Information Use in Conceptual Design: *Existing Taxonomies and New Approaches*

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This paper explores the issue of design information and its effect on conceptual design. After outlining the nature of information and its role in product development, a number of taxonomies for concept design information are reviewed and most relevant information types highlighted. A new method for concept design that facilitates the searching and implementation of information in parallel with concept creation is then outlined. The performance of this method is analyzed with respect to the information sourced and used by student designer engineers when undertaking conceptual design work. On the basis of these results, a number of recommendations are made for the provision of information resources during concept design.

Keywords – Collaborative Design, Conceptual Design, Design Information, Digital Libraries, Design Methods.

Relevance to Design Practice – Although grounded in the area of product development, this research is applicable to any organization undertaking idea generation and problem solving. It informs how organizations can improve the transference of information and research to conceptual design activity.

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Introduction

A common assertion that "all design is re-design" highlights the fact that the majority of concept design work is re-configuring existing technologies in new forms. Consequently, it is critical for any product development team to be aware of the most appropriate information for design (past solutions, market data, emerging technologies) in order to save duplication of effort and to stimulate creative energies in the most effective areas. When engaged in conceptual design work, however, this material is not always convenient for the design team to access, particularly if they are engaged in sketching activities that typically form part of the process (Goldschmidt, 1991; Schutze, Sachse, & Romer, 2003). For that reason this work examines the role of information in concept design, reviewing the different taxonomies proposed for its categorization. A new method for concept design is subsequently illustrated which requires the design team to search for information in parallel with developing concepts, with the performance of this method is evaluated through a study of eight design teams.

Background

Practicing engineers and designers frequently make use of existing examples when engaging in design work. For example, the design and innovation consulting firm IDEO (http://www.ideo.com) have for many years utilized something known internally as the "Tech Box" (Kelley & Littman, 2001). Essentially the Tech Box is a trolley with numerous drawers of interesting mechanisms, sample materials, fastener designs and so on, it began life with an employee who kept these examples as an aid during the concept development process. This was so well regarded by their designers that the company quickly formalized it as an internal design tool, eventually duplicating it across their many offices. It continues to evolve, with employees suggesting items for inclusion and use of the company's Intranet to catalogue the contents, providing a valuable and convenient resource for designers to utilize at their convenience. While the physical contents of the Tech Box can be easily handled, viewed, discussed and discarded by a group undertaking concept design, the digital information that is now commonplace in design is not so easily presented and integrated into concept design activity.

The rapid evolution of IT has in recent times enabled us to move beyond the limitations of paper records in the management of complex data sets and to enable the co-ordination of large teams on a scale that was previously impossible (Liu & Xu, 2001). The digitization of information associated with product development has numerous advantages: it can be conveniently accessed, revised and edited easily, stored with minimal physical overheads, and communicated instantly across distance. Even in the production of small-scale products, the management of digital information is today integral to the development process. In the context of concept design, it has been suggested that harnessing this potential can enhance creativity (Kappel & Rubenstein, 1999) and that computer supported collaborative environments provide

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a promising innovation to facilitate teamwork. Progressive discourse interactions can take place as teams build on information stored and shared, allowing problems, design ideas and solutions to be constructed and promoting a deep understanding (Lahti, Seitamaa-Hakkarainen, & Hakkarainen, 2004). As advances in computer hardware and software continue apace, and with the exponential growth of the Internet meaning previously arcane information is now readily available, the challenge is to find effective approaches to presenting and using digital information. This paper takes up this challenge and examines the effective utilization of information in concept design, and subsequently suggests a new approach to integrating digital information use into the team concept design activity.

Defining Information

Before reviewing the specific information types relevant to concept design, it is first necessary to define what we mean by information. It is often suggested that the first observation of a "wisdom hierarchy" was by T. S. Eliot (1965, p. 107) in his 1932 poem '*Choruses from the Rock*' which explores the struggle to find meaning in the modern world:

Where is the Life we have lost in living?
Where is the wisdom that we have lost in knowledge?
Where is the knowledge that we have lost in information?

Much of the academic literature on information use that has emerged in recent years is acknowledge to have derived from Ackoff's (1989) exploration the relationships between data, information, knowledge, intelligence and wisdom – now commonly referred to as the "DIKW hierarchy". Several authors have attempted to summarize the variations and similarities across the field. In a review of forty-five citations, Zin (2007, p. 488), concluded that the majority of models have a "human-centered, cognitive-based, propositional approach". In another review paper, Rowley (2007, p. 178), notes that while a large number of variations exist in definitions for data and information, wisdom is "a neglected concept in the knowledge management and information systems literature". For the purposes of this research, the following definitions are used:

- *Data:* observable properties of objects, events and their environment.
- *Information:* inferred from data, containing descriptions of how data can be used.
- *Knowledge:* the abstraction, generalization and application of information.
- *Wisdom:* judgment and the ability to review the other levels critically.

In his attempt to adapt the DIKW hierarchy for the purposes of interaction design, Shedroff (1999) identifies location (in global, local and personal terms) and context (the type of cognitive activities undertaken) as important factors in transformation across the hierarchy. In a similar vein, Figure 1 depicts the DIKW hierarchy adapted for the concept design domain. Broadly speaking, data is available to all in the form of catalogues, mechanisms, material samples and so on. These are sourced and structured by the design team for use in the particular design context, becoming information. The application of this information in the synthesis of new design concepts is regarded as forming knowledge items. Both information and knowledge are shared by the design team working on the particular design problem. Wisdom sits somewhat apart from the other levels in that it is the reflection and absorption of knowledge by individuals that allows them to critically apply any of these information types in the future. For the purposes of this research, then, information sourced by the team as relevant to the design problem and the effect this has on the subsequent development of new knowledge items (concepts) are the key aspects of study.

Communicating Information

The information sourced and generated during concept design must be shared effectively for the design team to be successful. The rapid verbal exchanges characteristic of the brainstorming-type, informal design sessions commonly utilized (Sutton & Hargadon, 1996) do not necessarily lend themselves well to the utilization of information sources. To achieve this, it is necessary to have clear methods of organization and communication. Individuals can build complex mental maps of information resources that may be understandable to them but confusing to others.

An example of this is the messy office desk that may look disorganized to casual onlookers but makes perfect sense to its occupier. In the development of the desktop metaphor for computing systems, the development of "files and piles" metaphors were of considerable importance. Piles of papers were found to be informal information stores which as well as negating the need for classification, performed important roles as reminders for tasks to be undertaken (Malone, 1983; Mander, Salomon, & Wong, 1992). Thus, messy office spaces which can seem disordered to the onlooker may nevertheless have a systematic way of organizing all the information resources contained in it and be able to work extremely effectively. Indeed, such individuals are often able to find a particular document immediately when required to do so: the personalization of information allows individuals to tailor these mental maps to their own requirements. For the team context, however, the challenge is that collective models are required to allow everyone to understand where and how resources are located to encourage their utilization. To

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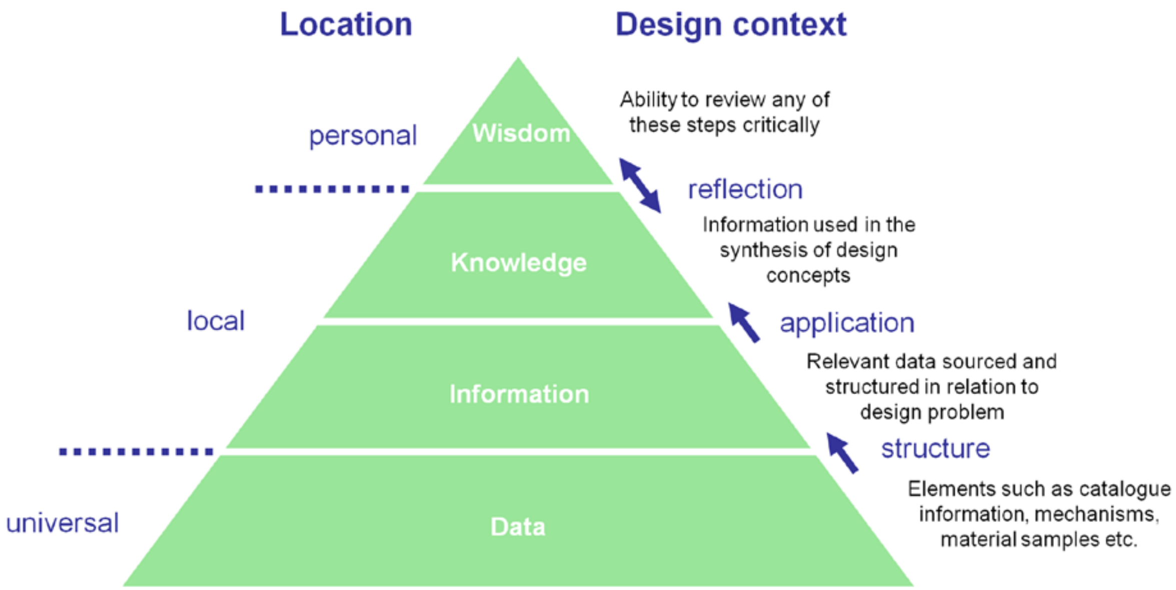


Figure 1. Information in the design team context.

achieve this, it is necessary to move beyond the files and piles metaphor to more specific knowledge models.

Based on a review of common representations for the exchange of information in the engineering design process, Hicks, Culley, Allen, and Mullineux (2002) identified categories as shown in Figure 2. *Structure* is highlighted as the main differentiator between *informal* and *formal* information. Elements such as hierarchies and accompanying contextual notes tend to shift information items into the realm of knowledge items, making them more re-usable in different design settings. This can be particularly important in an educational context when design students are learning when and how to apply new knowledge, but in industry the time required for adequate capture and organization can make such approaches unappealing. This is particularly applicable to conceptual design when teams are often working intensely and in informal ways.

The role of concept sketches as a focus for concept design provides a unique format for team members to communicate

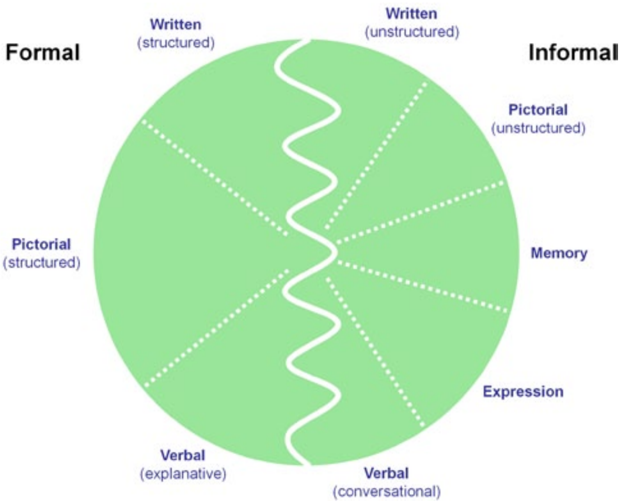


Figure 2. Classes of formal and informal information (after Hicks et al., 2002).

their thoughts and ideas. These concept sketches are supported by a number of other media, verbal communication and social structures that allow the team to work together effectively. This means that when one of these elements is inhibited (for example when a member of the design team is not comfortable sketching, or when someone is embarrassed about participating verbally in a brainstorming session) steps can be taken to overcome the problem (for example, allocate more time to sketch, take turns suggesting ideas).

When teams are distributed communication issues become even more critical and difficult to solve as many of these communication channels are restricted. The nuances of language and gesture used to fully express meaning, for example, are often lost across lower resolution webcam and videoconference technology. In highlighting the problems faced by virtual teams Gibson and Cohen (2003) emphasize the particular importance of maintaining high levels of *social* and *contextual* information in situations where teams are distributed. While it is important to recognize the importance of these, the work reported in this paper focused on enhancing the level of use of *task* information during concept design. The structures of access and use of this category of information, and any prescribed mechanics of interaction to optimize these, will inevitably inform the way the team subsequently communicates. It is necessary, then, to first consider the information elements being utilized through the process.

Information in the Design Process

The volume of information that is generated and managed through the product development process is significant. Different types of information are prevalent at different stages and Table 1 illustrates some examples of information typically generated and sourced through the stages outlined by Ulrich and Eppinger's (1995) process. The Concept Development stage aligns most closely to the work addressed in this research but there is significant overlap between these categories, and in the development of new concepts it can be expected that significant amounts of information in the

Table 1. Information and the design process.

Design Stage	Examples of information generated	Examples of information sourced
Planning	PDS/ briefing documents, project plan, meeting notes & general communications	market data, company reports
Concept development	brainstorming notes/sketches, sketches, drawings, rough calculations, meeting notes & general communications	competitor and related products, previous design schemes
System level design	sketches, drawings, rough mock-ups and physical models, cost evaluation calculations, meeting notes & general communications	patents, previous design schemes
Detail Design	detailed drawings and design calculations, final costing calculations, 3D solid models, mathematical and numerical models, meeting notes & general communications	textbooks, catalogues, suppliers" data
Testing and refinement	experimental data, manufacturing drawings, bills of materials, test specifications, assembly methods	standards, databases
Production ramp-up	sales presentations, demonstrations, photographs, product instructions, presentation graphics	customer feedback, retail data

Table 2. Taxonomies for engineering design.

Vincenti	Rohpohl (1997)	De Vries (2005)	Hubka and Eder (1988)
• Criteria and specifications • Quantitative data • Practical considerations • Fundamental design concepts • Theoretical tools • Design instrumentalities	• Socio-technological understanding • Technical know-how • Functional rules • Structural rules • Technological laws	• Functional • Physical • Relationship • Process	• For • About

stages from Planning through to Detailed Design could reasonably be expected to be utilized.

Information Taxonomies

Vincenti's approach to categorizing design information in *What Engineers Know and How They Know It* (1990) is built on case studies from the aeronautical industry. His categorization scheme has been shown to be popular with practicing engineers (Broens & de Vries, 2003). It identifies six categories of knowledge: *fundamental design concepts* (operational principles and normal configurations), *criteria and specifications* (specific, quantitative objectives for a device derived from general, qualitative goals), *theoretical tools* (mathematical formulas or calculative schemes, whether grounded in nature or based on past experience), *quantitative data* (universal constants, properties of substances, physical processes, operational conditions, tolerances, factors of safety, etc), *practical considerations* (information learned mostly on the job and often possessed unconsciously, rather than in codified form) and *design instrumentalities* (procedures, ways of thinking, and judgmental skills by which the process is carried out).

Rohpohl (1997) more theoretical approach the classification of technical knowledge identifies four types: *technical know-how* (implicit knowledge or skills for handling technologies) *functional rules* (instructions which can be used without being understood theoretically), *structural rules* (the "assembly and interplay of the components" of a technical system), and *technological laws* (theoretical knowledge for solving design problems), while also identifying a fifth type of knowledge as *socio-technological understanding* (knowledge of the interrelationship between technical objects, the natural environment and social practice).

A taxonomy based on the idea that the design of artifacts has to take into account their dual nature – the physical and functional – is suggested by de Vries (2005). He subsequently delineates knowledge as *physical* knowledge (e.g. knowledge of materials used), *functional* knowledge (knowledge of what it means to function as a kettle), *relationship* knowledge between the physical and functional nature (e.g. knowing that a certain material property makes a device useful for a particular function), and *processes* knowledge (in the functioning or in the making of the artifact). This holds an appeal given its practical nature and direct relevance to the engineering design activity.

In more simple analysis, presented by Hubka and Eder (1988), splits design knowledge into just two categories: knowledge *for* design (appropriate science and technology) and knowledge *of* or *about* design (the science of designing). Knowledge of or about design becomes more important for long-term projects in terms of helping teams navigate through the design process. For a concentrated concept design activity, however, it is likely that knowledge for the design task at hand will be more highly valued.

A summary of these taxonomies is illustrated in Table 2. The demonstrated esteem and greater granularity of Vincenti's scheme makes it an appealing choice on which to base any analysis of information use in concept design. Vincenti himself acknowledges that this list is not exhaustive and that overlap exists between categories. They do, however, tend to relate to different stages of the design process, with *fundamental design concepts* most useful in the development of new solutions (although *criteria and specification*, *quantitative data*, and *theoretical tools* can also be identified as relevant under certain circumstances). Vincenti's definition of fundamental design concepts as "operational principles and typical structures" can be interpreted can be interpreted broadly as any self-contained, independent information source that can be utilized in used in concept design work. It is worthwhile considering, then, the composition of concept design information specifically.

Concept Design Information

Court, Culley, and McMahon (1996) work on Information Access Diagrams suggests that designers prefer to follow well established, reliable information paths, and observes that when undertaking new designs, colleagues, drawings and catalogues were preferred sources of information. Similarly, Chuang and Chen (2008) contend that in creating and developing new concepts, visual sources such as images, sketches, models and competitor products are typically used. These types of visual and informal information have been shown to outperform textual sources in studies of idea generation (Mckoy, F.L., Vargas-Hernández, N., Summers, J.D. & Shah, J.J., 2001). A great deal of information can be encapsulated within a single item, for example a concept sketch could contain information on material properties, function, aesthetics and so on. Indeed, the notion of concept sketches as "gestalts" has been mooted (Kulkarni, Summers, Vargas-Hernandez, & Shah, 2001), suggesting that designers can "read off" a sketch more than was initially invested in its creation. Smith, Kohn, and Shah (2008) make further suggestions regarding the effect of the quality of material presented, concluding from studies that exposure to commonplace ideas resulted in unoriginal designs, but seeing novel ideas resulted in more original designs. A number of specific taxonomies to address concept-related information have been developed, and these are reviewed below.

Concept Taxonomies

In developing a classification system for design concepts that is understandable for human beings and can be utilized in computational programming, Horváth, Kuczogi, and Vergeest (1998, p. 4) , developed an ontology (broader than a taxonomy in that it has "an intentional semantic structure that defines and arranges all related notions") that includes *entities* (a set of objects), *situations* (a specific arrangement) and *phenomena* (a set of physical effects), with these combining to form a particular *behavior*. The objective of this systematic approach is to develop a clear definition of concepts relating to a particular application, formalize relationships between them based on their categorization, and convert these into alternative designs.

Muller and Pasman (1996, p. 113) describe a model for extracting design knowledge from existing concepts with the purpose of using it to structure an image database to support concept design. They suggest a typology (a typology focuses on idealization through "abstraction and classification of precedents") of *proto-typical* (use) features, *solution-typical* (form) features and *behavioral-typical* (use) features. Possible overlap or issues with categorization are viewed as having possible positive effect with respect to increasing the "bandwidth" or range of possibilities for a certain feature when undertaking conceptual design work.

Similarly, studies on cognitive processes by Benami and Jin (2002) suggest that ambiguous entities provide a greater level of stimulation in creative design work than non-ambiguous entities. Derived from the *function-behavior-structure* model suggested by Gero and McNeill (1998) in their analysis of design protocols, they classify stimuli into four categories – *behavior, form, function* and *knowledge* – and found that for a group concept design session behavior stimuli, which were the most ambiguous, led to the generation of most ideas. Considered to all fall inside Vincenti"s *fundamental design concepts*, these taxonomies have been aligned and summarized as shown in Table 3.

Table 3. Taxonomies for concept design.

Horváth et al. (1998)	Muller and Pasman (1996)	Benami and Jin (2002)
• Entities • Situations • Phenomena • Behavior	• Proto-typical • Solution-typical • Behavioral-typical	• Function • Form • Behavior • Knowledge

Concept Design Stimuli

Given that the interpretation of resources during the creative task can be so unpredictable (a sketch may contain information on form, function, behavior or any combination; a competitor product may provide reference or stimuli with regards to any number of its characteristics) a more practical approach to the identification of stimuli was deemed necessary. Rather than attempting multiple interpretations of concept content, describing information based on its relative location in the physical (person, team, world) or contextual (same, similar or dissimilar) sense were identified as established and useful approaches.

Shedroff (1999) describes information as being *global*, *local* and *personal*. Information at the global level is described to be more like data – unstructured and without context. Local sources come from the problem domain and are, therefore, more likely to be knowledge constructs that have direct relevance. Personal information is the wisdom contained within individuals that must be externalized and shared with other team members.

In developing an approach to the management of creative stimuli specifically Howard (2008) proposes a matrix based on the source of information: whether it was *internal* or *external* (to the industrial domain) and *random* or *guided* (in how specific the retrieval mechanism was to the task) as differentiators. Howard additionally emphasizes the effectiveness of *guided*, *internal* resources in concept design, showing that designers generally prefer the higher levels of relevance of these sources and demonstrating that they stimulate more ideas per stimulus than more abstract or distant analogical resources.

Alongside their formal taxonomy described above, Benami and Jin (2002) additionally delineate *short distance* (closely related) and *long distance* (distantly related) analogies, recommending that stimuli should be "meaningful, relevant, and ambiguous" for optimal design performance.

Finally, Ulrich and Eppinger (1995), whose process has been utilized in the development of Table 1, categorize conceptual design methods as *internal* and *external* to the design team. Methods that are internal utilize knowledge and information contained within the team while external methods rely on past projects, design theory and other sources to inform the process.

Table 4. Taxonomies for concept design stimuli.

Shedroff	Howard	Benami and Jin	Ulrich and Eppinger	Adapted
Personal			Internal (to team)	Personal
Local	Internal (to domain)	Short distance	External (to team)	Direct
Global	External (to domain)	Long distance		Indirect

Their choice to categorize concept design methods along these lines illustrates the fundamental importance of the location of stimuli when used in concept design.

The various schemes above have been rationalized to best fit the research context as shown in Table 4. The adapted scheme delineates information as *personal* to individuals in the team, *directly related* to the industry or problem domain, and *indirectly related* in the form of other globally available information sources.

Application to the Design Context

When considering quick-to-access and easy-to-use resources necessary for concept design, these typically fall under Vincenti's (1990) fundamental concepts category in that they are self-contained entities describing operation, configuration and structure. Despite its potentially confusing terminology (internal and external could easily refer to individual as well as domain) Howard's (2008) work in identifying guided, internal (direct) sources as most effective for concept design is considered highly appropriate and illustrative of the appropriate level of practicality. In focused, progressive concept design work, the resources principally used are chosen selectively, not randomly and these relate to the specific design task rather than relying on high-level analogy. While a proportion of indirect stimuli may also be appropriate to encourage more radical ideas, the presence of comprehensive direct stimuli is of primary relevance in ensuring that the team has the requisite knowledge and expertise at their disposal to reach feasible and adequately detailed solutions. This does not necessarily preclude the possibility of diverse and imaginative design solutions. With fundamental, guided, and direct information sources identified then as the most relevant to the design context the research moved on to examine the types information actually sourced by design team members when required to do so as part of the concept design process.

ICR Grid – Sourcing Information During Concept Design

The ICR Grid is a new design method developed by the authors (Wodehouse & Ion, 2010a, 2010b) that aims to improve utilization of information during concept design. It is a prescriptive method which requires design teams to find and build information resources in parallel with creating solutions. It maintains the freedom of designers to decide on the direction of exploration by adopting a solution-based approach while encouraging flexible thinking by using different modes of conceptual thinking (analysis, synthesis and evaluation). The output of the method is a linked grid of concepts and information sources. It was, therefore, deemed instructive to compare the actual information sourced when using the method with the taxonomies for concept design information outlined above. This was achieved using a series of eight concept design sessions where teams used the method and the information and conceptual output were monitored. The rationale for the method and the subsequent experimental set-up are outlined below.

Rationale for Method

As a basic psychological process, concept design is often divided into three phases. Osborn (1953) describes the creative problem-solving process of comprising: *fact finding* (problem definition and preparation), *idea finding* (thinking up ideas and leads) and *solution finding* (evaluation and adoption). Similarly, Cross (1994) argues prescriptive processes tend to follow a basic structure of *analysis-synthesis-evaluation* where analysis addresses all the design requirements for a problem, synthesis addresses solutions for each performance specification and evaluation addresses the accuracy with which these meet the requirements. Sim and Duffy (2003) identify a set of generic design activities numbering 27, but still categorize these three main aspects. It has been suggested (Cross, 1994; Dorst & Cross, 2001) that shifting between these modes in a flexible way can be beneficial, given the designer's tendency to make "rapid explorations of problem and solution in tandem, in the co-evolution of problem and solution" (Cross, 2004, p. 440) rather than follow linear stages. Goldschmidt (1991) has made similar observations regarding the sketching, emphasizing the importance of "shifts in perception" that occur during this activity with regard to creativity and the development of novel design solutions.

While a number of authors have discussed the benefits of a move from an *phase-based* to an *activity-based* approach in terms of the evolution of problem and solution in parallel (Cross, 2004; Dorst, 2003), it has also been suggested that "continuous information gathering" can be important in supporting this (Hummels & Frens, 2008, 2009). Similarly, Restrepo and Christiaans (2004, p.12) have argued that designers are often solution-led rather than problem-led, and conclude that information and its accessibility are critical in supporting this activity-based strategies, "Even when information exists and is relevant, it would not be used if its source were perceived as inaccessible. These are good reasons to make information tools more accessible to designers and, why not, fun to use! "

A focus of the ICR Grid was, therefore, the provision of information support for concept design in a way that allows intuitive rather than prescriptive working while also having sufficient structure to allow the co-ordination of individuals within a team. Figure 3 suggests how the traditional linear, phase-based

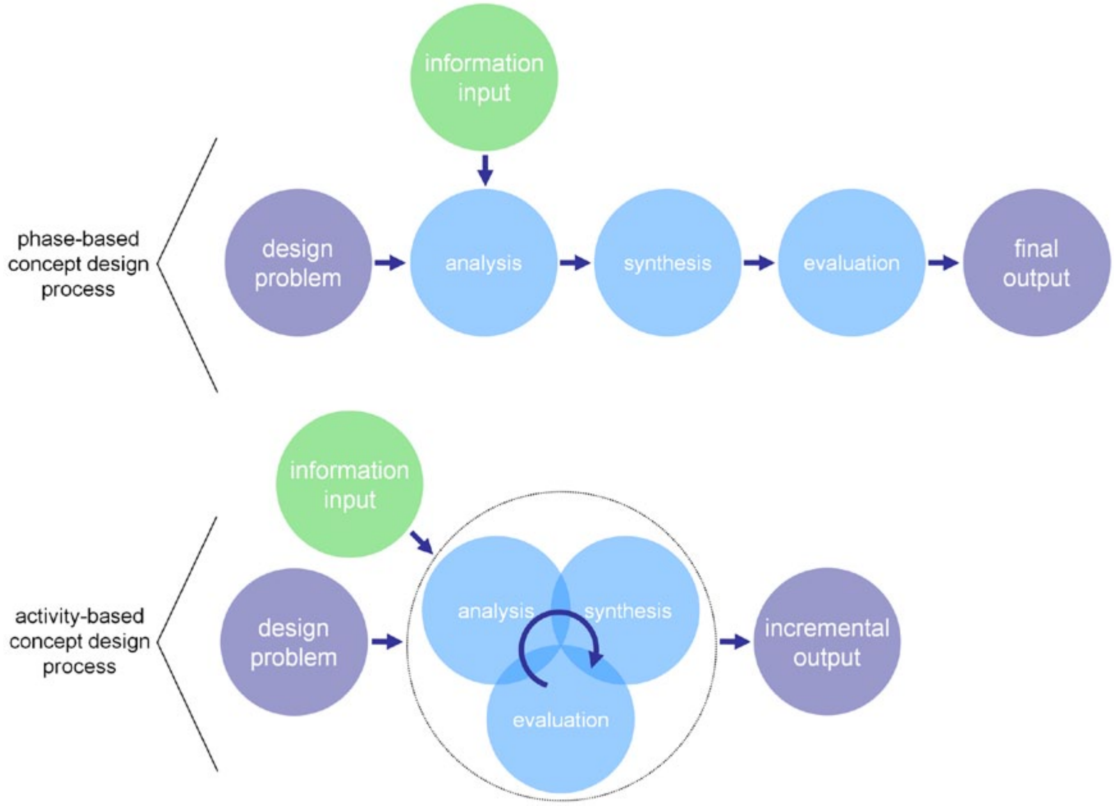


Figure 3: Idealized phase-based and activity-based concept design processes.

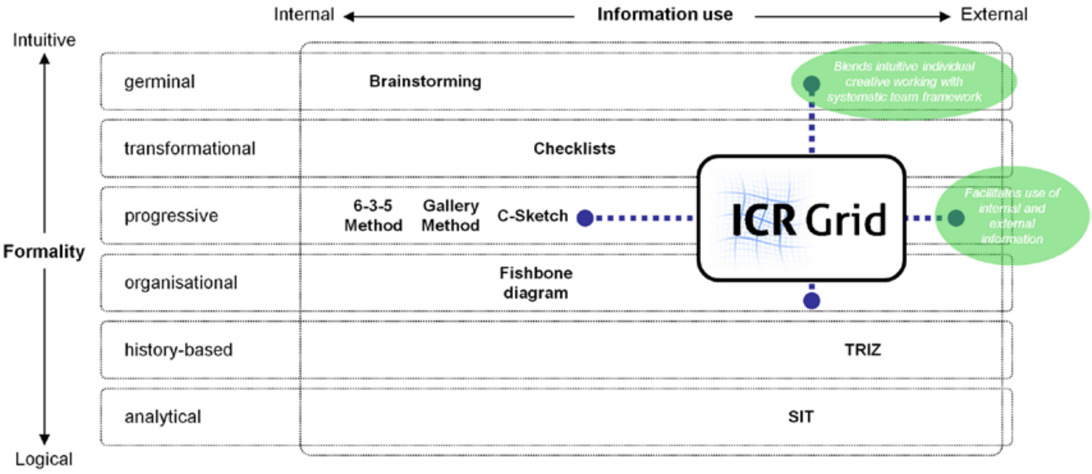


Figure 4. Placement of ICR Grid in development process.

process can be revised in an activity-based model that increases the proximity of information to the task of designing. Given the freedom that is afforded to the participants in finding information they feel is necessary to help develop ideas generated within the session, this provides an ideal forum to analyze the information types sourced and utilized during conceptual working. Rather than demanding significant work on design requirements and research as a pre-cursor to concept generation, the ICR Grid builds on this by aiming to embrace the fuzziness of design problems and allow designers – who will often engage in sketching and idea creating activity as soon as a problem has been identified – to bring information *into* this process in an activity-based approach that allows repeated iterations of cognitive activities. While it does not specifically address a co-evolution of problem and solution, it is anticipated that the reflective activities undertaken as part of its iterative approach will allow participants to ensure that the specifications set at the beginning of the process are revised as necessary.

Context

In considering the particular qualities of the ICR Grid, Figure 4 shows it in relation to the categories of concept design method outlined by Shah, Kulkarni, and Vargas-Hernandez (2000). Intuitive methods tend to rely on information contained within the team, while systematic methods make more use of external information. The ICR Grid can be considered a blend of the two in that it gives the participants the freedom to pursue ideas and information as they see fit. The most similar concept design tools are therefore progressive ones such as 6-3-5 (Rohrbach, 1969), C-Sketch (Kulkarni, et al., 2001) and the Gallery Method (Hellfritz, 1978) which provide a similar framework for teams to undertake open-ended design work. The ICR Grid's prescriptive structure, however, differs in the systematic utilization of both internal and external information. This means it incorporates search activities that other methods would not normally encompass, and furthermore the output is a combination of information and conceptual work, linked and categorized according to the design context.

Structure

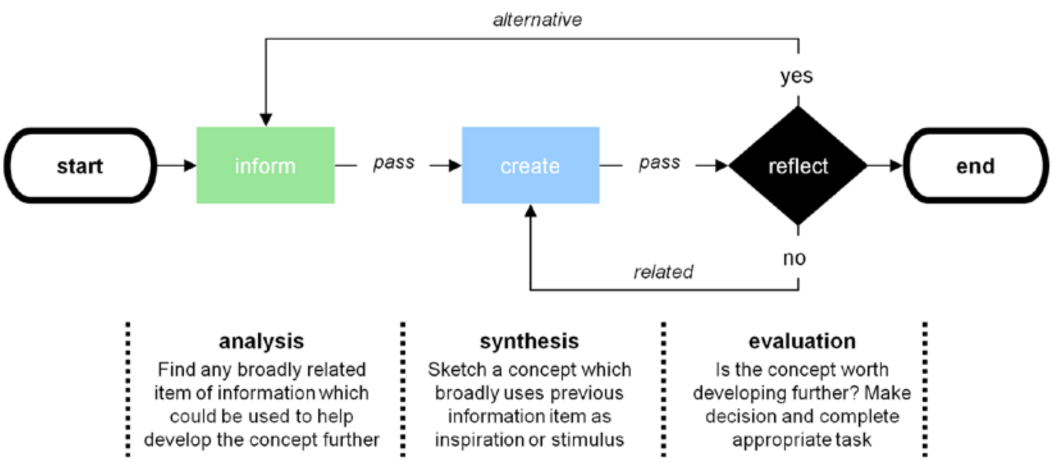
A flowchart for the method is summarized in Figure 5(a). It can be viewed as a development of the 6-3-5 Method (Rohrbach, 1969), adding a number of new elements to optimize it for more focused concept development. Most importantly, it introduces search tasks in order to help build information context and provide design stimuli. These are rotated around the group and used in the creation of concepts with minimal verbal communication. Another major addition is the competitive element introduced through the use of evaluation, that is, after a concept has been created, it is again passed on to the next participant who reflects on whether the idea is worth developing further. If a positive decision is made, a new information resource is found to apply to the concept and added to the library. If a negative decision is made a new concept is created. This cycle continues for a number of rounds, creating a grid of information and ideas linked by the actions taken during the session as shown in Figure 5(b).

Experimental Set-up

Given that the information sources retrieved using the method are decided by the participants themselves and are motivated by their requirements at the point of need (as conceptual sketch work is being undertaken), it was instructive to analyze the items retrieved in relation to the derived taxonomy. Eight teams of three were formed randomly from a pool of twenty four senior undergraduate MEng students and postgraduate MSc students, all with an engineering background. In each session, the team had to undertake a 30-minute concept design task. Four teams used brief A (to design a chisel-edge pencil sharpener), and four brief B (to design an ice cream scoop) – simple mechanical devices of similar complexity. The brief for each task specified three key requirements for each design (suitable for one-handed operation, easy to wash etc.) to force participants to consider different parameters when undertaking the tasks.

The experiments took place in a co-located setting, with participants working face-to-face. Each participant was issued with a briefing document and paper template for completing concepts and circulating around the group, along with a laptop to find and manage digital information during the session. During each round of the session, participants completed the allocated spaces of the paper template before passing it to the adjacent participant.

(a)



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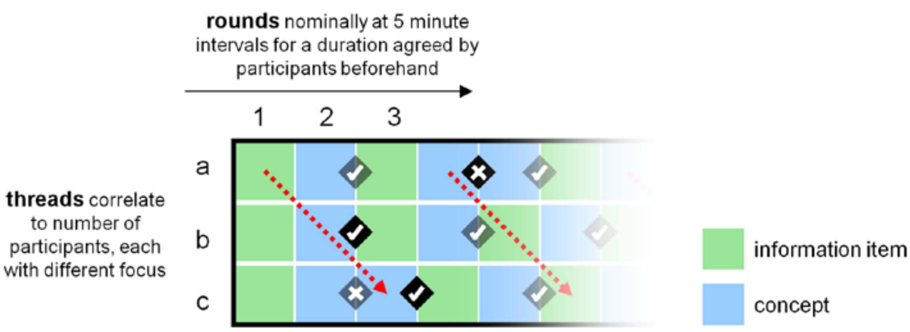

Figure 5. Format of the ICR Grid: (a) flowchart of activity and (b) grid output.

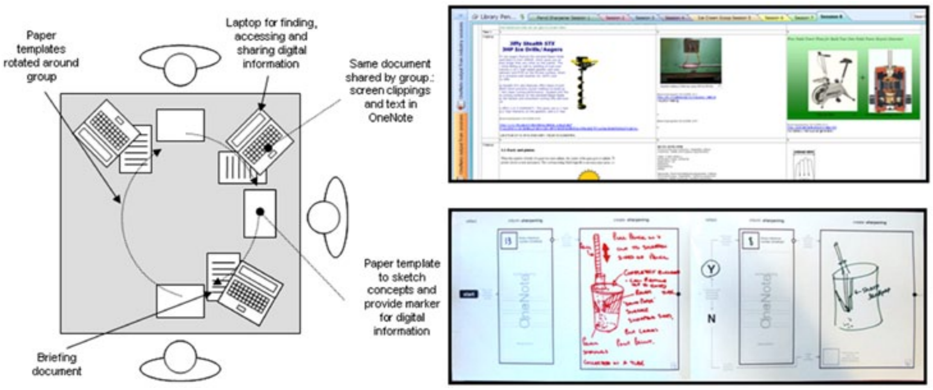

Figure 6: Set-up for design sessions.

Paper Template

The programming and configuration of a bespoke system was not feasible in the timeframe of this work. Instead, it was decided to proceed with a paper-based format for documentation of design sketchwork, integrated with digital support for information sharing. The paper templates issued to participants were in "book" form – it consisted of a series of pages with spaces to identify the resources used and to sketch concepts. The books were then rotated around the team as the session progressed. Each participant was asked to use a particular color of ink to help identify the creator of each concept. At the end, the books could be opened out and placed in parallel to show the overall progress of the session.

Software Configuration

The software used on the laptop to manage the shared information resources was Microsoft OneNote (http://office.microsoft.com/oneNote), an integrating package that allows information from a range of sources, including notes, documents and screen clippings, to be captured and shared. The result is an information hub more akin to a designer's notebook than a traditional electronic document, with an informal mix of media. A crucial advantage of OneNote for use as an information management tool in the sessions was that it allows a group of people to open and edit a document simultaneously. Utilizing the clipboard feature which allows areas of web pages to be selected, dragged and dropped into the shared document, then split into tabs based on the design criteria, was found to be a good way to create a reasonably dynamic and responsive shared digital library. With the addition of some accompanying text, the thumbnails pulled from the most relevant aspects of web pages allowed a group to quickly share and assimilate the information found. It was decided to specify Google as the primary method of searching for new information for reasons of familiarity.

Information Retrieval Results

From Vincenti's (1990) taxonomy of design knowledge, as described above, the relevant categories were found to be *fundamental design concepts* (representations of existing principles, configurations or structures), *quantitative data* (relevant constants, properties or processes respectively), *criteria and specifications* (universal constants, properties of substances, physical processes, operational conditions, tolerances, factors of safety,), and *practical considerations* (information learned from experience). Items were additionally identified as *direct* or *indirect,* after Howard's (2008) internal/external delineation, in order to better distinguish items directly related to the design application and those brought to bear from different contexts. In all cases, the sources were what Howard considers *guided* stimuli, in that they were purposely chosen by the participants for a specific application rather than randomly selected. The proportion of information types, the effect of the design problem, the subsequent quality of concept output and the role of Information Literacy are discussed below.

Information Types

The proportion of different information types sourced during the sessions is illustrated in Figure 7. It was found that the majority of information (70 of 82 items) consisted of fundamental design concepts. These were typically images of relevant products, either direct competitors or similar devices that could conceivably be adapted. Often, an image of a device was used to illustrate a particular aspect of the design, for example the mechanism of operation or material use. This practical form of resource was aligned with the solution-orientated nature of the sessions. Items relating to categories such as criteria and specification and quantitative data were far less frequent, requiring participants to take a more reflective view of the design problem.

It was found that 53 of the 82 items were directly related to the problem domain, indicating that the participants tended to stay within the product category when sourcing information. For example, competitor products consistently proved an important source of reference. There were, however, significant numbers of indirect items in the fundamental design concept category. Consisting of products or technologies from different (but relevant) areas, these proved more challenging resources in terms of both retrieval and application, requiring participants to think more carefully about the transference of ideas or elements across domains.

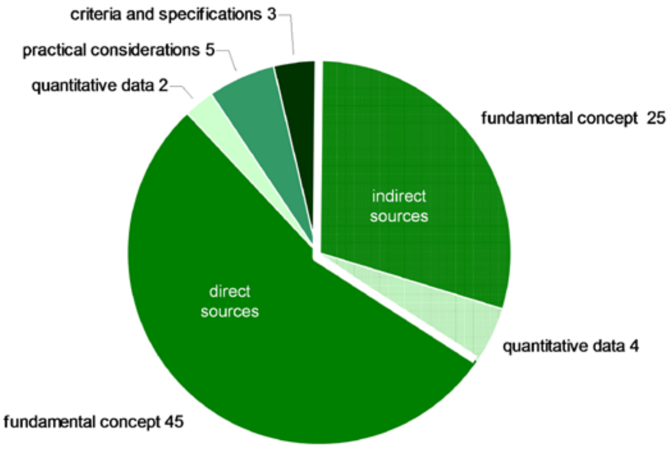

Figure 7. Information sourced across eight sessions.

Design Topic

The information sourced for the different design briefs is highlighted in Table 5. Although the design problems were intended to be of similar complexity, it emerged that the ice cream scoop was more challenging. There was a tendency to develop simplistic, spoon-type concepts rather than the diverse mechanical approaches it was hoped would emerge. This was reflected in the information sourced, which tended to rely on basic competitor information. The pencil sharpener sessions showed a greater range of approaches introduced such as cutting, scraping, sanding and so on, and this may be reflected in the greater number of indirect information sources retrieved. The context of the design session is therefore of importance: if concept diversity is deemed desirable, participants should be encouraged to look beyond competitor products to more tangentially related and analogous products and technologies at the information searching stage.

The lack of familiarity with the product and application also resulted in a number of sources related to practical considerations such as the process of scooping ice cream and how to clean utensils. No items in this category were sourced for the pencil sharpener, attributable to the fact most participants were already familiar with such background information. This suggests that although direct, fundamental concepts are generally most applicable for general concept design work, the level of familiarity with the problem and background of participants may require greater proportions of other information types to provide supporting material as necessary.

Quality of Output

To analyze the conceptual output from the sessions, Shah (2003) measure of quality (a subjective rating system) was adapted by combining it with a rating for concept detail. To determine the subjective rating, three functional categories were weighted and rated (0 – not addressed, 1 – poor, 2 – okay, 3 – good) according to a combination of the perceived originality and feasibility of the concept embodiments. The ratings were based on the author's own experience and judgment and, having a compete overview of concepts produced during the sessions, every effort was made to be as consistent as possible. The detail ratings were derived from the level of annotation and sketch detail, and were used as an indicator for the depth of thinking associated with a concept. The subjective ratings and detail ratings were then combined give a quality score for each concept and averaged to give an overall score for each session. The participants were not briefed on how their work would be analyzed, and therefore the ratings approach was not considered an influence on the output.

Figure 8 shows the number of information items against the subsequent averaged concept quality for each session. There was a direct relationship between the number of information items found and the subsequent quality of concepts product. While this could be interpreted as the information having a positive effect on the concept design activity, it could also be attributed to general group performance: higher performing groups managed to find more information as well as creating better concepts. In examining the teams' information resources in more detail, typical sessions were dominated by fundamental concepts, while also containing a number of other information types (practical considerations, quantitative data, criteria and specifications) as well as both direct and indirect sources.

Session 4, however, deviated noticeably from the others, producing better quality output from fewer sources. On closer inspection of the information set found by the team, it was found to contain a range of information types but mostly of a direct nature. They were all well-considered in terms of application to the design context, resulting in concepts that were realistic and feasible. The quality measure did not, however, consider the novelty or variety of concepts produced in the sessions, and it may be that greater number of indirect sources would result in concepts of greater diversity. There was also an inclination for some sessions to fall into a pattern whereby participants consistently found similar items (such as competitor products) and it was noticeable that those of lower quality against the number retrieved (7 and 3) had particularly one-dimensional resource sets. Therefore, while it

Table 5. Information sourced by design session.

	Fundamental design concepts		Practical considerations		Quantitative data		Criteria & specifications	
	direct	indirect	direct	indirect	direct	indirect	direct	indirect
Pencil sharpener: Sessions 1-4	20	21			1	2	1	
Ice cream scoop: Sessions 5-8	25	4	5		1	2	2	
Total	45	25	5	0	2	4	3	0

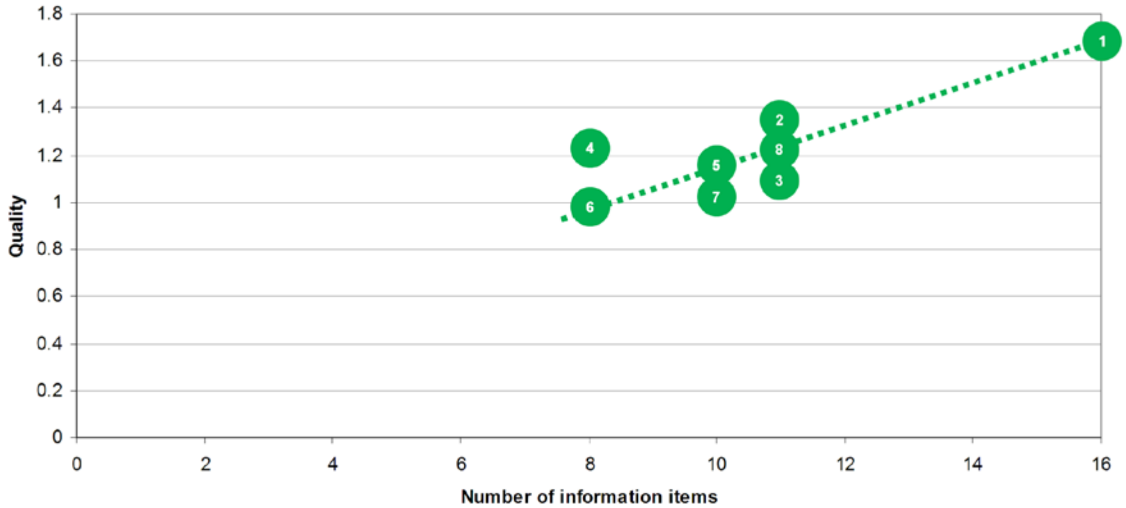

Figure 8. Information items created versus quality.

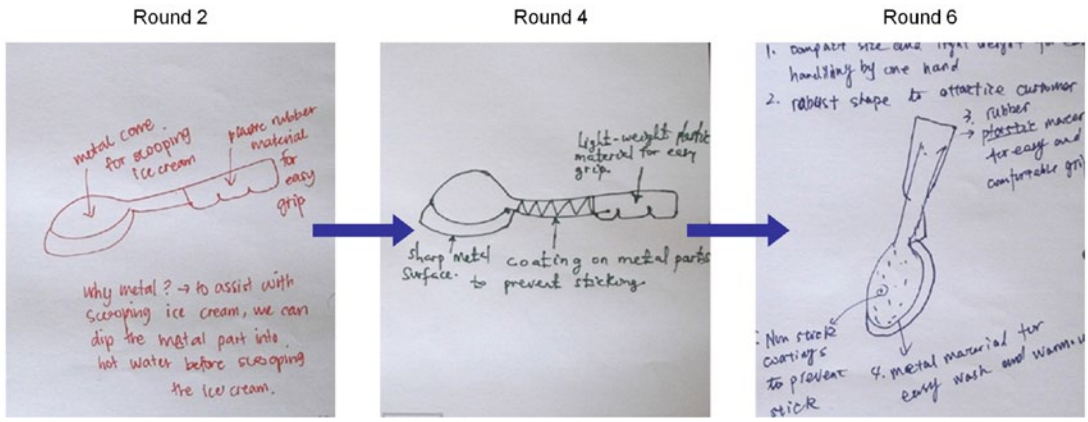

Figure 9. Session 8, Thread 2 illustrating the utilization of information.

was not possible to identify detailed correlations between types of information sourced and concepts subsequently produced, it is suggested that fundamental, direct information sources are important to developing well-substantiated concepts, there would ideally be a mix of different types to provide a variety of stimuli for the concept generation task.

Embedding Information

One of the aims of the ICR Grid is to allow participants to continually introduce new information and encourage new technologies, principles or data to be embedded. Figure 9 illustrates the advantage of being able to find information to introduce new principles for development in Session 8, which was addressing the ice cream scoop brief. Round 2 shows a cylindrical cutter being used. In Round 3, information relating to heating elements has been introduced, and this has been incorporated as a fundamental part of the concept with a similar product configuration. Finally in Round 6, an enhanced mechanical configuration combining cutting and heating actions is proposed. The relevant information sourced prior to each of these rounds (on cutters, heating elements, and mechanisms respectively) gives the designer more confidence to incorporate these tellingly into the design configuration.

Information Literacy

In terms of Information Literacy (IL), finding competitor products (direct stimuli) can be rated the easiest type of information to source: simply using the product name or category is enough to return results on related products. Finding different, but potentially relevant, products or technologies (indirect stimuli) requires the participant to think about possible features or major specifications relating to the design, with search results typically providing more tangential information. More sophisticated behavior is shown when participants identify the underlying characteristics and principles that could be adopted, and interpret how these could be applied. Although this did happen sporadically, most searches seemed to be of a more cursory nature. These degrees of sophistication are reflected in the overall numbers across the sessions and in particular for the ice cream scoop, with the high proportion of direct information sources.

Although no prior IL was given to participants, it did emerge as an important factor in ensuring high quality information was sourced – familiarity with the Internet is not necessarily sufficient. It may be that participants are required to undergo some initial training to better understand how search strategies such as concept mapping (Tergan, 2005) can assist in developing appropriate search terms, and more sophisticated search features such as AND, NOT and OR can be used in the execution of information searches. Additionally, targets could be set or particular information types requested to ensure that the resources available to the group have an appropriate balance for effective concept generation.

Conclusions

This paper has reviewed design information relating to the concept design stage of the product development process. An appropriate taxonomy for categorizing information was derived from the literature and direct, fundamental design concepts identified as the most relevant information type. Tests were then carried out using a new design method, the ICR Grid, which requires participants to source information in parallel to creating concepts. This allowed the information sourced by eight groups of student designers in a series of tests to be analyzed. It was found that while direct, fundamental design information was the most commonly sourced type, a range of information items, including a proportion of indirect sources, may be best suited to conceptual design. This ensures there is a blend of reference/exemplar items with more tangential/analogous items to encourage an appropriate diversity of well-substantiated concepts.

Although the student participants were at senior undergraduate and postgraduate level, their lack of experience was undoubtedly a factor in the information they sourced. Experienced design engineers may, for example, have focused on finding a greater proportion of indirect information to spark new directions rather than direct, reference related material to ensure their concepts were feasible. Tests focusing on different participant disciplines and experience would therefore be instructive in developing a fuller understanding of the suggested information provisions.

Finally, given their limited duration the sessions focused entirely on sampling and linking to relevant websites. With more time and greater scope, the sessions could include access to the physical materials often used in concept design, such as models, sketches, catalogues and so on. For immediate implementation in this context, digital photographs of the relevant material would suffice. As computing technologies continue to evolve, however, more sophisticated, interactive representations of physical objects can be expected to emerge, potentially requiring us to reconsider once again what we mean by information.

References

1. Ackoff, R. L. (1989). From data to wisdom. *Journal of Applied Systems Analysis, 16*(1), 3-9.
2. Benami, O., & Jin, Y. (2002). *Creative stimulation in conceptual design.* Paper presented at the ASME 2002 Design Engineering Technical Confereces and Computer and Information in Engineering Conference, Montreal, Canada.
3. Broens, R. C. J. A. M., & de Vries, M. J. (2003). Classifying technological knowledge for presentation to mechanical engineering designers. *Design Studies, 24*(5), 457-471.
4. Chuang, Y., & Chen, L. L. (2008). How to rate 100 visual stimuli efficiently. *International Journal of Design, 2*(1), 31-43.
5. Court, A. W., Culley, S. J., & McMahon, C. A. (1996). Information access diagrams: A technique for analyzing the usage of design information. *Journal of Engineering Design, 7*(1), 55-75.
6. Cross, N. (1994). *Engineering design methods, strategies for product design*. Chichester, UK: John Wiley & Sons.
7. Cross, N. (2004). Expertise in design: An overview. *Design Studies, 25*(5), 427-441.
8. de Vries, M. J. (2005). *Teaching about technology: An introduction to the philosophy of technology for non-philosophers*. Dordrecht, the Netherlands: Springer.
9. Dorst, K. (2003). The problem of design problems. In N. Cross & E. Edmonds (Eds.), *Expertise in design* (pp. 135-147). Sydney: Creativity and Cognition Studio Press.
10. Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem–solution. *Design Studies, 22*(5), 425-437.
11. Eliot, T. S. (1965). *Selected poems*. London: Faber and Faber.
12. Gero, J. S., & McNeill, T. (1998). An approach to the analysis of design protocols. *Design Studies, 19*(1), 21-61.
13. Gibson, C. B., & Cohen, S. G. (2003). *Virtual teams that work*. San Francisco: Jossey-Bass.
14. Goldschmidt, G. (1991). The dialectics of sketching. *Creativity Research Journal, 4*(2), 123-143.
15. Hellfritz, H. (1978). *Innovation via galeriemethode* [Innovation via the art gallery method]. Koenistein im Taunus, Germany: Eigenverlag.
16. Hicks, B. J., Culley, S. J., Allen, R. D., & Mullineux, G. (2002). A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design. *International Journal of Information Management, 22*(4), 263-280.
17. Horváth, I., Kuczogi, G. Y., & Vergeest, J. S. (1998). *Development and application of design concept, ontologies for contextual conceptualization.* Paper presented at the ASME Design Engineering Technical Conferences, New York, NY.
18. Howard, T. (2008). *Information management for creative stimuli in engineering design.* Bath, UK: University of Bath.
19. Hubka, V., & Eder, W. E. (1988). *Theory of technical systems*. Berlin: Springer-Verlag.
20. Hummels, C., & Frens, J. (2008, September 4). *Designing for the unknown: A design process for the future generation of highly interactive systems and products.* Paper presented at the Engineering and Product Design Education, Barcelona, Spain.
21. Hummels, C., & Frens, J. (2009). The reflective transformative design process. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems* (Extended abstracts, pp. 2655-2658). New Yrok: ACM.

22. Kappel, T. A., & Rubenstein, A. H. (1999). Creativity in design: The contribution of information technology. *IEEE Transactions on Engineering Management, 46*(2), 132-143.
23. Kelley, T., & Littman, J. (2001). *The art of innovation*. London: Profile Books.
24. Kulkarni, S., Summers, J. D., Vargas-Hernandez, N., & Shah, J. J. (2001). Collaborative sketching (c-sketch) - An idea generation technique for engineering design. *The Journal of Creative Behavior, 35*(3), 168-198.
25. Lahti, H., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2004). Collaboration patterns in computer supported collaborative designing. *Design Studies, 25*(4), 351-371.
26. Liu, T., & Xu, X. W. (2001). A review of web-based product data management systems. *Computers in Industry, 44*(3), 251-262.
27. Malone, T. W. (1983). How do people organize their desks? Implications for the design of office information systems. *ACM Transactions on Information Systems, 1*(1), 99-112.
28. Mander, R., Salomon, G., & Wong, Y. Y. (1992). A "pile" metaphor for supporting casual organization of information. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 627-634). New York: ACM.
29. Mckoy, F. L., Vargas-Hernández, N., Summers, J. D. & Shah, J. J. (2001). *Influence of design representation on effectiveness of idea generation*. Paper presented at the ASME 2001 Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Pittsburgh, PA.
30. Muller, W., & Pasman, G. (1996). Typology and the organization of design knowledge. *Design Studies, 17*(2), 111-130.
31. Osborn, A. (1953). *Applied imagination: Principles and procedures of creative problem solving*. New York: Charles Scribner's Sons.
32. Restrepo, J., & Christiaans, H. (2004). Problem structuring and information access in design. *Journal of Design Research, 4*(2). 1551-1569.
33. Rohrbach, B. (1969). Kreativ nach regeln. *Absatzwirtschaft, 12*, 73-75.
34. Ropohl, G. (1997). Knowledge types in technology. *International Journal of Technology and Design Education, 7*(1/2), 65-72.
35. Rowley, J. (2007). The wisdom hierarchy: Representations of the DIKW hierarchy. *Journal of Information Science, 33*(2), 163-180.
36. Schutze, M., Sachse, P., & Romer, A. (2003). Support value of sketching in the design process. *Research in Engineering Design, 14*(2), 89-97.
37. Shah, J. J., Kulkarni, S. V., & Vargas-Hernandez, N. (2000). Evaluation of idea generation methods for conceptual design: Effectiveness metrics and design of experiments. *Journal of Mechanical Design, 122*(4), 377-385.
38. Shah, J. J., & Vargas-Hernandez, N. (2003). Metrics for measuring ideation effectiveness. *Design Studies, 24*(2), 111-134.
39. Shedroff, N. (1999). Information interaction design: An unified field theory of design. In R. Jacobsen (Ed.), *Information design* (pp. 267-292). Cambridge, MA: MIT Press.
40. Sim, S. K., & Duffy, A. H. B. (2003). Towards an ontology of generic engineering design activities. *Research in Engineering Design, 14*(4), 200-223.
41. Smith, S. M., Kohn, N. W., & Shah, J. (2008, October 3). *What you see is what you get: effects of provocative stimuli in creative invention.* Paper presented at the NSF International Workshop on Studying Design Creativity, Provence, France.
42. Sutton, R. I., & Hargadon, A. (1996). Brainstorming groups in context: Effectiveness in a product design firm. *Administrative Science Quarterly, 41*(4), 685-718.
43. Tergan, S.-O. (2005). Digital concept maps for managing knowledge and information. In S.-O. Tergan & T. Keller (Eds.), *Knowledge and information visualization* (pp. 185-204). Berlin: Springer-Verlag.
44. Ulrich, K. T., & Eppinger, S. D. (1995). *Product design and development* (3rd ed.). New York: McGraw-Hill.
45. Vincenti, W. G. (1990). *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore, MA: John Hopkins.
46. Wodehouse, A. J., & Ion, W. J. (2010a). Digital information support for concept design. *CoDesign, 6*(1), 3-23.
47. Wodehouse, A. J., & Ion, W. J. (2010b). The integration of information and ideas: Creating linkages through a novel concept design method. *Parsons Journal for Information Mapping, 2*(2). Retrieved August, 2010, from http://piim.newschool.edu/journal/issues/2010/02/
48. Zins, C. (2007). Conceptual approaches for defining data, information, and knowledge. *Journal of the American Society for Information Science and Technology, 58*(4), 479-493.