROC+, reveal missing terms and incorrect relations. This process aimed to address deficiencies experienced in terms of the tool answering competency questions (Table 2).

Although some Case Study Partners reported that they had exhausted the number of terms collected with stakeholders early on in case study meetings, they were individually encouraged to continue to add new ontological terms using ROC+, however there was no ‘quality control’ of this activity. This was part of the overall aim for the ontology, not to be a static entity, but to be continuously expanded and enriched to stay relevant for answering practitioners’ questions. However, this facility also created some issues, as in some cases the suggested terms were not uploaded to the system; or the suggested contributions were not accompanied by any contextual information making it difficult for partners constructing the ontology to establish relations.

The domain experts validated concepts, relationships between concepts, hierarchy and correct use of synonyms. In this process they realised that, whilst the number of terms was high, the relations between them were not always accurately expressed (and therefore the semantic index was not optimal). This required some significant restructuring of some of the relations components, revising or even removing some of the initial Case Study Partner and stakeholder terms and relations.

4.4 Evaluation

As described above, functionality with respect to usefulness was tested throughout the search engine development stages by Case Study Partners, and latterly the stakeholders. There was no consensus amongst Case Study Partners testing the tool about what constituted 'usefulness'. While most judged this according to relevance, this was a context specific term. For example, some considered the practical orientation of the retrieved information to be a key criteria for usefulness while others valued new scientific information.

Due to Case Study Partners' concerns that the search engine was insufficiently developed, stakeholders were shown demonstrations with worked examples for Version 1-3, and only tested Version 4, which was available late in the project. Case Study Partners reported that the stakeholders understood the potential of the search engine and gave positive feedback on the functionality, based on a demonstration and description. All stakeholders particularly liked the ability to search and access documents in different languages, they also saw the option to suggest new terms and add documents to the system as an interesting feature. In general, Case Study Partners said that the query editor functions, broader, narrower and related terms, were appreciated by stakeholders because they steered and allowed a "complete search". The query editor helped the Case Study Partners and stakeholders testing the search engine to progressively refine their question by following the alternative search directions offered. Early queries were broad and generic, and they commented that the query editor supported them in defining these more clearly. The way in which search queries were articulated by stakeholders varied greatly, although it was generally observed that both Case Study Partners and stakeholders query articulation behavior replicated that used for other search engines, which was based on key word searches rather than questions about solutions to specific problems. However, by becoming familiar with the search engine, and being steered by the query editor, the Case Study Partners reported that they "learned to adapt their questioning" beyond single terms to questions, as demonstrated for the IAC case study.

As the search engine was evaluated, and its functionality tested, Case Study Partners involved became aware of the importance of the ontology in its construction. In particular, it became apparent that, while the list of terms was important, it was identifying the correct relations between the terms that was critical for the ontology and tool functionality. In one case study, for example, the importance of spending time developing the ontology was highlighted by the Case Study Partner who found that key terms were still missing even in the later stages of the project:

> “Too late in our project I understood the real importance of the ontology. What amazes me is that there have been many more terms incorporated into the ontology. So there has been a lot of effort apparently in developing the ontology. But too many crucial terms for my case studies are not there”.

Another Case Study Partner also noted difficulties, for Versions 2 and 3 they remarked that they were still unable to find relevant answers, saying:

> “When you write the question of farmers on a very specific subject you can’t find it…. With the ontology we realise now that there are some weaknesses. We realise now how crucial the ontology is.”

For this reason it was sometimes felt by Case Study Partners that there was little progress made between Versions, and they became protective of their stakeholder time in providing a forum for more testing. They also noted that stakeholders did not fully appreciate their role as tool co-designers. In some cases they asked colleagues to test the tool rather than stakeholders themselves, as their colleagues can understand that, as one Case Study Partner explained, “I’m not demonstrating the [search tool] I’m asking you for feedback so we can improve the system”.

In turn, this led some to question the value of ontology construction. One of the Case Study Partners described how ontologies were a completely new concept for his stakeholder group and that it was not easy to convince them that working with ontologies had added value compared to the clever use of existing search engines like Google. The Case Study Partner remarked:

> “My little knowledge and lack of experience on this subject might be one of the reasons [for stakeholders not understanding the concept]. But also the fact that we could not show any relevant output did not help to convince the people that the search engine will work and will supply interesting information and solutions”.

Whilst Case Study Partners as project partners appreciated the effort involved in the search engine development, and shared the overall ambition of the project with all partners, there has been frustration that some feedback had not been sufficiently addressed between test versions, and when prototypes did not function well.

In terms of the project’s iterative methodology, as one Case Study Partner noted:

> "Of course they [stakeholders] are, to a certain extent, willing to contribute to the development of the system, that is what they have done so far. But we should realise that the frequency at which we can show progress in [the search engine] is not very high. This is no problem as long as we can show significant progress each time we meet them".

This was also the experience in another case study where the Case Study Partner remarked:

> "Yes, the last meeting [was particularly difficult]. Because we were showing them something that was not ready yet. It was like driving the prototype of a car and the car doesn't start. It is like a metaphor for the car, this is a beautiful Ferrari, but without wheels".

The Case Study Partners had to manage the expectations of the stakeholders, and to demonstrate progress and ultimately deliver the completed search tool, as promised in early meetings. The Case Study Partners all remarked that that they would also have appreciated longer and more in-depth technical and validation tests over the period of tool development.

5. Discussion

This analysis offers a number of insights into the process of creating a user-centred ontology as a basis for a search engine by working with experts and stakeholders. These insights are not only relevant to this project and specific tool, but have wider significance, as they can be applied to other contexts where practitioners are involved in ICT tool design and development in trans- and interdisciplinary projects.

According to Carlile (2004), a syntactic capacity, in the form of repositories of knowledge from science and practice, is not an adequate capacity to share and assess knowledge, as interpretive differences in the meaning of a word can limit the effective exchange of knowledge between actors at a syntactic boundary. The search engine described here created a user-centred ontology to develop a semantic capacity to allow actors to identify a common meaning as a basis for finding solutions within specific domains.

5.1 Building a semantic capacity

In the evaluation phase the potential users reported that the search engine functioned effectively at a number of levels; the query editor helped users to refine questions, it supported and steered problem formulation and question reformulation, and suggested synonyms and relations which enabled a shared language to be ‘spoken’ between the experts and stakeholders. However, it was observed that developments are still needed before the query editor can fully function as a ‘digital assistant’. This can be attributed to two main reasons.

Firstly, some problems could be traced to the construction of the ontology. The significance of ontology to the effective functioning of the search engine became clearer to all actors involved as development progressed. Some Case Study Partners came to realise “too late” how important the ontology was, possibly suggesting that they did not fully understand the concept or the centrality of their, and the stakeholders’ role, in ontology creation. They took inconsistent and sometimes incomplete approaches to collecting terms in case studies, and sometimes suggested terms without giving any context, making it difficult for relations to be assigned.

There were also limitations in the construction with respect to determining relations. The validation process exposed some fundamental issues with respect to the relations architecture of a number of the ontology terms. This led to revisions in the ontology at a late stage with some adjustment and exclusion of earlier Case Study Partner and stakeholder inputs. From this point the Case Study Partners and stakeholder took a marginal role as the domain experts became the main contributors and architects of the ontology. The role of validation is key to prevent defects spreading to subsequent design and implementation activities (Walisadeera et al., 2015). However, this revision and the dominance of expert terms questions the extent to which stakeholder terms and relations were retained in the ‘common vocabulary’ which was always seen to be at the core of the search engine, in that it aimed to remove the ambiguities and vagueness of natural language in the domain (Willems et al., 2015). It also questions future opportunities for users to suggest or add terms and concepts which was part of the vision of a dynamic ontology.

Secondly, the limitations concern the different arenas in which the experts and the stakeholders operate, and in the way in which they express, or the meaning they attribute to, their innovation issues and questions. Some concepts raised by Case Study Partner and stakeholders could not be easily incorporated into the ontology. Context specific concepts and terms related to supply chains and economics, for example, which were not familiar to the domain experts constructing the ontology, did not have obvious synonyms. This shows how case study stakeholder perspectives extend to the wider system in which they operate where problems and solutions are multi-dimensional. Allen et al. (2017) described a similar limitation in DSS development where stakeholders held whole-system views, and had diverse expectations, problem scoping and evaluation of outcomes which did not align with conventional DSS outputs. The significance of these concepts cannot be sufficiently represented by single terms, equivalent to those employed by domain experts. Furthermore, the 'kind of' or 'related to' relations were challenged to fully replicate the relationships and processes embedded in certain questions articulated in the case studies. It would seem that the expressive relationships among concepts required to represent knowledge cannot always be fully captured in an ontology architecture of terms and hierarchies (Walisadeera et al., 2015). As previous studies have shown, what becomes knowable in an information system, can be strongly guided by the way that a group of experts decides how information will be named, structured, and processed (Poirier, 2017). Additionally, in testing the tool, it was apparent that Case Study Partners made different value judgments about usefulness. This accords with what Straccia (2006) calls fuzzy concepts in ontology-based information retrieval systems, where the notions of 'relevance' or 'aboutness' used to judge retrieved information are always dependent and subjective. This questions whether the improved semantic capacity offered by a user-centred ontology is sufficient to fulfil the ambition of creating a digital assistant which can serve as an intermediate between experts and practitioners.

Such dissonance can be described as a pragmatic boundary, where a pragmatic level is a further level of communication complexity beyond syntactic and semantic in the framework proposed by Carlile (2004)[10]. In this hierarchical representation (with diffuse boundaries between the categories), if a semantic response does not offer the means for sufficient shared knowledge, then a pragmatic capacity is needed for knowledge transformation to effectively share meaning. According to this framework, a search engine can break down with a move away from the syntactic level, if its capacity, as a type of common knowledge, and actor's ability to use it, are not well matched (Carlile, 2004). This break down in the case of the tool described here, where alignment of meanings of some concepts was not always achieved, can be attributed more to the project time constraints than to the concept of enhancing semantic capacity with a user-centred ontology (Fig 5). Case Study Partner and stakeholder input became increasingly marginal as the validation process carried out by domain experts intensified with the approaching project deadline. The opportunity for further iterations to expand terms and ensure that the ontology represented common meanings and interests was less than expected. As Carlile (2004 p563) notes "being able to propose,

[10] Although in Carlile's framework the categories syntactic, semantic, and pragmatic were respectively linked to the information-processing, interpretive, and political perspectives in organisation theory, it can be applied to the search engine development described here.

negotiate, and transform knowledge lies at the heart of trial-and-error problem solving at a pragmatic boundary" and managing knowledge at a pragmatic boundary requires multiple iterations. As the actors participate in each iterative stage they improve it by collectively developing a more adequate common lexicon, meaning, and interests. Stakeholders and Case Study Partner input represented the practical aspects of the domain, with innovation issues being identified and expressed as context specific questions, while competency questions from the case studies are used in validation and evaluation. Potentially further iterations to deepen and extend these activities and more focus on, and standardisation of, stakeholder contributions to the ontology, would have helped to connect across this boundary (Fig 5). However, as noted next, managing such iterations in a time and resource limited project setting can be demanding.

[Insert Fig 5]
Fig 5. Framework for managing knowledge at a pragmatic boundary

5.2 The demands of the approach

Commentators note that, with respect to Information Systems development, to successfully build a large and complex system, team members have to continuously communicate and learn from each other regarding the architecture and capabilities of the new system, and in articulating the users intentions (Joshi et al., 2007). The need for dialogical processes between designers and users, which requires user-adaptation of tools and reflexive approaches is well recognised (Beguin et al., 2012). In constructing the search engine the project team discovered that the novelty, and ambition, of the approach, required a flexible and iterative approach by all involved. As such the feasibility of, and the means of achieving the vision for the search engine, was constantly reviewed and critiqued by partners throughout the project in an on-going, reflective process. In turn, this needed good cross-partner communication and a shared conceptual understanding, ambition and set of expectations. Involving Case Study Partners as project partners and the responsiveness of the computer scientists to stakeholder and Case Study Partner validation and evaluation was a particularly positive feature. However, inevitably there were some different interpretations and expectations within the project team, interaction was limited to project meetings, and time required for ontology development under-estimated.

Whilst the aim was for a user-centred ontology to be built with stakeholder input using an iterative approach, managing relationships brought some frustrations in the case studies in terms of utilising stakeholders' time and meeting their expectations. Tensions emerged between the need to build and test an ontology systematically over a period of time and the potential users' demand for some evidence that their time was being used effectively in building a functioning tool. As Cerf et al. (2012 p907) note "as the prototype approaches the final version, it is difficult for the designer to backtrack, due to the costs and time invested. On the other hand, exploring the most operational aspects with a highly conceptual artefact … is difficult". This raises questions about finding an appropriate balance between allocating sufficient time to search engine development and spending more time in the early stages of co-constructing the ontology architecture, against testing early prototypes with users. The role of Case Study Partners as gatekeepers or intermediaries in reconciling differences between tool developers and stakeholders is also noteworthy. Many studies of tool development consider the essential role of the facilitator in leveraging tool outputs and engaging tool outcomes (Castella et al., 2005) but few consider the tensions they need to manage (Ingram et al., 2016). In accordance with Ditzler et al. (2018), who note that capacity, agency, interest, and mandate of the users is key in the activation of what they refer to as 'second-order functional affordances', experiences in this study reveal multiple interests in tool co-design. Furthermore, using an ontology for structuring and representing problem specific knowledge into a knowledge repository requires dedicated time and effort, with demanding procedures, methods, staff, and professional expertise needed to organise information so that it can be queried in a context-specific way (Miah et al., 2014, Walisadeera et al., 2015). These observations are equally pertinent to other projects tasked with information management or DSS development requiring iterative and participatory user-input (Hochman et al., 2009). More generally these findings highlight the limitations of operating within the temporary organisational boundaries of a research project (Godenhjelm et al., 2015).

6. Conclusion

Providing tools that can access research data intelligently and cost effectively is important in agriculture to effectively mobilise knowledge resources and so improve innovation. This paper described an original and innovative approach to capturing a large body of research-based knowledge in agriculture and making it accessible and meaningful to the users. It reveals the complex and intensive processes operating when users are involved in ontology construction, and the challenges of capturing relationships and systemic concepts to enable effective dialogue between user and digital system. It also shows that the extent to which user-centred ontologies can replicate the contextualisation process of knowledge exchange, and deal with the subjective and fuzzy world of knowledge representation is dependent on the approach to their construction (Straccia, 2006).

The paper makes a theoretical contribution to our understanding of tool co-design by adapting the framework of syntactic, sematic and pragmatic capacities to the agricultural search engine context. The analysis shows how involving users in the design of the user-centred ontology moves the search engine from an information processing synaptic capacity to a semantic capacity (beyond current web semantic abilities) where common meaning concerning specific agricultural domains can be represented and shared. It proposes that the remaining interpretative differences can be overcome by building pragmatic capacity and managing knowledge at a pragmatic boundary through further multiple iterations with users.

In developing these concepts this paper adds to the body of work responding to the need to develop novel design methods and further open up co-design (open innovation), and to blur the boundaries between designers and users in agricultural innovation (Berthet et al., 2018). It also contributes to what has been called a turn for the 'scruffy' in the field of web semantics (Poirier, 2017), which is "perpetuated by the persistent reminders that the world views and concepts diverse people use to describe their world don't often fit into tighter systems of representation" (Brügger and Milligan, 2018 p267). Finally, the paper raises questions more widely about how large amounts of information and data in agriculture can be managed to provide meaningful knowledge to users, and about who manages and curates representation of this knowledge (Pauleen and Wang, 2017, Poirier, 2017).

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