UNDERSTANDING OF KNOWLEDGE GENERATION DURING DESIGN PROCESS IN INDUSTRY

Gokula Vijaykumar A.V[1] **Amaresh Chakrabarti[2]**
[1]Research Scholar, [2]Associate Professor
Innovation Design Study and Sustainability Laboratory
Centre for Product Design and Manufacturing
Indian Institute of Science, Bangalore, India
[1]vijay@cpdm.iisc.ernet.in, [2]ac123@cpdm.iisc.ernet.in

Abstract

Knowledge reuse is considered as one of the most effective ways to meet the current demands of product development in the changing global scenario. Even though literature contains many knowledge reuse approaches, representations, and capture and retrieval methods, adoption of these methods and tools in the industrial set-up is minimal. Possible reasons for this status are that the knowledge needs of designers and industries are not appropriately understood and addressed. This research attempts to bridge this gap by undertaking a descriptive study in an industry in order to understand the processes of knowledge generation during the product development process. We propose a descriptive collaborative model in which interactions of the designers with people and tools play the central role in this knowledge development process. The paper will describe the preliminary understanding obtained about the various types of tasks, interactions and knowledge occurring in the design process.

1. Introduction

The current design scenario of ever increasing customer requirements and continuous reduction in product life cycle forces companies to develop more complex and innovative products with high quality and low cost concurrently in order to meet the decreasing time to market and this too with product development personnel frequently changing jobs. Globalization is here to stay and more so in the area of product development. As experienced by many industries today, both knowledge and expertise are getting geographically distributed along with resources and equipment. To overcome these challenges, companies should utilize all competence available, work in teams and scout for talent across the globe.

The competence developed within a company can be synergistically used and leveraged only if the necessary knowledge produced during the design process is efficiently captured, structured and made available for reuse across its projects and units. The perceived benefits of retaining the required knowledge are enhanced innovation through cross pollination of ideas, avoiding duplication of tasks, reduction of learning time, better training for new designers, and improved retention of core competence even with low retention of product development personnel.

In literature many knowledge reuse approaches, representations, and capture and retrieval methods are proposed. But adoption of these methods and tools in an industrial set-up is minimal. Possible reasons for this status are that the knowledge needs of designers and industries are not appropriately understood and addressed. This research attempts to bridge this gap by undertaking a descriptive study in an industry in order to understand the processes of knowledge generation during the product development process.

The subsequent discussions in this paper are organized in six sections. Section 2 provides a detailed literature survey about knowledge processing and interactions in design and the relevance of this paper. Section 3 defines the technical terms used in this paper with examples. Section 4 elaborates the proposed descriptive collaborative model. Section 5 discusses the various data collection methods employed to collect the required data from the industry and its limitations. Section 6 elaborates the preliminary observations found from the data analysis. Section 7 discusses overall conclusions from this preliminary observations and the further work to be carried out.

2. Literature Survey

This section elaborates the need and present understanding of knowledge processing activities and interactions.

2.1 Need to understand knowledge processing activities

In design research, information and knowledge are often used interchangeably and defined rarely. To avoid confusion in this section, information and knowledge are considered as used in the following research papers. The definitions used in this paper are given in Section 3. Ehrlenspiel [1] notices that designers need 20-30% of their working time for information gathering. Marsh [2] observes that designers spend on an average 24% of their time in information acquisition and dissemination, and the majority of the information is obtained from personal contacts rather than formal sources. Crabtree et al. [3] point out that project delays are mainly due to time spent in information acquisition and information access. The associated delays range from a single day to a year. MacGregor et al. [4] observe that engineers use company systems and colleagues in the same office to get information and engineers perceive that 34% of their time is taken in sourcing and locating relevant information. Frankenberger & Badke-Schaub [5] argue that availability of information is a central factor for the success of design. They observe that designers spend more time individually than in teams but critical situations occur in collaboration. Ottosson [6] estimates that less than 20% of the information that we get is used in building up new pictures of the world while the remaining part comes from our earlier pictures stored in the brain. He argues that when two individuals interact with each other to solve a problem their collective knowledge is larger than when they do not interact. Busby (1998) found that engineers often fail to learn from their experiences because the feedback provided to engineers from previous projects was often unreliable, delayed and negative, and sometimes missing altogether.

2.2 Understanding and models of knowledge processing activities

Court & Culley [7] use Information Access Diagrams to provide an understanding of how engineering designers access design information. They identify memory as a significant area source of information; and irrespective of the type and stage of design, similar access paths are followed. Clarkson & Hamilton [8] observe that knowledge is often localized and resident in key personnel and not documented or retrieved easily by other designers.

Wu & Duffy [9] develop a model to present information flow in design based on Situation Theory [Devlin, 1991]. The model includes input information of sender(s) and receiver(s), interaction between agents, output knowledge of agents, the goal of interaction, and the goal of sender and of receiver. They argue that this model helps to analyze design information systems and provides a basis for investigating the situatedness of design information flow. McMahon et al. [10] speculate an information-connection model for design activities and argue that the quality of resultant designs is dependent on the quality of information connection. The model consists of information connection activities and information generation activities with their respective costs and times.

2.3 Interactions

Larrson et al. [11] observe that one to one conversations are common in co-located teamwork and they serve as a natural part of creative teamwork. MacGregor et al. [12] observe that interactions between engineers for information exchange and collaborative design are in a ratio of approximately 5:1 and these two interact cyclically. Eppinger & Salminen [13] found that even where the development process shows uni-directional information transfer, the actual communication between individuals are predominantly bi-directional exchanges. Eckert et al. [14] observe that inadequate information flow is due to not understanding the big picture, not knowing what to know, information distortion, and difference in interpretation of representations. Minneman [15] addresses ways that design work emerges from interactions among individuals and groups as they establish, develop, and maintain a shared understanding. Negotiating understandings, conserving ambiguity, tailoring engineering communication for recipients and manipulating mundane representations are identified as crucial group activities.

Brereton et al. [16] investigate how social interactions shape a product: the content of an evolving design depends upon negotiation strategies and other subtle and ubiquitous social interactions. Team members' orientation to a solution or process is demonstrated by the levels of commitment in utterances; team members continuously engage in monitoring multiple issues at multiple levels of attention. Harvey C.M., & Koubek R.J., [17] argue that to communicate successfully, one person must 'mutually accept' the other's references before the conversation proceeds. The effectiveness of the communication process is based on what is called "common ground" (Clark and Willes-Gibbs, 1986).

Eckert & Stacey [18] categorize the variety of interaction in design by the "dimensions of communication situations": form of communication, form of task, subject expertise, tool expertise, organization, and representation of information. They argue that no single approach to support communication is sufficient to handle the richness and variety of possible communication acts. Beyer et al. [19] argue that basic patterns of communication include information object communicated, its means of communications, sender and recipient. The objectives are to inform oneself, to ask, to provide information, to forward information, to inform somebody, and to exchange information. Lockledge & Salustri [20] provide a formal process to construct a mechanism for structuring design communications using a variation of the Design Structure Matrix that may keep participants updated on the design status. Frankenberger et al. [21] develop a model to describe the interaction between individual prerequisites, group prerequisites, external conditions, task, design process and

2.4 Summary and relevance to this paper

On average designers spend 30% of their working time in knowledge acquisition and dissipation during the design process. The efficacy of the designers will be improved significantly only if the knowledge generated during the design process is properly organized for later use. The current understanding of the knowledge processing activities is not detailed enough to support this process. Also the models do not cover the whole spectrum of knowledge processing activities. The exhaustive list of interactions occurring in the design process and its influences on knowledge processing activities is not discussed in the current literature survey. The subsequent sections will address the above gaps found in the literature survey.

3. Terminology

Chakrabarti A., et al. [22] argue that glossary is important for engineering design research because it will foster unambiguous communication among the research community. To emphasize their argument, terms used in this research paper are defined below with examples (in italics) from the observed case study.

Design: A complete and detailed description of the product. *CAD drawing describing the design of single cavity injection mould with bill of materials.*

Requirements: The technical and non-technical issues of the intended product considered by the designers during the engineering design process are termed as requirements. *Technical issue observed is to design a single cavity mould for a base component. Non-technical issues observed are vendor follow up and scheduling of the project.*

Requirement satisfaction: The degree to which the design satisfies each requirement. For non-technical issues, how well the project was completed with respect to the scheduled target dates. For technical issues, it will be adjudged with the help of repeatability or correction occurs after the requirements were satisfied. No repeatability occurred during the observed period. It will also be adjudged with the help of outcomes and duration and it involves subjectivity. This analysis is not carried out in the present observation.

Tasks: A piece of work to be done to satisfy requirements. *Some of the observed tasks are "modifying existing mould design", "measuring dimensions from physical model" and "asking for particular file or information".*

Tasks Satisfaction: The degree to which the purpose of the piece of work to be done gets satisfied. It will be adjudged with the help of repeatability or correction occurred after the tasks were satisfied. No repeatability of tasks occurred during the observed period. It will also be adjudged with the help of outcomes and duration and these involve subjectivity. This analysis was not carried out in the present observation.

Interactions: Mutual or reciprocal action or influence of objects to produce / exchange or intended to produce / exchange knowledge. *Some of the interactions observed are One + Computer, One to One + Comp and One to One + Comp + Doc + Calc.* The representation of interactions such as One + One + Comp + Doc + Calc and One + Computer should be read as observed subject interacting with another through computer, document and calculator, and observed subject interacting with computer alone respectively.

Interactions satisfaction: Interactions satisfaction is expressed in terms of communication satisfaction (ability to express or share and understand the discourse), Generate-Evaluate-Select-Verification cycle performed and intensity of the interactions (number of issues or proposals per duration of the interaction). Designers are able to express their thoughts clearly to others but misunderstandings were found during discourse. Generate-Evaluate-Select-Verification cycle is discussed in Section 6. The intensity of the interactions is yet to be analyzed.

Data / Information/ Knowledge: Data, information and knowledge are relative concepts that cannot be defined in absolute terms. An awareness stage and an interpretation stage differentiate between data, information and knowledge [23]. The definition and example are explained in Fig. 1 and Fig. 2 respectively.

Knowledge Satisfaction: The degree to which the knowledge required for the designers for the particular task is available within himself or in the organization. Detailed analysis is elaborated in Section 6.

Product-based knowledge: Design knowledge concerned about objects being designed. *The statement such as "That draft?" and "Which line?" are classified into product-based knowledge.*

Process-based knowledge: Design knowledge concerned about how to design. *The statement such as "without that line you do once", "cut till the inside surface" and "now I will make this way" are classified into process-based knowledge.*

Issues: Any problem, concern, or question can be an issue. *Some of the issues observed are "what wrong in this?", "Which line?" and "This you are cutting up to which surface?".*

Proposals: A proposal is a statement or assertion which resolves the issue. *Some of the proposals are "we can make this way and that way also" and "in a way if you ask me I will prefer for this".*

Generate: The process of producing new or elaborate solutions by designers. *Some of the proposals generated are "there is nothing wrong in this" and "that is without this radius".*

Evaluate: The process of assessing and criticizing a solution by designers. *Some of the proposals evaluated are "See here you added extra plastic here" and "he is taking a cut here".*

Select: The process of taking decisive actions. *Some of the decisive actions are "there is nothing wrong in that" and "wait I will show you".*

Verification: The process of agreeing/disagreeing, checking and confirming by designers. *Some of the verification words are "OK", "Ya" and "Correct".*

4. Collaboration model & research objectives

A descriptive collaborative model has been proposed to illustrate the designing and knowledge operations through interactions. Fig. 3 describes the collaborative model.

In this model, requirements satisfaction has been considered as a primary objective of an engineering design process, because satisfying design requirements achieve the customers' needs, apart from enabling the development of the design into a product [24]. Each requirement consists of a set of tasks with purposes and outcomes, and is executed through a complex variety of interactions. For example, a designer may have to interact with another designer, clients, tools, groups of designers or group of clients. Each interaction may lead to new tasks, and will involve various knowledge operations: knowledge production, sharing, storage, structuring or reuse. Requirements, tasks, interactions and knowledge will influence each other in the consequent order.

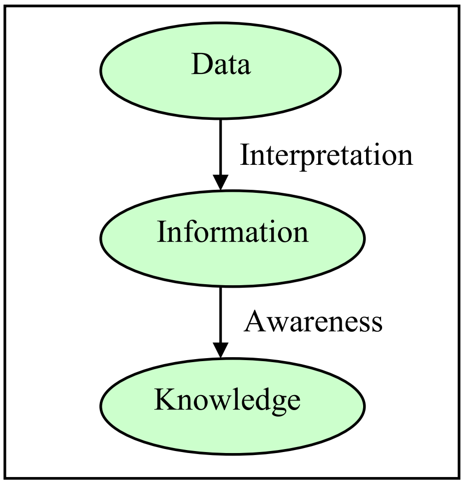
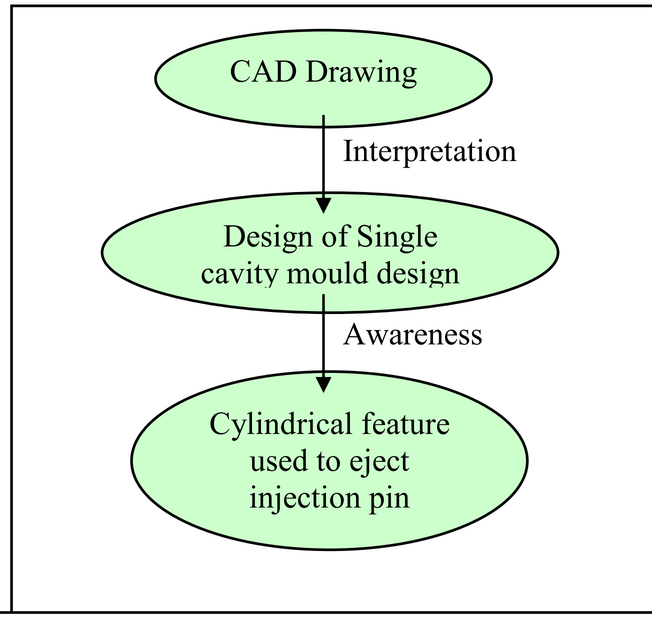
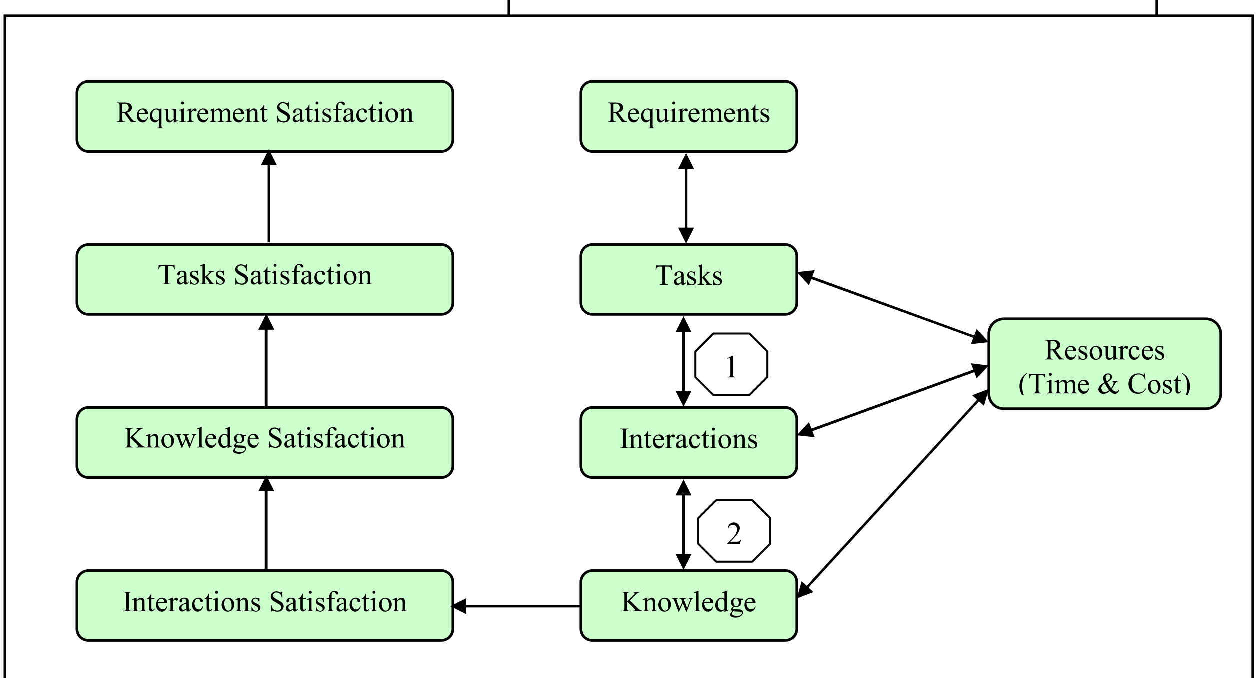


Fig. 1 Definition





share, reuse knowledge properly (knowledge satisfaction) through effective interactions (interactions satisfaction); the satisfaction of every purpose of the tasks will influence the requirement satisfaction of the artifact. In this competitive scenario the requirement of the artifact should get satisfied in a resource effective way. The resources can be clubbed into two categories: time and cost. The set of tasks, interactions and knowledge will and get influenced by available resources. We can say that the quality of interaction is good, only if it satisfies the purpose of the tasks in a resource effective way.

In this paper we discuss the links numbered 1 and 2 shown in the Fig. 3. The focused questions are,

- What are the various types of tasks that occur and their proportions?
- What are the various types of interactions that occur and their proportions?
- What are the types of knowledge produced and their proportions?
- How are the tasks, interactions and knowledge related to each other during product development processes?
- Is there any pattern that emerges during knowledge generation process?

5. Data capture methods and its limitations

To answer the research questions a case study was undertaken in a product development organization. Three designers involved in different projects were observed for a week each. The data capture methods employed to collect the required data are questionnaires, unstructured interviews, voice recordings, digital snap-shots, video recordings, desktop sharing and data sheets. The questionnaires were used to collect information about organization, projects and subjects involved in the observations. Unstructured interviews were conducted with the observed subjects whenever necessary to understand the subjects' activities or problems that occurred during observation. Voice recordings were employed whenever there was an interaction between the observed subject and other people. Digital snap-shots were used to capture the final outcomes of the subject when they were interacting with their notebooks or paper. Video recordings were used to capture the data generation during the complex interactions that involved two or more people with documents or other information sources. Desktop sharing was used to capture the subjects' interactions with the computer. The CAD package UNIGRAPHICS was used mainly by the observed subjects. For desktop sharing VNC software developed by RealVNC was used. To capture the shared desktop Hycam2 software developed by Hyperionics was used. Data sheets gave details about the purpose of the tasks, interactions, place of interactions, duration of the interactions and whether interactions were satisfying or not. The limitations and hindrances that occurred during the observations were,

- The data not produced but eventually understandable in the interactions are context and incomplete sentences which is later fulfilled in analysis.
- For desktop sharing first we employed NetMeeting software developed by Microsoft Corporation. But during observations we found that there were interoperability issues between NetMeeting and Unigraphics CAD software.
- Linguistics constraint. The subjects have interacted in languages which the observer was not able to understand.
- Desktop capture, snap-shot and audio do not synchronize properly due to the complex nature of the interactions as well as the constraint of the observer to operate all the devices concurrently. Hence we used video recording to capture the complex interactions.
- The digital camera with digital zoom of 4x was not able to take a snap-shot of written documents clearly. Hence we used a scanner to digitize the written documents.
- The digital voice recorder does not record the voice properly when the subjects are in motion. Also subjects were not interested to put voice recorder inside their pockets.

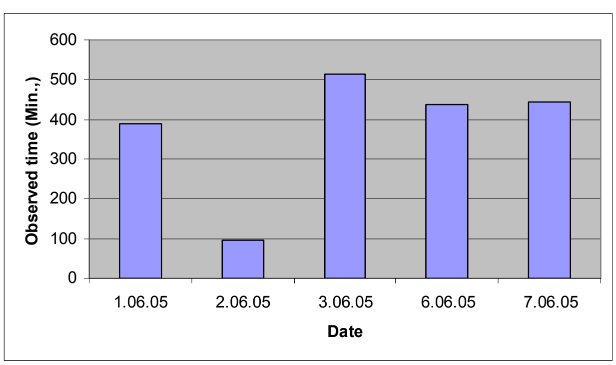


Fig. 4 Observed durations

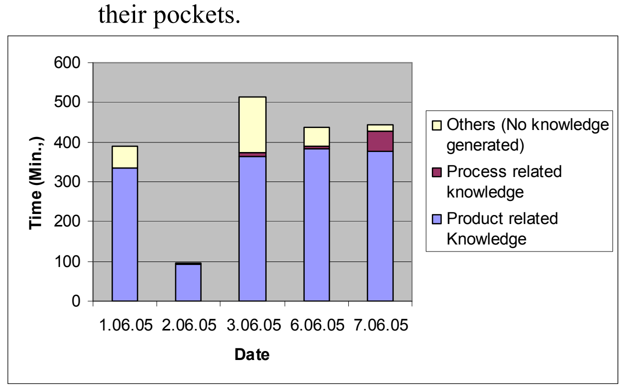
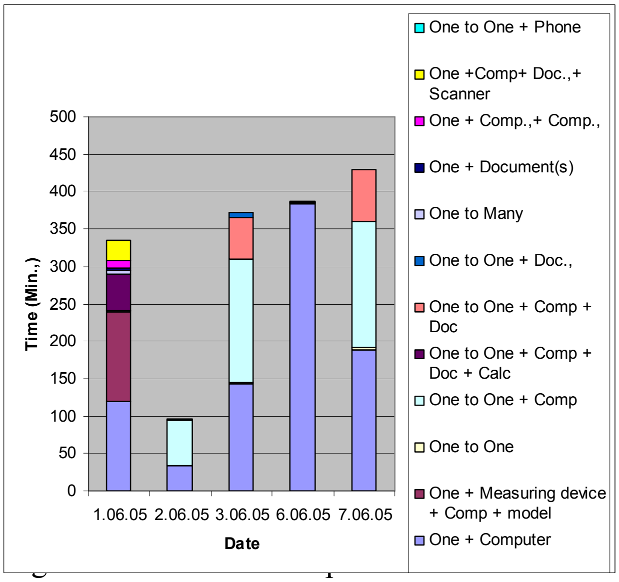
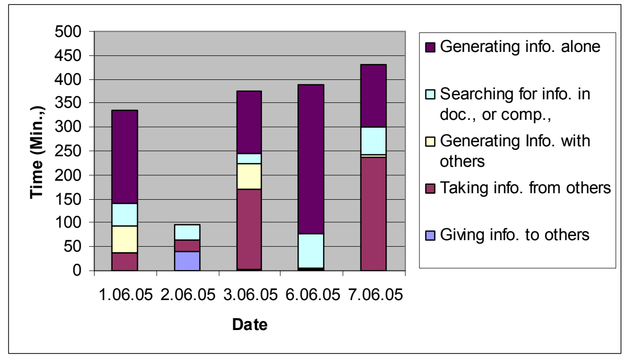


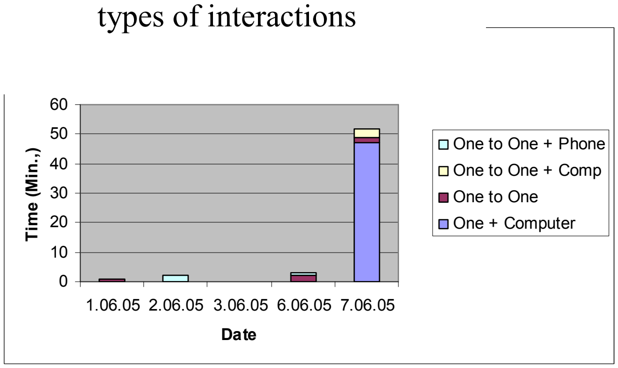
Fig. 5 Amount of time spent on types of knowledge





types of interactions

Fig. 7 Amount of time spent on types of tasks



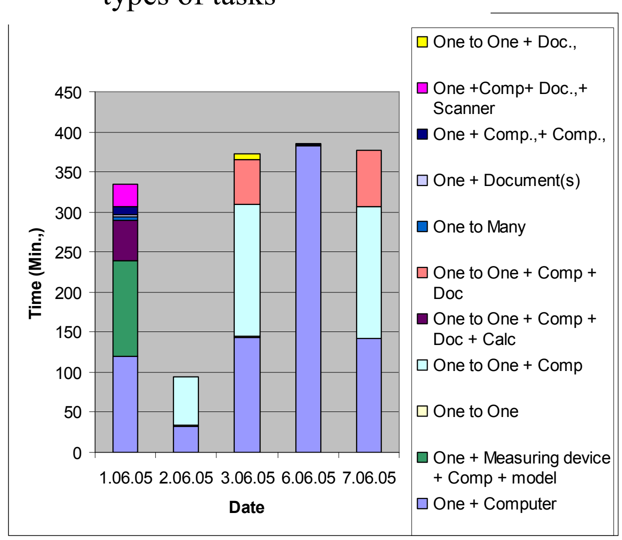
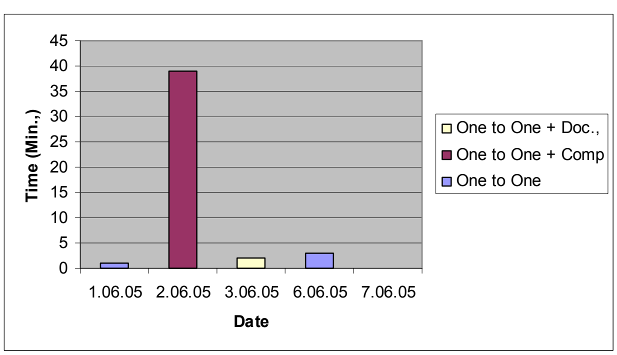


Fig. 8 Interactions leading to product-based

Fig. 9 Interactions leading to process-based

knowledge

knowledge



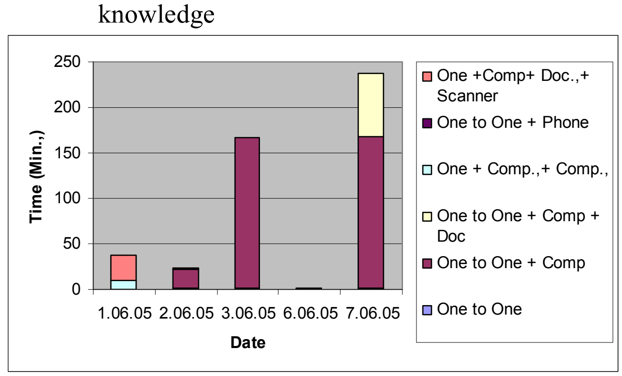
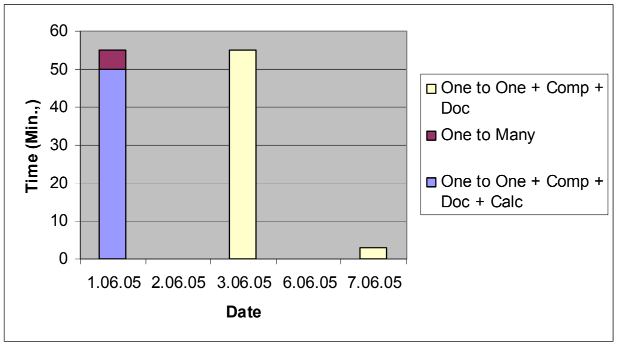


Fig. 10 Giving information to others vs. Interactions

Fig. 11 Taking information from others vs. Interactions



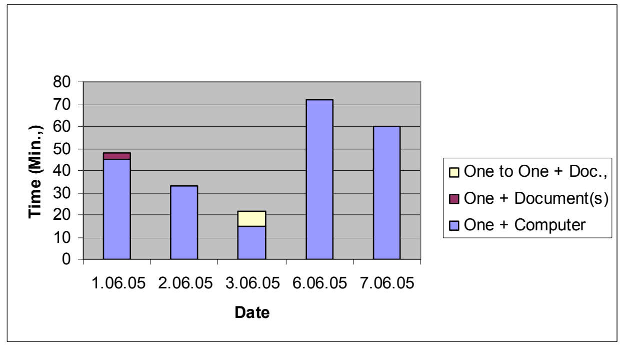


Fig. 12 Generating information with others vs. interactions

Fig. 13 Searching for information in documents or computer vs. interactions

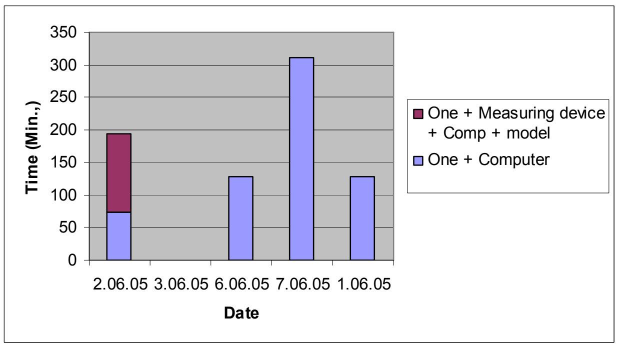
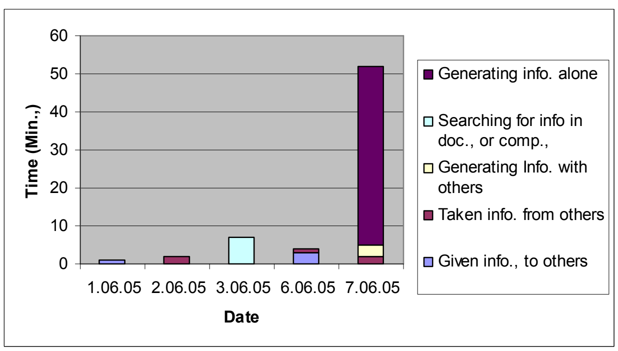


Fig. 14 Generating information alone vs. interactions



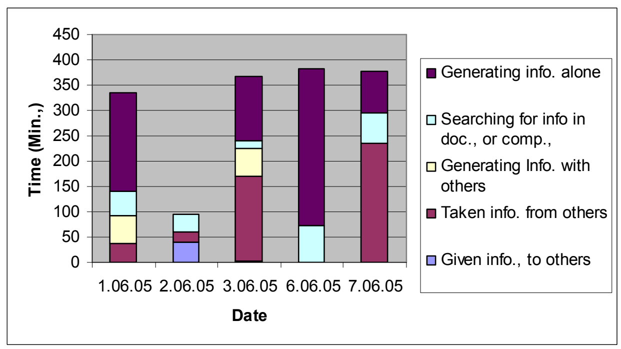


Fig. 15 Types of tasks vs. Product-based knowledge

Fig. 16 Types of tasks vs. Process-based knowledge

Table 1 Synthesis of two approaches

	Blessing Kunz and Rittel	Generate	Verification	Evaluate	Verification	Select	Verification
Product–based Knowledge	Issues	1	2	3	4	5	6
	Proposals	7	8	9	10	11	12
Process–based Knowledge	Issues	13	14	15	16	17	18
	Proposals	19	20	21	22	23	24

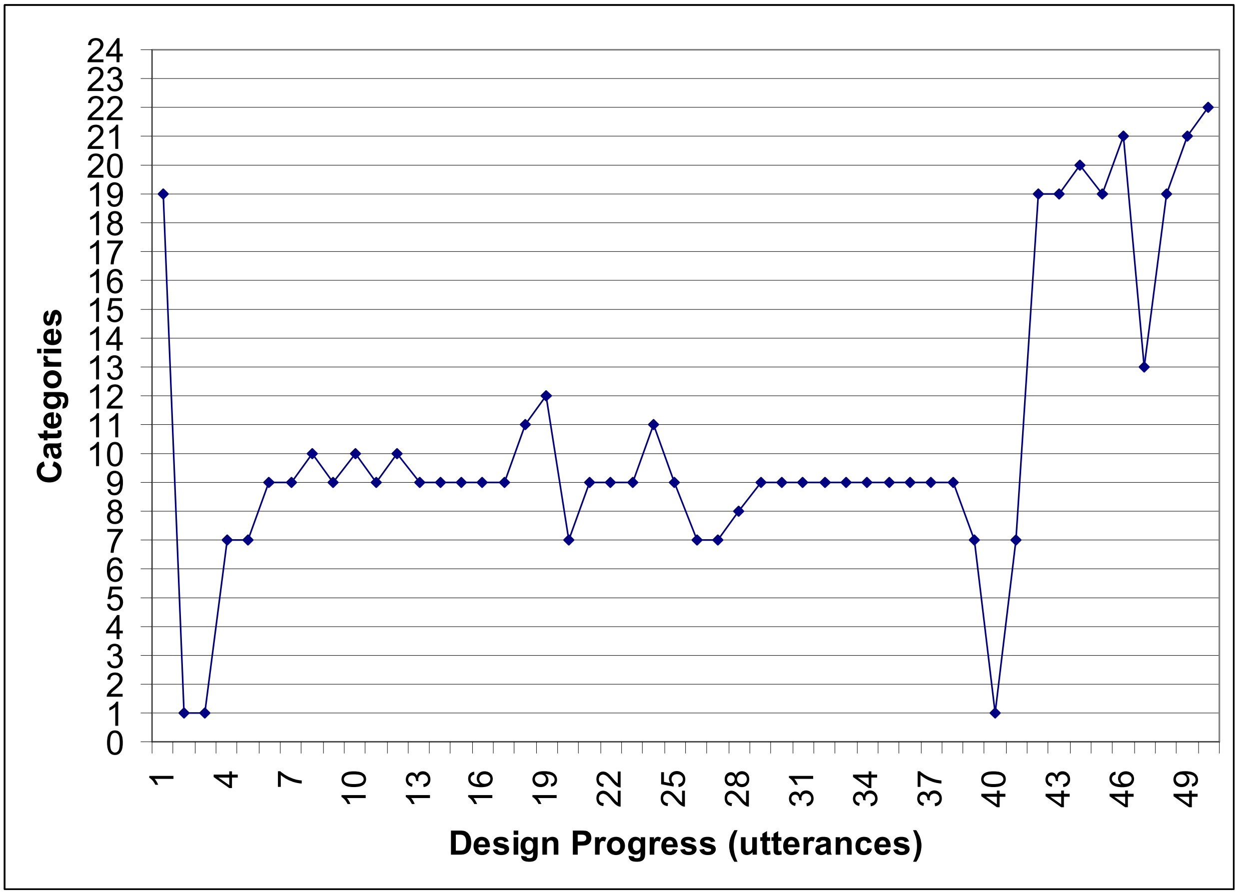


Fig. 17 Patterns emergent from knowledge generation process

6. Preliminary results

In this paper results are discussed based on the data gathered from a single subject. The underlying reason being that in the available time an in-depth analysis of the data collected is much better than breadth-wise analysis. It was observed that the subjects have not been disturbed or influenced by the observations. Fig. 4 represents the amount of observed duration on the subject. The average time observed is approximately 6 hours per day. Fig. 5 represents the amount of time spent by the subject for product-based, process-based knowledge and others (where no design knowledge was produced). The observation from the figure is the amount of time spent for product-based knowledge (82.6%) is much higher than that for process-based knowledge (3.5%). Fig. 6 represents the variety of interactions performed by the subject in order to satisfy his tasks. In the twelve interactions found, the most frequently observed interactions were One + Computer (46.14%), One to One + Comp (20.94%) and One to One + Comp + Doc (6.66%).

The information exchanges based on the tasks performed by the subject are classified into five categories. They are: Giving information to others, Taking information from others, Generating information alone, Generating information with others and Searching for information in documents or computer. None of the tasks performed by the designers were intended to capture information. i.e. the information capturing happened as a part of the five information exchanges mentioned above. Fig. 7 represents the amount of time spent by the subject on various information exchanges on each day of observation. The most frequently observed information exchanges are generating information alone (40.5%), taking information from others (24.8%), searching for information in documents or computer (12.5%), and generating information with others (6%). Giving information to others is less (2.4%). It may be due to the novice nature of the observed designer. In this study designers spend 37.3% of their working time in knowledge acquisition and dissipation during the design process that is slightly higher compared to 20–30 % mentioned in the literature. Fig. 8 and Fig. 9 represent the types of interactions leading to product based and process based knowledge respectively. The interactions that played an important role in the production of product based knowledge are One + Computer (43.6%), One to One + Comp (20.7%) and One to One + Comp +

Doc (6.64%). The interaction that played an important role in the production of process based knowledge is One + Computer (2.5%). Interaction that does not produce product based knowledge is One to One + Phone.

Figures 10-14 represent different categories of information exchange leading to different types of interactions. The interaction One to One + Comp (2.07%) predominates in giving information to others. The interactions One to One + Comp (18.7%) and One to One + Comp + Doc (3.7%) predominate in taking information from others. The interactions One to One + Comp + Doc (3.1%) and One to One + Comp + Doc + Calc (2.66%) predominate in generating information with others. The interaction One + Computer (11.96%) predominates in searching for information in documents or computer. The interactions One + Computer (34.13%) and One + Measuring device + Comp + physical model (6.37%) predominate in generating information alone. Fig 15 and Fig. 16 represent the categories of information exchanges leading to product based and process based knowledge respectively. The types of information exchange which dominate in the product based knowledge are generating information alone (38%), taking information from others (24.56%), searching for information in documents or computer (12.12%), generating information with others (5.84%), and giving information to others (2.2%). The type of information exchange that dominates the process-based knowledge is generating information alone (2.5%).

We tried to see the knowledge generation patterns emerging during the design process by synthesizing two approaches, namely design matrix proposed by Lucienne Blessing [25] and Issue-based information systems proposed by Kunz and Rittel [26]. Table 1 provides a synthesis of the two approaches. We classified the issues and proposals into product-based and process-based knowledge. We introduced a verification process in between generate-evaluate-select process as it was found during classification. The number inside the table is used to represent the categories in the Fig. 17.

Fig. 17 explains the knowledge generation patterns with respect to the proposed synthesized model by analyzing 50 utterances from one to one interaction occurred during the observation.

Observations from Fig. 17 are the following:-

- In the interaction no patterns emerge in the Generate-Evaluate-Select-Verification cycle.
- During the interaction designers left some of the generated issues and proposals and moved on to the subsequently generated issues.
- The number of utterances occupied for product-based issues and proposals are more compared to process-based issues and proposals.
- The number of utterances occupied by the proposals both in product-based and process-based are much higher compared to issues.
- Verification is not performed for all the utterances. Verification is performed to aid the communication between the designers. Most often it is performed in the evaluation process.
- The select process is the most ignored part both in the product-based and process-based knowledge.
- The evaluation process is not at all considered during issues both in product-based and process-based knowledge.
- There is an abrupt swift from the product-based to process-based knowledge.

Even though this is only a preliminary study we can still conclude that focusing on One + Computer, One to One + Comp and One to One + Comp + Doc interactions may lead to achieving the primary objective of that of capturing much of the necessary knowledge generated during the design process without intruding the designer's activities.

7. Conclusions and Future study

In this paper we discussed our observations of knowledge generation during design process in the observed industry. A collaborative model is proposed to understand the knowledge generation process better. We have shown the various types of tasks that occur and their proportions, the various types of interactions that occur and their proportions, and the types of knowledge produced and their proportions. We have shown how tasks, interactions and knowledge generated are related. The patterns of knowledge generation process are discussed with the help of a synthesized model. In the knowledge processing activities, knowledge generation is a basic activity. With the help of this we plan to study knowledge capture and reuse aspects. The most important question to be answered in this study will be what knowledge is developed that is not captured but should be otherwise.

References

1. Ehrlenspiel K., "Knowledge-explosion and its consequences", ICED 1997, Vol. 2, pp 477-484.
2. Marsh J.R., "The capture and utilisation of experience in engineering design", Ph.D. Thesis, St. John's College, Department of Engineering, University of Cambridge.
3. Crabtree R.A., Fox M.S., and Baid N.K., "Case studies of coordination activities and problems in collaborative design", Research in Engineering Design, Vol. 9, 1997, pp 70-84.

4. MacGregor S.P., Thomson A.I., and Juster N.P., "Information sharing within a distributed collaborative design process: A case study", Proceedings of DETC 2001.
5. Frankenberger E., and Badke-Schaub P., "Information management in engineering design – empirical results from investigations in industry", ICED 1999, pp 911-916.
6. Ottosson S., "Collaborative product development considerations", Human behavior in designing, Ed. Udo Lindemann, pp 164-173.
7. Court A.W., and Culley S.J., "A methodology for analyzing the information accessing methods of engineering designers", ICED 1995, Vol. 2, pp 523-528.
8. Clarkson P.J., and Hamilton J.R., "'Signposting' The design process", ICED 1999, pp 107-112.
9. Wu Z., and Duffy A.H.B., "Using situation thoery to model information flow in design", ICED 2001, 155-162.
10. McMahon C.A., Lowe A., and Culley S.J., "An information-connection model for design", ICED 1999, pp 1651-1656.
11. Larsson A., Torlind P., Karlsson L., Mabogunje A., Leifer L., Larsson T., and Elfstrom B-O., "Distributed Team Innovation- A framework for distributed product development", ICED 2003.
12. MacGregor, S.P., Thomson, A.I., and Juster N.P., "A multi-level process based investigation of distributed design", Proceedings of the Engineering Design Conference 2002 (EDC 2002), Kings College London, England, July 9-11 2002.
13. Eppinger S.D., and Salminen V., "Patterns of product development interactions", ICED 2001, pp 283-290.
14. Eckert C.M., Clarkson P.J., Stacey M.K., "Information flow in engineering companies – problems and their causes", ICED 2001, 43-50.
15. Scott L.Minneman, "The social construction of a technical reality: Empirical studies of group engineering design practice", Ph.D. Thesis, Department of Mechanical Engineering, Stanford University.
16. Brereton M.F., Cannon D.M., Mabogunje A., and Liefer L.J., "Collaboration in design teams: How social interaction shapes the product", Analysing Design Activity, Eds Nigel Cross, Henri Christiaans and Kees Dorst, pp 319-341.
17. Harvey C.M., and Koubek R.J., "Toward a Model of Distributed Engineering Collaboration", Computers in industrial engineering, Vol. 35, No 1-2, pp. 173-176, 1998.
18. Eckert C., and Stacey M., "Dimensions of communications in design", ICED 2001.
19. Beyer N., and Weber F., "Concepts and prototype for a practical communication environment for supporting and managing concurrent product development", ICED 1999, pp 1431-1436.
20. Lockledge J.C., and Salustri F.A., "Design communication using a variation of the Design Structure Matrix", ICED 2001, 27-34.
21. Frankenberger E., Badke-Schaub P., Birokhofer H., "Factors influencing design work empirical investigations of teamwork in engineering design practice", ICED 1997, Vol. 2, pp 387-392.
22. Chakrabarti A., Murdoch T., and Wallace K., "Towards a glossary of engineering design terms", International conference on engineering design, 1995, pp 185-186.
23. Ahmed S., Blessing L., and Wallace K., "The relationships between data, information and knowledge based on a preliminary study of engineering designers", ASME Design Theory and Methodology, DETC99, Las Vegas, Nevada.
24. Nidamarthi S., "Understanding and Supporting requirement satisfaction in the design process", Ph.D. Thesis, Gonville and Caius College, Department of Engineering, University of Cambridge.
25. Blessing L., "A process-based approach to computer-supported engineering design", Ph.D. Thesis, University of Twente, Netherlands.
26. Kunz W. and Rittel H.W.J., "Issues as Elements of Information Systems. Working Paper 131", Center for Planning and Development Research, Berkeley, USA, 1970.