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Engineers and the Web: An analysis of real life gaps in information usage

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Abstract

Engineers face a wide range of gaps when trying to identify, acquire, and utilize information from the Web. To be able to avoid creating such gaps, it is essential to understand them in detail. This paper reports the results of a study of the real life gaps in information usage processes of 17 engineers. Using the critical incident interviewing technique, 65 examples of information usage processes were uncovered. An inductive analysis of these data, using the constant comparison method, yields five classes of identification gaps, of acquisition gaps, and of utilization gaps. Within these fifteen gap classes, 79 types of information usage gaps are identified. The results of this study confirm and extend existing studies on information usage gaps. Future research should examine whether such gaps need to be bridged and, if so, how they could be bridged.

Keywords: Information usage processes; Engineers; Gaps; Critical incident technique

1. Introduction

Over the last decade, the Web has become an increasingly important source of information for engineers (Kraaijenbrink & Groen, 2006). With the growing use of the Web as a source of information, new challenges have entered engineers' information usage processes. Examples include dealing with information overload and establishing the quality of information found on the Web (Choo, Detlor, & Turnbull, 2000). To effectively deal with such challenges, it is necessary to understand them in detail. Existing studies have provided general insights into the challenges associated with information usage but they have not provided the detail necessary to effectively deal with them. The objective of this paper is to start filling this hole in the current literature by an in-depth analysis of information usage gaps.

As studies on sense-making gaps have demonstrated, an analysis of gaps is a very effective approach for producing detailed information on a process (Dervin, 1992, 1999; Savolainen & Kari, 2006). Using this approach, this study provides a detailed analysis of real life information usage gaps met by engineers in

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small- and medium-sized enterprises (SMEs) involved in new product development (NPD). Data have been gathered using the critical incident interviewing technique (CIT) (Flanagan, 1954). An analysis of the real life examples uncovered using this technique generates a typology of information usage gaps on a level of detail not previously provided by other studies.

The contributions of this paper are twofold. First, it analyzes the complete information usage process of engineers, ranging from the initial identification of information to its usage in the firm. By categorizing the gaps that engineers face in this process, the paper provides a more comprehensive and systematic view of the Web information usage process, and the challenges associated with it, than found in earlier publications. Second, the paper documents the application of the CIT in the analysis of information usage processes. Although not new, the CIT has yet to be well documented. By providing a detailed description of how the CIT was applied in this study, the paper can guide other researchers in applying this technique.

The paper is structured as follows. Section 2 provides a review of the current literature on engineers' information usage processes. Subsequently, Sections 3 and 4 outline the theoretical approach and the method used in this study to analyze information usage gaps. Section 5 presents the result of this analysis, and the paper ends with a discussion and conclusions (Section 6).

2. Literature review

Information usage processes have been intensively studied since the 1960s. Since then, these processes have been studied both at the level of individuals (e.g., Case, 2002; Krikelas, 1983; Kulthau, 1991; Taylor, 1968) and at the level of firms (e.g., Aguilar, 1967; Choo, 2002; Daft & Weick, 1984; Rosenbloom & Wolek, 1967). Since the rise of the Web in the 1990s, studies on information usage have, at both levels, increasingly included electronic environments in general and the Web in particular (Choo et al., 2000; Kraaijenbrink & Groen, 2006; Marchionini, 1995). Similar studies have focused on various groups of Web users, including children (Borgman, Hirsh, Walter, & Gallagher, 1995), consumers (Menon & Raghubir, 2003; Moorthy, Ratchford, & Talukdar, 1997), and the general public (Jansen, Spink, & Saracevic, 2000; Spink & Jansen, 2004). The specific focus group of this study, engineers, has also been studied extensively. As examples, studies have been conducted on information usage by scientists and engineers (Anderson, Glassman, McAfee, & Pinelli, 2001; Ellis & Haugan, 1997; Gralewska-Vickery, 1976), by R&D departments (Allen, 1977), and by new product developers (Court, 1997).

Numerous aspects of engineers' use of information have been studied to date. A topic that has received much attention involves the types of information and the types of information source that are used. Studies have shown that engineers use a broad spectrum of information including market, technological, and organizational knowledge (Faulkner & Senker, 1995). It has also repeatedly been shown that this information is obtained mainly from customers and suppliers (Jetter, Kraaijenbrink, Schröder, & Wijnhoven, 2005; Johnson & Kuehn, 1987; White, Bennett, & Shipsey, 1982). Such studies have also shown that engineers prefer personal to impersonal sources (McGee & Sawyerr, 2003; Tenopir & King, 2004), prefer informal to formal sources (Julien, 1995; Tenopir & King, 2004), and prefer internal to external sources (Robertson, 1974). Further, there have been studies explaining the decision to use one particular source or channel over another. Amongst the factors affecting this decision are accessibility (Fidel & Green, 2004; Gerstberger & Allen, 1968), trust (Hertzum, 2002), task complexity (Byström & Järvelin, 1995), and minimizing effort (Hardy, 1982). From this brief overview, it can be concluded that information usage by engineers, and in particular information seeking on the Web, have already been studied extensively.

Using information from the Web involves many challenges. Previous studies have highlighted challenges such as dealing with information overload (Turetken & Sharda, 2004) and establishing the quality and relevance of information found on the Web (Borlund, 2003; Choo et al., 2000; Spink, Greisdorf, & Bateman, 1998). Moreover, studies on website design and evaluation have suggested ways to meet these challenges. Examples include choosing an appropriate browsing structure (Lai & Yang, 2000; Olston & Chi, 2003), designing for interaction (Chen & Yen, 2004; Ellis, Wilson, Ford, Lam, & Burton, 2002; Spink, 2002), and applying cognitive design (Dalal, Quible, & Wyatt, 2000).

Together, these studies have produced numerous useful insights into the way engineers use information found on the Web, into the challenges that are associated with this, and into ways to deal with these

challenges. What these studies have in common is that they provide general knowledge that is likely to be generalizable to a wide range of information users. However, these studies provide little guidance in how to deal with the specific challenges facing engineers when they want to use information from the Web. For example, knowing that accessibility is an important factor in explaining the choice of a particular information source does not tell us how to make a particular website more accessible. Similarly, knowing that interactive websites are more effective than non-interactive ones is not the same as providing guidelines on how to make a particular website more interactive. These observations support Saracevic's (1999) general concern of a growing gap between the human side and the system side of information science. This study starts to close this gap in the current literature by providing a detailed analysis of the gaps that engineers face in using information from the Web.

3. Analyzing information usage gaps

The analysis of information usage gaps in this study draws on the notion of sense-making gaps (Dervin, 1992, 1998) and its recent application to Web searching by Savolainen and Kari (2006). Sense-making gaps are cognitive gaps as perceived by individuals, and they have been described as follows: "From time to time, movement is blocked by the perception of a cognitive gap – a situation in which people are unable to make sense of their experiences. To bridge this gap, individuals seek information to make new sense and use this information to help them continue on [...] their journey" (Choo et al., 2000, p. 4). Hence, a sense-making gap triggers an individual to start looking for information. In addition to cognitive gaps, there can also be affective and situational gaps in the information usage process (Choo et al., 2000; Menon & Varadarajan, 1992). Affective gaps concern the fulfillment of emotional needs and are associated with uncertainty, anxiety, frustration, and stress (Kulthau, 1991, 1993; Wilson, 1997). Situational gaps arise in a situation (environment, context) in which actors are operating but cannot fulfill their tasks or perform their activities (Wilson, 1981).

As used in their original senses, these three types of gaps *trigger* a search for information – information that can be used to bridge the gap. This study, however, like Savolainen and Kari's study, analyzes gaps *during* the search for information from the Web. That is, this study does not analyze the reasons why engineers start looking for information but the gaps they face when they want to use information from the Web. Following Dervin's definition of a gap, an information usage gap is defined here as a discontinuity in the information usage process. In order to cope with such gaps, engineers will have to employ a gap-bridging activity. Following Savolainen and Kari, Web information usage is understood here as a dynamic process of gap-bridging triggered by gap-facing.

During the information usage process, engineers will face and bridge various gaps. The purpose of this study is to uncover and categorize these gaps. This requires an inductive approach in which the researcher enters the field without too many theoretical preconceptions. This does not mean that the researcher should enter the field with a completely open mind (Glaser & Strauss, 1967). Rather, researchers need an appropriate lens to guide them to where one might expect gaps. An appropriate lens for this study is a model of the information usage process. Such a model suggests where to look for information usage gaps rather than what the actual gaps are likely to be. When we look at the range of information usage models, it appears that information usage is a process involving multiple steps (Choo, 2002; Corner, Kinicki, & Keats, 1994; Ellis & Haugan, 1997; Kulthau, 1991; Leckie, Pettigrew, & Sylvain, 1996; Wilson, 1997, 1999). Since we did not want to be directed by any specific model, it was decided to use a simple and general model reflecting the common factors in all these models. In this general model, information usage is considered to be a three-step process. Firstly, in order to be aware of its existence and location, information needs to be identified, for example by browsing, searching, or accidentally encountering information. *Identification* is an interactive process between information source and information user, eventually resulting in a 'compromised need' and – if successfully completed – in the finding of information (Dervin, 1992; Taylor, 1968). After information is identified, it needs to be transferred to the user. The second step is thus information *acquisition.* In the case of Web searching this is not as straightforward as it may seem. In many cases it will not be the information as it appears on the Web, but some meta-information reflecting the information that one needs. In such cases, actually acquiring the information will require additional effort such as interactive communication and cooperation between

information source and information user. Finally, since the information is acquired for some purpose, it will probably be used by the engineer that has acquired it, or by one of their colleagues. The final step is therefore *utilization.* For example, the information could be stored in an archive, it could be applied in a business process, or it could be transformed into a more usable form (e.g., by translation). In the research described below, gaps associated with each of the three steps have been identified and categorized.

As touched upon in the above discussion on situational gaps, context is an important factor in many of the information usage models where it is mostly included as a factor from which information needs arise and in which information is used (e.g., Belkin & Croft, 1992; Krikelas, 1983). Additionally, as stressed by Johnson (2003), context is a crucial factor in shaping the information usage process: depending on the context, information usage processes can be very different. This implies that context should be taken into account in studies on information usage. Probably the most commonly applied method in studies on Web searching involves carrying out research in an experimental setting (Savolainen & Kari, 2006). This has many benefits (such as internal validity and reliability) but a limitation of such research is that it is conducted without a realistic context. Since sense-making gaps are highly context-specific, experimental research is not appropriate for this study. A better approach is to study real life information usage processes in their context. An appropriate method for such a study is to inductively gather rich information on the information usage behavior of a particular group of people and, in this study, engineers.

4. Method

The three-step model of information usage gaps outlined above provides a means to analyze the information usage behavior of engineers during new product development (NPD). In this way, an inductive approach was followed staying as close as possible to the practices of engineers. In such an inductive approach it is important to obtain a rich and comprehensive picture of actual practice (Lee & Baskerville, 2003; Miles & Huberman, 1994). Spradley (1980) recommends highly intrusive techniques such as participant observation for this type of research. However, since information usage is an intangible process and not performed at one specific point in time, it is impracticable, if not impossible, to use this technique successfully. Instead, the critical incident interviewing technique (CIT) was used (Flanagan, 1954). The CIT is recognized as a valid, reliable, and effective method for gathering rich qualitative data for a variety of purposes, including the analysis of information behavior (Fisher & Oulton, 1999; Urquhart et al., 2003). Of the available interviewing techniques, CIT is considered to give one of the most accurate and reliable retrospective reports of processes as they take place in practice. Using this technique, interviewees are asked to describe in detail both successful and unsuccessful examples of the process under study. It is crucial in this type of interview that interviewees are allowed to concentrate on description and are not distracted by being asked for explanations of their behavior. If explanations are needed, these should only be sought after the description is complete.

A crucial step within the CIT is the demarcation of the critical incident. In this paper, this concerns whether respondents should be asked to describe incidents concerning Web information usage or information usage in general since the Web is but one of many information sources used in the NPD process. Moreover, in the information usage process, engineers switch frequently from one source to another, implying that the Web information usage process is interwoven with the wider information usage process. Given this strong connection between the Web information usage process and the wider information usage process it was decided to ask respondents to describe examples illustrating processes of wider information usage. This paper, however, only reports those results that concern the use of information from the Web.

4.1. Interview scheme

Based on the characteristics of the CIT, a semi-structured interview scheme was developed that consisted of three parts. The purposes of the first part of the interviews were twofold. Firstly, it helped the interviewer gain a rich picture of the context and the general way in which information was used in the company. Secondly, it prepared the interviewee over the type of critical incidents to be described in the second part of the interview. This first part included the following topics:

- Description of the company, its products, markets, and recent and future developments.
- Description of the general NPD process in the company, including the role of the interviewee.
- Description of the general information usage process during NPD in the company, including the identification, acquisition, and utilization of information from external sources.

The second and main part of the interview was used to obtain descriptions, explanations, and reflections of at least one successful and one unsuccessful incident concerning information usage in the company. To avoid distracting interviewees during the descriptive part, explanatory and reflective questions were only posed after the description was complete. Interviewees were asked about the following topics for each incident covered:

- Description of a specific example of information usage during NPD in the company, including the identification, acquisition, and utilization of information from external sources.
- Explanation of why they acted in the described way.
- Reflection on problems and potential improvements.

The final part of the interview was used to elicit additional details concerning the incidents by confronting the interviewee with a number of classifications, taken from the literature, on types of NPD problems, information needs, types of information, and information sources. This prompted respondents to reflect on their answers and helped them to remember additional details.

4.2. Sampling

The targeted interviewees were engineers and NPD managers working for high-tech manufacturing SMEs. In selecting interviewees, the principle of theoretical sampling was used (Glaser & Strauss, 1967). Using this principle, the type and number of respondents are not established in advance, but result from the need for further exploration until theoretical saturation is achieved. The enquiry started with a selection of four respondents in the electronics industry, two in the chemical industry, and one machine manufacturer (see Table 1 for details). After an initial analysis of the seven interviews, it was concluded that there was a need for additional interviews: (1) at one similar machine manufacturer; (2) at one similar chemical company; (3) at one engineer-

Table 1
Profile of respondents and their companies

Company	Industry	Number of employees	Founding year	Interviewee
First round				
CSE (CE)	Electronics – optical measurement	2	1994	Director/engineer
Rebix (RX)	Electronics – analogue devices	1	1997	Director/engineer
Unitron (UT)	Electronics – control systems	7	2000	Director/NPD manager
MMS (MM)	Electronics – diagnostic	50	1988	Engineer/NPD manager
Dick Peters (DP)	Chemical – wax emulsions	35	1956	Engineer
Drywood (DW)	Chemical – coatings	20	1895	Engineer/NPD manager
Bouman (BM)	Machine – specialties	90	1990	Engineer/NPD manager
Second round				
Lionix (LX)	Nanotechnology – mech, optical, fluids	16	2001	Engineer
Medspray (MS)	Nanotechnology – fluids	6	2001	Director/engineer
Emotech (ET)	Machine – coating	23	1970	Engineer/NPD manager
Eurochemie (EC)	Chemical – lubrication, cleaning	35	1991	Engineer/NPD manager
Idé partners (ID)	Engineering – industrial series	10	1990	Engineer/NPD manager
Procedé (PC)	Engineering – process technology	23	1993	Director/NPD manager
Procedé (PC)	Engineering – process technology	23	1993	Engineer/NPD manager
Final round				
Artecs (AT)	Chemical – polymers	5	2002	Engineer/NPD manager
Genetwister (GT)	Genomics – agricultural	25	1998	Director/NPD manager
Norit (NO)	Machine – membrane filtration	4	1995	Director/NPD manager

ing company; (4) with two people with different roles in one company; and (5) at science-based rather than technology-based companies in one industry. After analysis of these additional seven interviews, it was felt that saturation point had been reached. That is, no new types of information usage gaps were to be found. To examine whether this was indeed the case, additional interviews were completed in three very different companies. In these three additional interviews no new types of information usage gaps were identified, which strengthened the confidence in having reached saturation point.

4.3. Analysis

Each of the 17 interviews lasted between 70 and 180 min, with an average of about 2 h. They were recorded and fully transcribed, resulting in 768 pages of double-spaced text. Information usage gaps were identified by comparing successful cases (i.e. where gaps were bridged) with unsuccessful cases (i.e. where gaps were not bridged) using the constant comparison method (Glaser & Strauss, 1967). The total number of information usage processes described by the interviewees was 65, that is an average of close to four incidents per interview. For each example described by the interviewees, the sequence of activities and aspects was coded into an MS Excel spreadsheet. Subsequently, words were identified indicating the existence of information usage gaps, that is, indicating a difference between an actual and a preferred state. Such words can express a gap (e.g. problem, difficult, too, not, do not), a preference (e.g. want, prefer, like), or an adjustment (e.g. change, translate, adjust). As a next step, the identified gaps were categorized into as many categories as possible, as recommended in the constant comparison method. The final step was to reduce the number of categories to enable a more efficient classification.

5. Results

The analysis of the 65 incidents generated a list of gaps faced by engineers during the information usage process. Tables 2–4, present identified gaps that are respectively associated with information identification (five categories), acquisition (five categories), and utilization (five categories). As such, these tables are the main outcome of this study. Below, examples reflecting each of the fifteen categories are discussed in more detail.

5.1. Information identification

The first group of information usage gaps concerns the identification of information from outside the company. As shown in Table 2, these gaps mainly relate to how the information is organized and presented by its source, and to what extent users are able to specify their specific information needs. Five categories of gaps were identified with several examples of each shown in the table.

The respondents mentioned a number of gaps that were related to their information needs. Looking for common factors, these gaps suggest that most information sources are oriented towards users that need specific information for a specific purpose whereas the engineers that were interviewed often had much vaguer intentions when they began to look for information. For example, they wanted to grasp how a particular domain that was new to them was organized (‘orientation’) or they wanted to get ideas on how to proceed when they became stuck in an NPD process (‘inspiration’). With intentions that are so vague, it is not surprising that the respondents considered the path leading to the uncovering of information sometimes more important than the finding of the information itself. Precisely because they were not sure of what information they actually needed, they were quite happy to find interesting information that they had not even considered during their search path. This gap between an engineer’s initial need for information and their final need is a natural characteristic of the information usage process (see, for example, the discussion on information identification in Section 3). However, as the engineers saw this gap as hindering them in identifying information, it is an important gap for them.

Where the respondents did have a clear idea of what information they needed, they found numerous gaps concerning the availability of that information. An interesting gap is that the users sometimes needed information that did not yet exist (or at least information which one or more ‘sources’ indicated did not exist). As NPD involves the invention of new things, it seems natural that, given the particular context of this study, this

Table 2
Information identification gaps

Gap	Explanation
Related to information needs	
Specified/unspecified need	Querying is only possible on specific criteria; seekers want to query in more general terms
Specific/general need	Seekers want information for orientation and inspiration; sources provide it for fact finding and retrieval
Initial/compromised need	Initial need of seekers is not the same as final/compromised need
Path/result need	Seekers want to find information and learn from the seeking path to this information; sources provide the information but not in a way that seekers learn from the path to this information
Related to the availability of information	
Quantity	The amount of information provided by sources is too large or too small for seekers
Diversity	The diversity of information provided by sources is too large or too small for seekers
Customizability	The amount and diversity of information supplied at a time cannot be changed while seekers want this facility
Existence	Seekers need information that does not yet exist
Not published	Seekers need information that is not published
Accessibility	Seekers need information from an inaccessible source (e.g., no Web presence)
Awareness	Seekers need information from a source of which they are unaware
Central/side issue	What is a side issue for the source in domain A is central issue for the seeker in domain B
Related to the categorization of information	
No categorization	Information is not categorized by sources; seekers want it to be categorized
Unhelpful categorization	Information is categorized by supply structure (e.g. departments of the organization); seekers want it categorized differently (e.g. by product)
Equivocal categorization	Sources provide an equivocal categorization; seekers want an unequivocal one
Multiple categorizations	Sources provide a single categorization, seekers want multiple categorizations of the same information
Related to the navigation options that are provided	
Sideward links	Seekers want links to similar information; sources do not provide this
Upward/downward links	Sources only offer the opportunity to browse downwards in the browsing tree; seekers also want to browse upwards
Forward chain links	Seekers want to know to whom organizations supply their products; sources do not provide this
Backward chain links	Seekers want to know who are an organization's suppliers; sources do not provide this
Deep links	General search engines do not access information on the 'deep Internet'; seekers want this
Multiple channels/ sources	Seekers want access to multiple channels/sources simultaneously; sources do not provide this
Browsing depth/width	Sources provide deep/narrow browsing structures; seekers want shallow/wide ones
Unequivocal/equivocal	Seekers want unequivocal navigation; sources provide equivocal navigation (e.g., ambiguous labeling of links)
Multiple navigation options	Seekers want multiple ways to navigate (e.g., various browsing trees for the same information); sources provide only one way
Position in website	Seekers want to know their location in a website; sources do not provide this
Source/information	Seekers want to go from information to its source and vice versa; sources do not offer this
Search/browse/order	Seekers want the search, browsing, and ordering function to be integrated; sources provide them separately or only partly integrated
Related to the language that is used	
Spelling	Sources use spelling *X*; seekers use spelling *Y*
Language	Sources provide information in language *X*; seekers want it in language *Y*
Jargon	Sources use commercial name *X* (e.g., brand name) for a product with the technical name *Y*; seekers only know technical, or general, name *Y*
Homonyms	To sources, *X* means *A*; to seekers, *X* means *B*
Relativity of qualifiers	For example, for sources 'heavy' means '10 tons'; for seekers 'heavy' means '1 microgram'
Synonyms	Sources use label *X* to describe *A*; seekers use label *Y* to describe *A*

gap should have appeared frequently. The fact that the engineers found that the necessary information did not yet exist, was not in all cases a negative outcome. It could provide them with an opportunity to develop this information (alone, or together with the 'source') and use it in order to create a competitive advantage. Hence, in this particular context, discovering that the information needed does not exist could be the best possible outcome.

The third category of identification gap relates to the categorization of information. It appeared that the way information was categorized by and between sources was a major barrier to identifying information. Probably the most crucial type of gap that was mentioned in this category is that many sources categorize their information based on the structure of their own organization rather than in a user-oriented way. As an example, as engineers, the respondents were often looking for particular components they could use in making a new product. In order to find such components, they needed categorizations based on component features (such as size or capacity). However, suppliers of such components often categorize this information based on the departments that produce the components within the company. As this categorization was unrelated to the component features the engineer was interested in, it was very hard for the engineer to find the required information.

Navigation was a fourth area in which gaps were mentioned. Of particular interest in the context of this study are the forward and backward chain links to suppliers and customers. A frequently used strategy in gathering information about competitors was to identify their suppliers and customers. While information on customers was usually available ('forward chain links'), it was very hard to discover a company's suppliers ('backward chain links'). Another interesting gap was that only very few websites provide the opportunity to move up a browsing tree. When arriving at particular information, such as a product description, the respondents often wanted to know whether a company produced other similar products. For that, they wanted to be able to move up one level in the browsing tree to find out whether there were other products in the same category. Sources' websites, however, usually failed to provide such an option.

Finally, information identification was hindered by language gaps between information sources and users. This gap turned out to be particularly important in terms of formulating keywords. Many respondents indicated that identifying appropriate keywords to enter into a search engine was the most difficult part of the whole information usage process. Search engines were usually used as the first step of the process. At this point, the respondents did not really know what they were looking for, but only had vague ideas about the new product they had in mind. This means that the engineers had to think both about what they were going to look for and how they would label this. Once they had thought up some terms to enter, they faced the problem that information sources often used different terms to themselves. Only when they had worked out what terms were used in the domain concerned, could they continue without too many problems. One language gap that appeared particularly significant was the use of commercial brand names and technical names in describing a product. Being technical, the engineers usually used a technical name in querying a product. However, sources' websites, generally used as marketing channels, usually used commercial brand names instead. This made it hard for the engineers to identify the relevant product.

5.2. Information acquisition

The second group of information usage gaps is associated with the acquisition of information. These gaps concern the transfer of information from a source to a user. As Table 3 indicates, five categories of information acquisition gaps were identified.

The first type of acquisition gap is related to carriers of information. NPD is a process aimed at the creation of physical products and, for the development of such products, engineers require a huge amount of information. Some of this information is available in the form of documents and people. However, other information is not available in such forms. Therefore, engineers also need physical products and components as carriers of information. They order these products/components and deconstruct them in their lab. This means that the ordering of products/components through the Web is an important aspect of information acquisition. In the interviews, the respondents commented that sources treat these aspects separately; that is, information provision and ordering facilities are usually provided at separate locations within a website and are not well linked.

Even when information is available, this does not mean it can be acquired by a user. Property right issues form another acquisition barrier, for example, in the form of patents. While patent databases were reported to be important sources of information, legal restrictions meant that acquiring and using the information was often impossible. A related gap is the fact that sources tend not to publish valuable information on the Web. Publishing information in full would amount to giving the information away for free. Therefore, sources

Table 3
Information acquisition gaps

Gap	Explanation
Related to information carriers	
Format	Seekers want information in format X (e.g., a .doc file); suppliers provide it in format Y (e.g., a pdf document)
Carriers	Seekers want information on carrier 1 (e.g., a document), sources provide information on carrier 2 (e.g., in a person)
Information/product	Seekers want both the information and the physical object it represents (e.g., a product or a component); sources do not provide this
Related to intellectual property	
Property rights	Seekers are not allowed to use the specific information that they need
Meta-information	Seekers want information; sources provide meta-information but not the information itself
Selection	Seekers want information; sources provide excerpts in order not to give away all information
Related to the roles and matching of actors	
Level of collectiveness	Seekers want information from particular people; sources provide information as a company
Interests	Interests of source and seeker are too similar or too different
Level of expertise	The levels of expertise of source and seeker are too similar or too different
Expertise area	Areas of expertise of source and seeker are too similar or too different (e.g., marketing vs. R&D)
Domain	Domains of source and seeker are too similar or too different
Technological platform	Technological platforms of source and seeker are too different
Related to time	
Reaction time	Seekers want fast responses from sources; sources respond too slowly
Time availability	Seekers have time t available but need time $t + 1$ to acquire information
Iterations	Acquiring specific information requires too many iterations
Related to finance	
Affordability	Seekers need information they cannot afford
Value	The value of information is different for sources and seekers
Finance model	Seekers want finance model X (e.g. pay per use) whereas sources offer model Y (e.g., a subscription service)

publish meta-information, describing the information, or only excerpts from the information. Information users, however, need the full information. Hence, from the perspective of the user, there is a gap between the information they have identified and require, and the information they can acquire directly.

A third category of acquisition gap relates to the roles and matching of actors. NPD involves the crossing of domains and areas of expertise, and respondents mentioned many gaps related to this. An interesting gap here concerns the level of collectiveness. On their websites, many companies present themselves as an organizational unity rather than as a collection of individuals. The engineers that were interviewed, however, were usually much more interested in particular people (usually other engineers) within the other company, for example because these would be the only ones in the company who would understand their questions. It seemed to be very difficult to obtain information from such individuals. Another gap in this category that was frequently mentioned was the gap between information source and user in terms of areas of expertise. It appeared that most websites were developed by the marketing department of a company. The websites were designed with a typical customer in mind as the target group. However, engineers are a very different group, using the websites for very different purposes. For example, the respondents did not want to buy products; they wanted to find the technical details of the product and its components. Websites, however, often fail to provide such details.

The respondents also mentioned a number of gaps related to time issues. In general, users want the information immediately. As it will take some time to find information and then obtain it, there is usually a time gap between the occurrence of an information need and acquiring the relevant information. From the interviews, it appeared that in using information obtained from the Web this time gap is strongly felt, a finding which is consistent with previous research. The engineers expected much faster responses using the Web than using other channels. Respondents even mentioned a few times that when they did not feel they were getting any closer to the information they needed within a few clicks, they would immediately switch to another web-

site and forget the previous one. Quickly perceiving a feeling of getting closer to the relevant information appeared to be more important than actually finding the information quickly. This seems to be in line with Pirolli and Card's (1999) information foraging theory.

Finally, the respondents mentioned acquisition gaps related to finance. An interesting gap here is between the value of information to the user and the value of this same information to the source. As noted above, many websites are developed for marketing purposes. Put simply, the objective of these websites is to increase sales of a company's products by providing information to potential customers. Hence, it is not the information that is seen as the most valuable component, but the products it describes. Conversely, the engineers that were interviewed were more interested in the information about a product than in the actual product. This means that the value of the actual information is higher for the user than for the source. The opposite was also found. For example, an engineer investigating a new market might find sources providing market reports but these reports are seen as too expensive by the engineer's company.

5.3. Information utilization

The final group of information usage gaps concerns the utilization of information. These gaps concern the question as to whether the information acquired is actually applicable for the NPD problem for which it was sought. Table 4 lists five categories of utilization gap which are discussed below in some detail.

The first type of information utilization gap relates to the application domain of the information and the information user. Using information from another domain (e.g., a different industry) than the domain of their own company is an essential part of the NPD work of engineers. They often take a solution that is used in another industry and change it such that it can be used in the given domain. Although this is an effective way of developing new products, it involves challenges. In the source domain, products are used for certain applications and described in terms of those applications. For example, in its original application, a small fluid container is used for the storage of insulin for diabetes patients. Consider an engineer in another industry wanting to use it as a container within a medicine sprayer: this engineer faces the problem that no-one has thought about this application for the container. Consequently, the engineer has to translate the information to this new domain.

A second category of gap relates to the level of aggregation of information. During the interviews it appeared that the information engineers found was often described at a lower or a higher level of aggregation than what they needed. For example, when engineers were trying to find out how a particular industry was organized, they could only find information from and about individual companies within that industry. A similar type of gap emerged when they were looking for information about specific components, products, or product packages. For example, engineers might be looking for information on a particular component, whereas sources only provided information about a product in which the component was used.

Thirdly, many gaps were mentioned that were related to the level of abstraction of the information. An important gap in this category concerns the constant interplay between application, function, and form during the information usage process of engineers. Since NPD, almost by definition, involves finding new solutions, respondents faced the problem that they more or less only knew what the solution they had in mind should do; that is, they knew the required function. However, they did not know what form was needed or indeed available to fulfill that function. Conversely, sources of information usually described the form or application of a solution, and not its function. An example concerns a case where one of the respondents needed small lamps that were more robust than ordinary light bulbs. He knew what size the lamp should be, how much light it should produce, and the maximum amount of heat it should produce (i.e. its function), but not whether such a lamp existed and, if so, what it was called (i.e. its form). Only after a long search did he find out that such a lamp existed: they were called high-efficiency LEDs, which was the name given by the source to reflect the perceived benefit of increased efficiency (application).

A fourth category of gap was related to the quality of the information provided. Quality includes criteria such as correctness, completeness, and certainty of information. For each of these criteria, and the other criteria mentioned in Table 4, there appeared to be a stepwise gap when moving from the information needed to the information found. That is, there were gaps between the information that was needed, the information

Table 4
Information utilization gaps

Gap	Explanation
Related to the application domain	
Description	Sources provide information meant for domain *A*; seekers want to use it in domain *B*
Restriction	Sources provide information for domain *A*, but its use is restricted to other domains (e.g., because a source does not want its information to be used by competitors in the same domain)
Projection	Sources provide information on the current situation; seekers need it for future situations
Strategic-operational	Information is provided for strategic reasons; seekers need it for operational use
Related to the level of aggregation of information	
Single/multiple	Sources provide information on a single product/company; seekers need information on multiple products/companies
Part/whole	Sources provide information on the level of components, products, or product packages; seekers need it on a different level (e.g., component level rather than product level)
Related to the level of abstraction of information	
Application/function/form	Sources provide information on the application, function, or form of a product; seekers want it on a different level of abstraction
Applied/fundamental	Sources provide applied information; seekers want fundamental information
Symptom/problem/solution	Sources provide information on symptoms, problems, or solutions; seekers want it on a different level (e.g., problems rather than symptoms)
Variable/indicator	Sources provide information on indicators; seekers want information on variables
Related to the quality of information	
Correctness	Needed/perceived/claimed/factual correctness of information differ
Completeness	Needed/perceived/claimed/factual completeness of information differ
Certainty	Needed/perceived/claimed/factual certainty of information differ
Depth	Needed/perceived/claimed/factual depth of information differ
Up-to-dateness	Needed/perceived/claimed/factual up-to-dateness of information differ
Stability	Needed/perceived/claimed/factual stability of information differ
Specificity	Needed/perceived/claimed/factual specificity of information differ
Related to missing and incomparable information	
Interpolation	Sources provide discrete information (e.g. in a table format); seekers want information for slightly different values (e.g. by providing a continuous graph)
Extrapolation	For example, sources provide information about cases 1 through 5; seekers need information about case 8
Standard/customized	Seekers want information about standard components; sources provide information about customized components
Commodity/heterogeneity	Information on the products of various suppliers is hard to compare because products are unique (no commodities)
Reference norm	Seekers want to compare their own case to a normalized reference case; sources do not provide the latter

received as perceived by the user, the information as claimed by the source, and the factual information that could be used. In order to utilize the information the respondents needed to bridge all of these gaps.

Finally, the respondents mentioned gaps related to missing and non-comparable information. The gaps in this category reflect the reality that the information provided is not the information that is exactly needed. In order to be able to use the provided information, engineers have to, for example, interpolate or extrapolate it because they need the information for a different value of a variable. The respondents also mentioned a few times that they had looked in vain for information representing a standard, or reference norm. In such a form, it would be relatively easy for them to translate the information to their own situation. The information they found, however, represented individual unique cases that were hard to compare and translate to their own situation.

6. Discussion and conclusion

As the developers of new products and processes, engineers are a driving force for innovation in today's society. In doing their work, they rely on a large amount of information from external sources, of which the Web is among the most important. This paper started with the assumption that, if we want to support

engineers, a deep understanding is needed of the challenges that they face when they use information obtained from the Web. An initial literature review had shown that the current literature does not provide such an understanding at the necessary level of detail.

This paper has begun the process of filling this hole in the current literature by studying information usage gaps as perceived by engineers when trying to use Web-based information. As context is a crucial factor in information use processes, it was decided to study information usage gaps in real life situations rather than in a somewhat artificial experimental setting. The critical incident interviewing technique was used to gather 65 real life examples of information usage by engineers. The analysis of these examples yielded five classes each of information identification gaps, information acquisition gaps, and information utilization gaps. Within each class, various types of gaps were identified (see Tables 2–4).

In comparing the results of this study with previous studies, the following observations can be made. Firstly, some of the gaps that were found in this study are in line with the findings of previous research on information usage by engineers. Examples include the gap between initial information need and final information need, and the gap between the amount and quality of information provided and that needed. Such consistency extends the generalizability of the comparable studies into the particular context of the current study. Also, through its comprehensive approach, the current study systemizes the insights into gaps identified in earlier studies.

Secondly, and more interestingly, many gaps were identified that had not been reported in previous studies. These include gaps related to forward and backward chain links (identification), to switching between information carriers (acquisition) and to translation from application through function to form (utilization). This identification of these 'new' gaps, listed in Tables 2–4, is seen as the key contribution of this paper. They not only suggest opportunities for website designers to modify websites to meet the needs of engineers, they also open up opportunities for new research.

Thirdly, no previous study has identified such a large number of information usage gaps. Although no particular number of gap types was expected in advance, the fact that 79 different types of gaps were found seems a surprisingly high figure. This is probably a result of the rich empirical research method that was adopted. Many of the earlier studies have used a deductive approach in which most of the theory and research is designed in advance of measurements since such an approach is rigorous, transparent, and predictable. In contrast, this study followed an inductive approach with only a theoretical lens to guide the data collection and analysis process. While the risk of this approach is drowning in the vast amount of information gathered, this study has shown that it can lead to new insights that are unlikely to be uncovered in a more deductive approach. Moreover, by providing a detailed account of the procedure that was followed, the paper illustrates how the CIT can be effectively used in practice.

Fourthly, designers of websites have given a lot of attention to the esthetics and appearance of websites. This attention seems surprising given that none of the gaps identified were related to such issues. In other words, perhaps website designers are focusing on the wrong issues. Rather than appearance, functionality seems to be the key issue for our respondents. They were looking for information, and the websites should help them as far as possible in that aim. The respondents also remarked that the information usage process should be fun to work with. However, by fun they did not imply that websites should include all kinds of animations, or java applications. One respondent gave an example of what he meant by fun: he thought Google was fun because during a search for information he found all kind of interesting things he was not looking for.

This study has provided a systematic categorization of gaps that engineers currently face when they try to find and use information on the Web. The long list of information usage gaps uncovered in this study suggests that there are several opportunities for improvement. In comparing this list to a range of current websites, we indeed concur with the engineers that many of these opportunities are currently not exploited. For example, the translation between form and function, as far as we can tell, has yet to be implemented in any website despite having been the main principle in the Theory of Inventive Problem Solving (TRIZ) for more than 50 years (Altshuller, 1996). It seems plausible that this gap between theory and practice exists partly because of a lack of understanding of the challenges associated with using information on the Web. As this study has contributed towards a better understanding, the findings can help to overcome the problem. However, both the designers and owners of websites may have good reasons for not grasping such opportunities. It might well be that many of the identified gaps are not worth bridging (in terms of benefits accruing to the website

owner) or seen as impossible to bridge. Therefore, future research should investigate to what extent it is realistic to bridge the gaps that have been identified here. Such research should address two types of questions.

Firstly, future research should address the question as to whether the gaps *should* be bridged. This concerns the size and the importance of the gaps for information users, and the number of information users facing similar gaps. The larger and more important the gap, and the larger the number of information users facing this gap, the more important and worthwhile it is to bridge it. While this study has concentrated on information users, future research should also include information sources since websites will only be successful when their interests are also met.

Secondly, future research should also address the question as to whether these gaps *can* be bridged. As can be deduced from Tables 2–4 some of the gaps would be hard to bridge by modifying website design alone. Examples of such gaps are the relative meaning of qualifiers and the different interests of actors. A well-designed website could contribute to narrowing these gaps, but cannot completely bridge them. Whereas the analysis of information usage gaps, and establishing their importance, can be achieved empirically, linking this to design requires a more creative approach (Laurel, 2003). One suggested avenue for future research is to ask engineers which websites they particularly like and dislike. These websites could then be analyzed and compared to provide clues on how gaps could be avoided by designing better websites.

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