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AN EXPLORATION OF DESIGN INFORMATION CAPTURE AND REUSE IN TEXT AND VIDEO MEDIA

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1 Introduction

High performance engineering design teams are composed of autonomous learners, who must independently identify and pursue their learning goals and content. The nature of design activity requires them to act that way; designing is, by definition, context dependent and open-ended. Design activity rarely revolves around a specific body of information or knowledge. When compared to traditional domain specific technology research activity, the autonomous learning behavior of designers necessitates a different and more robust set of knowledge capture and reuse methods and tools.

Autonomous learning of design teams can be facilitated by providing them with ubiquitous access to formal as well as informal information, and enabling them to extract and reuse key knowledge elements such as design-questions, design-decisions, and design-rationale as fundamental parameters of design thinking. There is a potential for increasing design team performance through facilitated reuse of existing concepts and knowledge.

The main premise of this research is that the design process can be improved and accelerated by ascertaining the nature of relevant and necessary design information, determining if it exists, and ubiquitously accessing it. This approach relies on a design information creation and reuse cycle; when new information is created, it is imperative that it is converted to appropriate digital formats, indexed, and rapidly made accessible. Clearly, if indexing can be done automatically, the utility of the cycle is significantly enhanced.

This paper describes a framework for capturing, indexing, and reusing formal and informal (tacit) design information. The key dimensions of the framework were implemented in the form of two existing information technologies that operate in different media, and tested in a quasi-controlled laboratory experiment that explored the affects of the technologies and the media on the information handling behavior and autonomous learning of design teams.

2 A Framework for Capturing and Indexing Design Information

Design information consisting of video records and predominantly text-based design documents were stored and indexed in two information systems. The affordances and utility of these systems and media were explored. In this section, the framework behind these explorations will be discussed.

2.1 Capturing and Indexing Video-based Design Information

Significant portion of the information generated by designers is tacit, and documentation and reuse of such tacit information has proven to be challenging [1,2]. In this research, the audiovisual medium is perceived to be effective in capturing informal design information as audiovisual data is inherently "richer" than traditional text data. Video allows for the capture of dynamic and time varying representations of actors, objects and events. What actors *do* and how objects *behave* are captured in a relatively direct and "neutral" way.

For instance, if a person is videotaped while entering and driving away in a car, the events—the person walking up to the car, entering the car, shutting the door, operating the car, etc.—are captured as they occurred without interpretation. It can be argued that the positioning of the camera, and therefore, the framing of the event is controlled by the camera operator, and constitutes interpretation, which yields subjectivity. However, when compared to other media, such as a text-based descriptive record of the event that took place, it can be argued that videotaping yields a more "objective" record.

Video interaction analysis has been used extensively in capturing, analyzing, and understanding designer behavior in a variety of contexts by individual [3,4] and communities of design researchers [5]. There is also an emerging focus on using video to facilitate user-centered design [6-8]. One dimension of that interest is concerned with documenting and representing user behaviors via video, and the other dimension treats video as a prototyping medium for visualizing and communicating product usage scenarios. However, video has not been explored extensively as a design information documentation paradigm in itself.

The events and activities that are of primary interest to this research involve individual or teams of designers engaged in any design related task. Any other event or activity might be of secondary interest depending on the content and nature of information that is being searched. To that end, a video processing system, Informedia, was identified and used to index and retrieve design team interactions that have been captured in video.

Informedia technology allows for the rapid retrieval of individual video segments which satisfy an arbitrary subject area query based on the words in the soundtrack, closed-captioning or text overlaid on the screen [9,10]. This approach uniquely combines speech recognition and natural language processing technology to automatically transcribe, segment, and index audiovisual data, and is applied to accomplish intelligent video search and selective retrieval.

For example, let us assume that the audiovisual record of an entire design team meeting on suspension design is processed via Informedia. After the meeting, if one wants to know whether the team discussed spring stiffness, one can run an Informedia search with "spring stiffness" as the query. If the words "spring" and "stiffness" were spoken during the meeting and recognized by Informedia, video clips of those sections of the meeting would be returned.

2.2 Capturing and Indexing Text-based Design Information

Text-based design documents have been traditionally used in design practice to document design information. In design practice, the knowledge acquired during a project is often captured and communicated in predominantly text-based reports. Such documents are treated as formal accounts of what has taken place and been learned during a project. They are also thought to be useful in informing future projects, and therefore, to be of strategic importance in establishing a knowledge base that can facilitate organizational learning.

It is important to note that written documents of this nature are treated as *formal* accounts since documenting concepts, processes, and designs in written form implies that the record is *edited* and *refined* prior to distribution/publication. There are exceptions such as design journals, which are also written documents. However, their intent is different; they are meant to inform their own creators, and not others (in the form of a report). They can be used in a report, but such usage implies that they will be edited and/or interpreted in some way.

Therefore, in this research, predominantly text-based design reports are hypothesized to be effective in capturing formal design information. They contain important "facts" such as specifications of designs, interpretations of concepts and approaches that were considered, description and outcome of relevant analysis that were conducted, and composition and processes of design teams. A digital library system, SMETE, was identified and used to index and retrieve design information contained in a set of design reports.

SMETE is a prototype for a national digital library for Science, Mathematics, Engineering and Technology Education [11]. SMETE infrastructure provides a World Wide Web based mechanism for indexing, searching, and retrieving multimedia information. Although it is possible to use SMETE to catalog audiovisual records as well as text-based documents, its indexing method requires the metadata for the video records to be generated and entered into the system manually. Therefore, the video record needs to be interpreted by a "librarian." This indexing approach, when compared to the automatic transcription and indexing approach of the Informedia system, is less suitable for processing audiovisual records.

3 Experimental Design

The design information capture and indexing framework discussed in the previous section was explored in a quasi-controlled laboratory experiment. The experiment was intended to extend the framework rather than validate it since the experiment was focused on the information reuse behaviour of designers; reuse considerations naturally follow from capture and indexing considerations.

In the experiment, six teams of two designers were asked to redesign the wheel of an existing "paper bicycle," which was designed by a student team during the 2003 offering of Mechanical Engineering 310, a graduate level design course at Stanford University. The paper bicycle exercise is a two week long design activity that takes place at the beginning of the course every year. In the experiment, the subjects were told that the performance of the wheel was not satisfactory because it was heavy, prone to structural failure, and expensive to manufacture, whereas the design of the frame the wheel was to fit was excellent. Therefore, the redesigned wheel had to fit into the existing frame. The subjects were also told that the marketing department had formulated a new requirement: the new wheel had to be manufactured from paper materials without the use of glue or adhesives due to environmental (recyclability) concerns. Finally, the subjects were informed that the redesigned wheel would be judged subjectively, and that the performance criteria would be the novelty of the design, and its ability to meet the redesign requirements outlined above.

All twelve subjects, except for one, were either enrolled in a mechanical engineering doctoral program, or had completed one. The subject who was not a mechanical engineer was enrolled in a masters program in computer science. Therefore, it is reasonable to conclude that the subjects were not novice designers due to their educational experience in engineering. None of the subjects had taken ME310, or designed a paper bicycle before.

The following were the guiding research questions for the experiment:

1. How do the information media used in the experiment affect the information handling behavior and autonomous learning of designers? What type of information do designers seek and which medium is most effective in providing the information?
2. How do designers reuse design concepts that were communicated in the information systems in their own design work? Do design concepts "migrate" from the information systems to the thinking of the designers?

Subjects were given access both to the Informedia and SMETE systems. They were trained on each system for approximately 10 minutes prior to the experiment, but they were not required to use the systems during the experiment. Instead, they were advised to use the systems if they perceived a need.

The Informedia system contained over six hours of video footage of ME 310 teams engaged in paper bicycle design between 1999 and 2004. The video collection consisted of team meetings, prototyping and testing activity, presentations, and lectures on paper bicycle design. All video footage was processed using Informedia's indexing capabilities. The subjects could search the video library by typing the search terms in the search field. If the search terms were encountered in the index Informedia built from the transcripts it generated automatically, the initial frames of the relevant segments of the video files were returned. At that point, the user could click on any of the returned images to view the video segments (Figure 1).

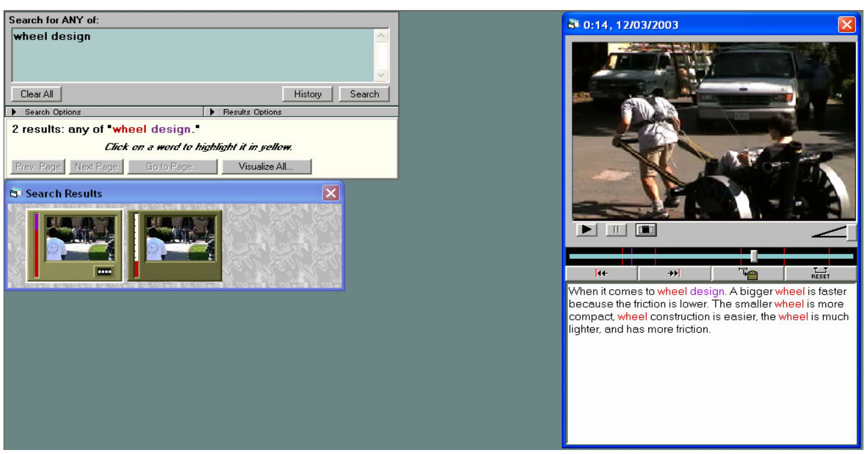

Figure 1. Informedia interface showing the results of a query with search terms, "wheel design." Two still images representing matches—video segments in which either of the words "wheel" or "design" are spoken—are visible below the search box. The bars on the left side of the still images indicate the relevance of the match. For instance, a segment in which both search terms are spoken would have a higher bar (better match) than a segment in which only one of the words is spoken. When one of the still images is clicked, the video segment associated with it is played on the viewer on the right hand side of the screen, together with the transcript of the corresponding audio channel.

The SMETE system contained paper bicycle design reports of 8 ME310 teams from 2003. Each design report was approximately 50 pages long. The collection included the report of the team whose wheel was to be redesigned in the experiment. The design documents were indexed at the paragraph level according to relevant SMETE metadata fields and a subject taxonomy (Table 1) that has been developed in a previous study on the information retrieval and reuse behaviors of mechanical engineers [12]. The implementation of that taxonomy in an information utility has been shown to reduce task completion time [13].

Table 1. Description of the subject terms used to index the paper bicycle design reports in SMETE.

Subject Term	**Description**
Alternative	Information regarding the choices or the decision about the object
Construction	Information regarding the topological arrangement of the object(s) as well as details of how they are put together and other manufacturing details (shape, dimensions, weight, volume, manufacturing process, etc.)
Location	Information regarding the physical position of the object in the device
Performance	Information regarding the evaluation, analysis, test results of the object
Rationale	Information regarding the purpose or the function of the object or reasons for the object being the way it is
Requirement	Information regarding constraints or the specifications of the object
Material	Information regarding the material they used in their construction
Concept	Information regarding the relationship between a set of design ideas forming a design solution
Analysis	Information regarding the description of a the object or its behavior in essential terms, often using mathematical symbols
Evaluation	Information regarding the opinion of the designer on the performance of the design
Failure	Information regarding a malfunctioning of the object
Function	Information regarding the design intent of an object. It can also be used to refer to the operation of the object
Process	Information pertaining to steps in the activity of designing
Specification	Information regarding the features of an object
Visualization	Information regarding the visual and/or animated description of the behavior of an object, including simulation

The application of the above taxonomy and the associated indexing paradigm in the experiment meant that if there was match for a search term in the SMETE index, the browser would download the report and automatically scroll to the paragraph associated with the indexed/searched term, allowing for rapid navigation to the relevant section of the document.

During the experiment, subjects were videotaped, and their interaction with the information systems were documented by digitally capturing the computer desktop environment in real-time so that their mouse actions were explicit.

4 Data Analysis

Four different analysis methods were considered to characterize and interpret the data:

1. Information Access: Attention to information contained in text-based design documents, video clips, or the WWW.
2. New Concept Generation: Introduction of new design concepts into the discussion.
3. Noun-phrase Generation: Introduction of unique noun-phrases into the discussion [14].
4. Question Asking: Asking of Deep Reasoning and Generative Design Question during the discussion [4].

In this section, the first two analysis methods will be applied to a single data set (one experiment session involving two designers).

4.1 Information Access

Information access was defined as either or both of the designers conceptually attending to the content of the information systems and the WWW. Content attention refers to a subject interacting with information contained in the text-based design documents, video clips, or the WWW. If subjects were interacting solely with the interface of the information systems—for instance, typing in a query—they were not considered to be attending to content. If subjects had identified content and were paying visual attention to it—for instance, by reading a section of a design report—they were considered to be attending to content.

It was also possible for subjects to be attending to content without paying visual attention to or without interacting with the information systems. For instance, they often located relevant content, read/viewed it, initiated a discussion while reading/watching it, and continued the discussion after they had stopped reading/watching it. The continuation of the discussion was considered to be conceptual attention, and therefore, system usage. Although one might think it would be difficult to determine when such a discussion has ended, and another discussion unrelated to the content has begun, making that distinction did not turn out to be problematic (coding was done collaboratively by two researchers on a consensus basis).

4.2 Concept Generation

Concept generation was measured in terms of unique design concepts that were introduced to the discussion. A design concept was taken to be the identification of one of the following:

1. A new resource that can be potentially utilized to apply a known method (i.e. using paper tubes as spokes, where "spoke" is a previously discussed method for providing structural integrity to a wheel).
2. A new method that can be potentially applied to utilize a known resource (i.e. press-fitting concentric paper tubes to join assemblies, where "paper tubes" are previously identified resources).
3. A new method that can be potentially applied to utilize a new resource (i.e. using crumbled paper to dampen dynamic forces between assemblies, where neither "crumbled paper" nor "dampening" are previously discussed resource and method).

Note the usage of the qualifier "potentially," which is meant to convey that concepts do not have truth-value and that the person proposing a concept is not necessarily concerned with its feasibility. This notion is derived from the premise of "Generative Design Questions," which are questions aimed at generating potential (hypothetical) answers and play a critical role in design thinking and performance [4]. For example, although the concept mentioned in the third point above, "using crumbled paper to dampen dynamic forces between assemblies," would most likely not work since paper has poor elastic deformation characteristics, it is still considered a concept.

During data analysis, after the introduction of a concept was identified, the concept's source and its semantic relationships to existing concepts were determined. Concepts could have their origin in one of the following:

1. **Migrated from Video Clip in Informedia**: Concept was clearly articulated and/or visible in a video clip contained in Informedia the subjects viewed. Subjects made explicit reference(s) to that video clip, and in many cases, copied the concept in the form that it was represented in the video clip.
2. **Migrated from Text-based Document in SMETE**: Same as above, however, concept was articulated and/or visible in the text-based design documents contained in SMETE as opposed to a video clip.
3. **Migrated from the World Wide Web**: Same as above, however, concept was articulated and/or visible in the WWW browser as opposed to the text-based design documents or video clips contained in Informedia. (Some subjects were innovative in their approach, and "fired up" a web browser and conducted searches on the WWW although they were neither encouraged nor discouraged to do so.)
4. **Designer**: Concept was primarily the outcome of the thinking of the subjects, and did not migrate into the thinking of the designers from an external source. In some cases, concepts were exclusively proposed by subjects. In others, subjects significantly extended existing concept(s) in creating a new concept.

Sources of some concepts were clearly referenced within the activity, and therefore, were relatively easy to identify. However, other concepts were a reaction to or a synthesis of existing concepts, and had many semantic relationships to other concepts. In that case, the primary enabler of the synthesis was considered to be the source of that concept. For instance, the subjects generated the concept of "Clamp around the Rim" to join the rim with the wheel surface. Then, they found information in a text-based design document on the concept of a "double rim," which hides connectors and streamlines rim surfaces, and applied it to their own design consideration. The first concept was named "Clamp around Rim…" and its source was coded as "Designer." The second concept was named "Double Rim with Clamp in Between…" and its source was coded as "Text-based Document" since the subjects simply reapplied a concept that they learned from an information system without making any significant conceptual changes to it.

It should be noted that a semantic relationship between two concepts does not necessarily imply a source for either concept. If concept A is "wheel," and concept B is "spoke," there is a semantic relationship between them since wheels have spokes. However, that relationship does not imply any information about the sources of the concepts; A could have originated from the designers, and B could have migrated from an information system.

Similar to information access coding, coding of concepts and concept sources was also done collaboratively by two researchers on a consensus basis.

4.3 Results

Data collected during one of the experiments were analyzed according to the definitions discussed in the previous section. The experiment lasted slightly over 1 hour and 45 minutes. The team spent 48.3% of its time during the experiment in attending to and processing content it located in the information systems (including the WWW), which is very significant (see Table 2.). The text-based documents were accessed the longest.

Table 2. Time spent attending to different information sources (actual and percentage of experiment duration).

Access Type	Access Duration	
	(sec.)	(% of total Time)
Text-based Documents in SMETE	1575	24.9 %
Video Clips in Informedia	999	15.8 %
WWW	484	7.6%
All Information Sources	3058	48.3%

Information access is represented graphically along the experiment timeline in Figure 2. Notice that, except for a short period preceding the 4200 second mark, the different information sources are not being attended to simultaneously.

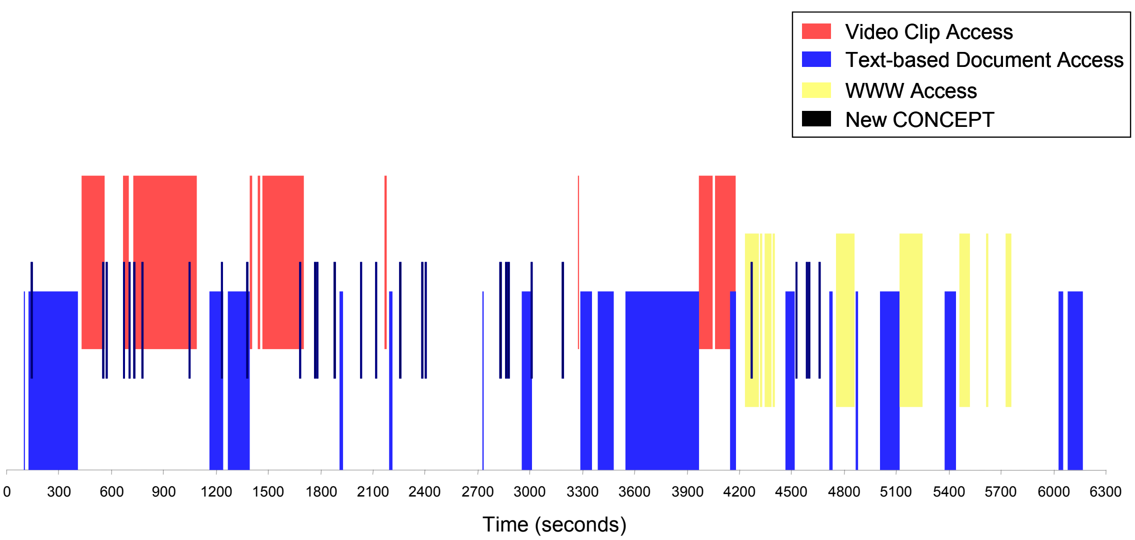

Figure 2. Experiment timeline illustrating information access intervals, and the introduction of new design concepts.

A total of 29 distinct design concepts were generated. 4 concepts migrated from the video clips contained in Informedia, 4 from the text-based design documents contained in SMETE, and 1 from the WWW. 20 concepts were primarily a product of the designers own thinking, and did not migrate from any of the information systems (Table 3).

The introduction of new concepts are plotted on the experiment timeline in Figure 2. As one would expect, majority of the concepts, 23 out of 29, were introduced in the first half of the activity.

Table 3. Number of concepts that have migrated from each concept source into the thinking of the designers.

Concept Source	# of Concepts
Migrated from Text-based Documents in SMETE	4
Migrated from Video Clips in Informedia	4
Migrated from the WWW	1
Designer	20

Tracking the evolution of concepts by documenting semantic relationships between them proved to be insightful. A concept with multiple upstream semantic relationships almost always meant that designers built upon previously introduced concepts that originated from different sources. This resulted in the synthesis of concepts with designer and information system (non-designer) sources.

The semantic relationships between the concepts are illustrated on the experiment timeline in Figure 3. For instance, the concepts "Plain Disc as Wheel Surface with Holes to Reduce Weight" and "Plane Disc with Laminated Paper Sheets" and "Nails as connectors" (concepts 4, 6, 12) were determined to be on a conceptual continuum since, in each adjacent pair in the continuum, the latter extended the former in working toward a function.

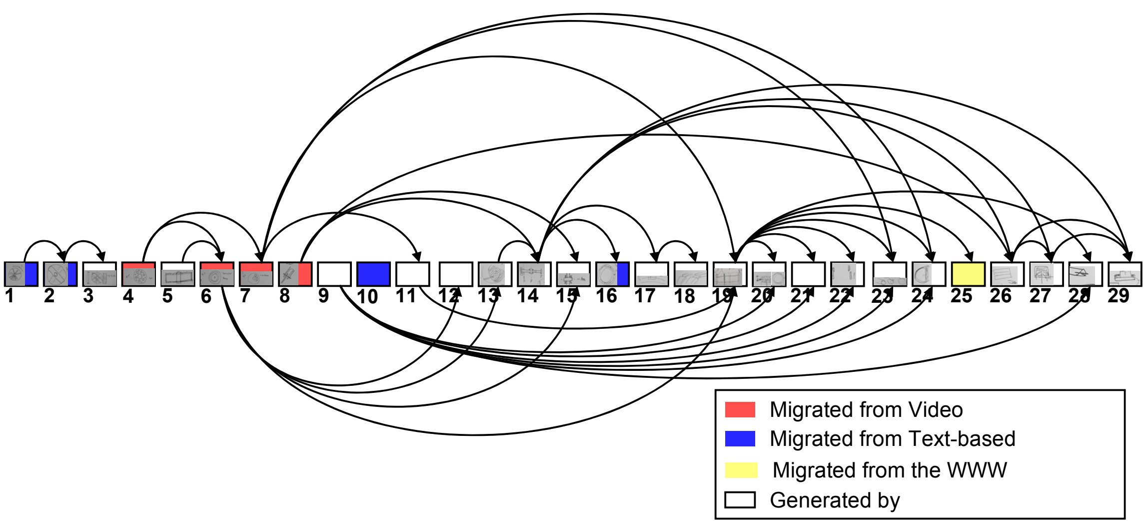

Figure 3. New concept generation and the semantic and temporal relationships between new concepts. The concepts are represented sequentially from left to right, left being earliest in the experiment.

Upon visual inspection, it is apparent that the concepts that migrated from video clips have a deeper network of downstream concepts that are semantically related to them compared to the concepts that migrated from text-based documents, the WWW, or the concepts that originated from the designers. For instance, Concepts 4 and 6 seem to have a particularly high number of downstream semantic relationships at several levels of depth, whereas Concepts 1, 2, and 10 do not seem to have many semantic relationships with the proceeding concepts.

5 Conclusions

This case study was an exploration of design information capture and reuse in text and video media. Qualitative and quantitative analysis of the data suggest the following:

1. The subjects, even when they were not forced to use any of the information systems that were made available to them, spent a significant amount of their time (48%) attending to content they located within the systems. This reinforces the notion that it is crucial for designers to seek and reuse information from related design activities.

2. In general, the different information sources were not attended to simultaneously.

3. Although the text-based design documents were accessed more than the video clips, an equal number of concepts migrated from each medium to the thinking of the designers. The majority of the concepts originated from the designers.

4. When the semantic relationships between the concepts are considered visually, it is apparent that the concepts that migrated from video clips have a deeper network of downstream concepts that are semantically related to them compared to the concepts that migrated from design documents, the WWW, or the concepts that originated from the designers.

5. The preceding point needs to be investigated further. A quantitative measure is currently being developed in order to characterize this phenomenon.

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