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KNOWLEDGE SHARING OBSERVATION AND MODELLING IN DISTRIBUTED DESIGN TEAMS

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1. Introduction

Designing requires knowledge processing and emergence. Previous investigations on the history of aeronautics [Vincenti 1990] showed that knowledge construction processes are essentially collective. This is true for knowledge concerning product, criteria, process or methods. Vincenti assumes: "Most of the information used in the rationalization of viewpoints (of design) is created by the exploratory process". However, few design models explicit the use of knowledge and the associated knowledge construction process. See for example the C-K theory [Hatchuel 2004], Takeda and Tomiyama model [Takeda 1992], Wu and Duffy model [Wu 2002].
Collaborative design process requires the participation of multiple persons who are more and more specialized, often distant geographically but whose tasks are very connected. Collaboration in design requires sharing expertises, ideas and resources. It implies a knowledge sharing between the different actors. Then, the effectiveness of the knowledge sharing process becomes critical.
This qualitative study describes how designers share trade knowledge during the design process. The objective is to model the knowledge sharing process between members of a distributed design team. For this, we have used the protocol analysis method. After setting up a laboratory design experiment, we have pointed out sequences where a knowledge sharing process is noted. These sequences allowed us, thereafter, to suggest (by induction) a design knowledge sharing generic model.

2. Design knowledge sharing

2.1 Data, information and knowledge

According to the Oxford dictionary, knowledge is "the fact, condition of knowing… the fact of being aware". In practice, this definition is not sufficient. Indeed, having knowledge about an object, a domain or a process has more meaning than simply being aware of it. Bucciarelli defines knowledge as “Understanding of the fundamentals of the appropriate paradigmatic sciences and an ability to act, to design, with that knowledge in hand” [Bucciarelli 2001]. Thus, he establishes a difference between knowledge and information, information is only a constituent of knowledge, it evokes meaning without containing the meaning itself. Several other studies (see for example [Ahmed 2000]) placed knowledge at the end of a hierarchical chain which starts with data. The distinction criteria are awareness, capacity to interpret and possibility to act. See figure 1.
When it is mediated, information is the transcription of facts into texts and graphs either on hard or numerical form. Thus, if an information is easily diffusible and shareable (since it can be coded in a data form), knowledge requires moreover an appropriation by an actor – designer, and its mobilisation for an action. To have a knowledge, it is necessary to have information, to be able to interpret it regarding the context, and to have the capacity to act starting from this information. As a consequence,

starting from an information, we can extract several knowledge as interpretations are multiple and depend on the context and persons who interpret. Coupling comprehension with action makes the design knowledge definition difficult [Bucciarelli 2001], but much more operational.

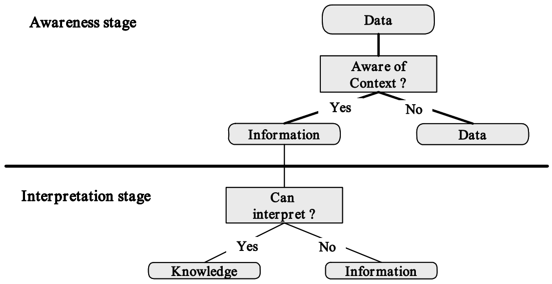

Figure 1. Data, information and knowledge, adapted from [Ahmed 2000]

2.2 Knowledge typology

In literature, several classifications of knowledge have been done. Some of them are based on the content of knowledge, others are based on its form. We present hereafter three typologies.

- Product and process knowledge: according to [Hubka 1996], two types of design knowledge exist: product knowledge and process knowledge. Product knowledge concerns the artefact to design, and process knowledge concerns the designing activity itself.
- Procedural and declarative knowledge: procedural knowledge is concerned with how to undertake some action, whereas declarative knowledge is concerned with facts and principles in a particular domain [Johnson, 1992]. Eder assumes that declarative object knowledge is knowledge acquired from experience including formal teaching/learning situations and learning by doing. Procedural object knowledge is knowledge that has been learned enough, such that the person no longer needs to think about it to use it [Eder 2004].
- Tacit and explicit knowledge: Nonaka [1995] split knowledge into these two categories. Tacit knowledge is often used in skilled and experienced based activities. Polyani affirms that “we can know much more than we can tell” [Polyani 1966] cited in [Nonaka 1995]. In contrast, explicit knowledge can give coded, formalised and transmitted reusable information.

2.3 Knowledge sharing

In collaborative design, knowledge is not often shared by all actors. Therefore, transmission, elaboration and sharing knowledge sequences appear. Distinguishing between tacit and explicit knowledge is relevant to target different sorts of exchanges. Four transformation processes were described by Nonaka [1995]: Internalization (explicit → tacit), socialization (tacit → tacit), externalization (tacit → explicit) and combination (explicit → explicit). Internalization and socialization appear with strong individual features and need time. In contrast, externalization and combination can be more easily observed in design meetings. Externalization requires the creation of a formal speech using of metaphors and arguments to palliate some lack of concepts. Combination allows producing new knowledge by induction and deduction.
This transmission process must not be understood in the sense of the classical theory of information transfer in which transmitted information from a transmitter to a receiver may be altered by noise. In one hand, a knowledge sharing process has to include transmission, absorption and action stages. On the other hand, knowledge sharing will be seen here as an emergence and therefore includes strong interactions between designers, not restricted to feedbacks. Finally, we consider knowledge as a collective property because the group action capacity depends on the co-building of a common referential. Hence, the case of a simple knowledge transfer. from actor A to actor B is seen as a collective knowledge emergence, even if the knowledge of actor A remains unchanged.

3. Empirical study

3.1 Experiment

To undertake our study, we set up a distributed engineering design experiment. The participating actors were undergraduate mechanical engineering students from our university. In order to observe and understand the process of sharing trade knowledge, we recruited students who followed different options. Three actors, representing three different engineering trades, took part in this project:

- *V* is the “Manufacturer” actor. He is from the Engineering and Process Management department. He has, in particular, competences in process planning and innovative manufacturing facilities.
- *Ch* is the “Designer” actor. He is from the Mechanical Engineering Design department. He has competences in design methodology, and CAD.
- *N* is the “Calculation” actor. She is also from the Mechanical Engineering Design department and has in particular, competences in mechanics and technology, and materials resistance.

The two departments are distant of 8Km, thus the students have few occasions to meet each others within the university courses. In particular, *V* did not know *N* and *Ch* before this experiment.

A distributed collaborative design environment was provided to the actors. This environment consists in NetMeeting of Microsoft, which allows applications sharing, and a shared whiteboard. Speakerphones were used for oral communications. The applications provided to the students consist in a CAD environment, namely CATIA V5, and usual Microsoft Office applications.

During their studies, the actors had several contacts with industry by ways of training periods in manufacturing companies. They are familiar with the provided working tools, except for the NetMeeting environment to which we trained them before the experiment. To strongly imply and motivate the students in this study, they were remunerated for their work. This organization makes it possible to come closer to a real designing situation as practiced in industry.

The experiment lasted for two weeks. Three synchronous distributed collaborative design sessions were programmed in this experiment. These meetings were fully recorded in order to analyse the designers’ activity. In addition, the designers performed their own tasks individually and asynchronously. At the end of each session, all the intermediate objects produced and used by the designers were duplicated.

We selected the design problem according to Dorst’s criteria [Dorst 1996] : ambitious and realizable within the time required and with the provided means. The goal is to design a tilting vise used to maintain parts of different matters during their machining process. The required deliverables are a product CAD model detailed enough to understand the complete working of the device, and containing the dimensions and the shapes of its various parts. This model must be accompanied with a calculation note which justifies the dimensions of the various parts and the choice of materials, and a document explaining the manufacturing process of the various elements. In the specifications’ note, we have specially integrated some specific terms related to the mechanical manufacturing trade. The manufacturing actor is placed in the situation of the holder of some knowledge to be shared with the other actors of the design team. Figure 2 presents a part of the specifications’ note.

- "To ensure an angular indexing all 15°"…
- "To authorize the installation of cover jaws whatever the position of the vise"…
- "The system must be set up using gibs of a width of10mm g6 and maintained in position using plain clamps or tapped T-head"...
- "To be able to indicate the exact position of the part in the space (at least the angle α, with a minimal precision of 2/10 degree)"…
- "To be easy to manufacture using the standard mechanical manufacturing facilities"…
- "When arranged, the product must be able to fit in a cube of 500mm of width"…
- "To be adapted to clamping screws on the standard tables of machine-tools"…

Figure 2. Some vise functional specifications

3.2 Findings

The data resulting from the recording of the three working sessions consist in 5 hours of records that we transcribed into a detailed corpus, and a set of documents. These are, on the one hand, documents collected at the end of each design session: a set of computer files such as system's CAD model. On the other hand, we have documents delivered at the end of the design: Finite Elements calculation report on CATIA V5, design report and production folder.
We have pointed out the situations of trade knowledge sharing between the actors. We describe three of them hereafter.

3.2.1 First situation

The first situation concerns manufacturing knowledge. It relates to the gibs, special parts that only machining experts know.

1. *N* asks what are the gibs, without specifying the recipient of her question. *Ch* affirms that he was going to ask the same question.
2. *V* explains verbally what are the gibs (functional explanation: "the gibs … they are parts that allow you to place your vise on the machining table…").
3. *Ch* and *N* affirm that they did not understand.
4. *V* draws them on the whiteboard of NetMeeting.
5. *Ch* understands but not *N*.
6. *V* gives her a structural explanation.
7. *N* asks for the function of these parts.
8. *V* gives her a more detailed functional and behavioural explanation…
9. *N* produces a calculation note to check these gibs (asynchronous work).
10. Discussion between *N* and *V* who validates her computation results by comparing them to standard dimensions that he already has.

3.2.2 Second situation

The second situation also concerns manufacturing knowledge. It relates to the jaw covers, also a specific term.

1. *N* asks what are the jaw covers.
   - *A*pparently even *V* does not know what they are.
2. *Ch* finds a definition on the web and reads it.
   - *V* remembers the term and gives a more detailed verbal explanation about it to *N* an *V*. they seem to have understood…
3. *Ch* draws a schematic diagram.
4. According to this drawing, *V* realizes that *Ch* did not understand where the jaw covers must be positioned.
5. *V* explains verbally once again…
6. Once again, in his drawing, *Ch* does not take into account the explanation.
7. *V* realizes that.
8. *V* explains verbally once again…
9. *Ch* resumes a more detailed schematic diagram; he draws the jaws and the jaw covers, and proposes to include several shapes of jaw covers.
10. *N* and *V* realize that *Ch* did not understand what are the jaw covers and how they are fixed on the jaws.
11. *V* "takes the hand" on the diagram and corrects it with *N*.
    - Ch affirms that he understood what are the jaw covers.
12. At the end of design, *Ch* models the vise and takes into account the jaw covers as explained by *V*.

3.2.3 Third situation

The 3rd situation concerns a knowledge relating to a mechanical component very present in the mechanical workshops: the indexer.

1. *V* asks how they plan to carry out the indexing and proposes a ball indexing system.
2. *V* describes this system as a small spring with a ball.
3. *Ch* seems to have understood. He details the functions to be integrated to the system.
4. *V* realizes that *Ch* did not really understand.
5. *V* explains again.
6. *Ch* affirms that he did not understand yet.
7. *V* "takes the hand" on the whiteboard, he draws the indexing system and explains verbally the system.
8. It is just at that moment that *Ch* and *N* really understand this system: they discuss with *V* the manner of taking it into account with the other elements of the system.
9. *V* agrees with the actions suggested by *Ch* to integrate the indexing system into the base.

4. Discussion

4.1 Enriched model

A three stages model containing transmission, absorption and action is not sufficient to describe the observed situations. We add to this model three more stages: a release stage, an intermediate validation and a final validation.
Indeed, the typical observed situations show the existence of a preliminary stage that is the release of the knowledge sharing process. Three modes of knowledge sharing process release are possible: the first one is an explicit ask expressed by an actor. The second is a spontaneous proposal made by an actor. The last mode is a reaction of an actor to the action of another actor. The first mode corresponds to the first and the second situation. The third situation is a combination between the first andcorrsponds to the second modes of release. The third mode was observed in other situations that are not presented in this paper.
The observed situations also highlight the existence of an intermediate validation stage. This validation is done by the receiver who confirms, either implicitly or explicitly, the absorption of the "knowledge" emitted by the transmitter. At this stage, it is difficult to state on the nature of what was absorbed: knowledge or simple information. We should rather speak about positive feedback.
This validation is only intermediate since it is followed by the "Action" stage which will allow the final validation of the action by the transmitter. This validation is the last stage of the process.
The enriched model we propose is reported on figure 3.

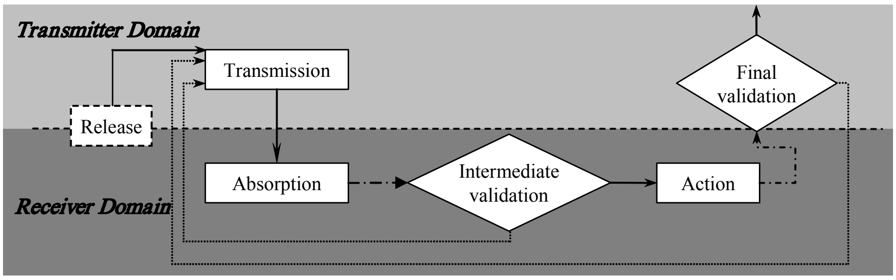

Figure 3. A knowledge sharing generic model

4.2 Description of the 3 situations

In figure 4, we describe the three typical situations on the basis of this model, numbers correspond to the designers actions as represented in 3.2.

4.3 Discussion

The three situations presented above seem to follow the suggested model. The model seems generic enough to take into account the diversity of the observed situations.

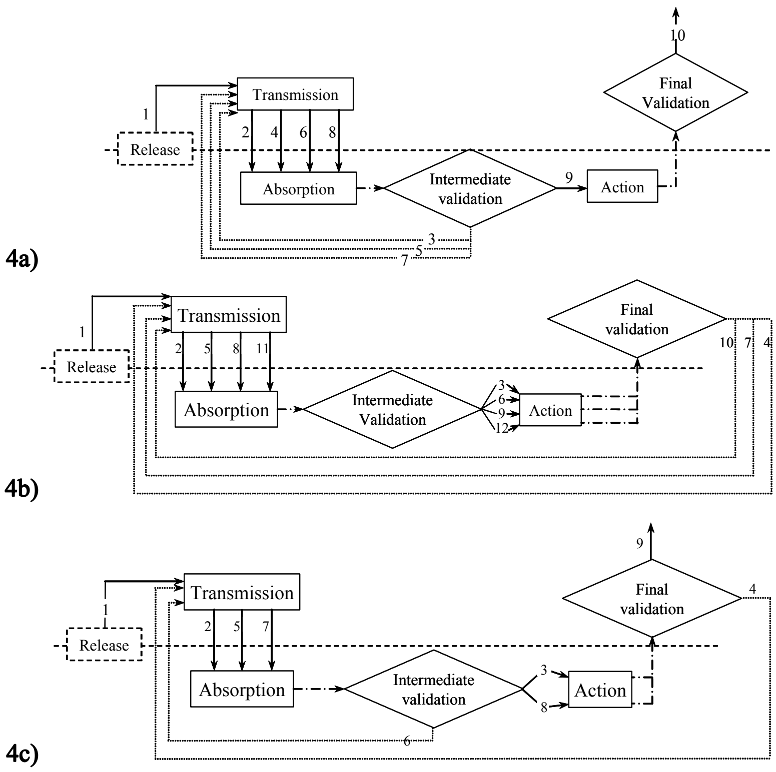

Figure 4. Description of the three situations of knowledge sharing according to the generic model suggested. 4a) First situation, 4b) Second situation, 4c) Third situation

4.3.1 Notion of roles

The knowledge sharing model we have proposed points out essential differences between the actions undertaken by the transmitter and those made by the receiver. In parallel with actions, the actors take different roles in the knowledge sharing process. These "role-mechanisms" [Hermann 2004] can be either explicit or implicit.

When we take as example an action “y” observed in a situation “x”, we will note it (x.y).

Releasing the process is an action which can be carried out either by a receiver (1.1), (2.1), or by a transmitter (3.1). By this action, this actor takes a role (role taking), defines the complementary role, and, depending on the situations, either allows taking this complementary role (to allow someone's role taking) or assign this complementary role to another actor (role assignment). This assignment can be implicit and automatic when a second actor takes the same role (in a situation with three actors) (1.1). This complementary role can be accepted (1.2) or rejected (2.1). In this last case, it becomes necessary that a change of role takes place (role change) (2.2). Thus, for example, in the first situation, two actors explicitly take the role of receiver and, by the same way, assign implicitly the role of transmitter to the third actor. The manufacturing actor refuses it. Hence, one of the two initial receivers takes the role of transmitter, and then he yields this role to the third actor (manufacturing actor) who, finally, accepts it. This role enabled him to validate the process at its end. We observe by this way a role change during the process. These role mechanisms are necessary to set a knowledge sharing situation. In some cases, they are dynamic (role changes for example).

The role distribution implies distribution of actions between at least a transmitter and a receiver. The latter must carry out the intermediate validations and engage the actions. The first must transmit information, be attentive to the intermediate validations of the receiver (positive or negative feedbacks), and finally, validate the knowledge sharing process. Indeed, in spite of the passage by a

partial validation achieved by the receiver, the final validation is a task made specifically by the transmitter. It’s possible only on the base of an action imperatively done by the receiver as an application of the received knowledge.
When the transmitter decides to carry out the action himself (2.11), he takes the risk to stop the knowledge sharing process and to leave it incomplete. The validation cannot be done.

4.3.2 Transmission modes

The diversity of the modes of transmission is also apparent. We observed a variation of these transmission modes according to the result of the intermediate validation stages made by the receiver, and the final validation stage made by the transmitter. When changing their transmission modes, transmitters used a particular pattern which is a trial and error cycle. In the observed cases, the transmitter always starts with a verbal transmission (1.2), (2.2), (3.2). We did not observe situations where this first transmission is really effective (situation without negative feedbacks). It is then supplemented by a graphic transmission. In several situations, numerous iterations are done before the transmitter changes his transmission mode. This is the case, for example, in the second situation where three verbal transmissions are made ineffectively (2.2), (2.5), (2.8), before changing the transmission mode to a graphic one, which proves to be more effective (2.11).
The graphic transmission of knowledge highlights the existence of "Knowledge Objects". They are the supports of knowledge sharing. They are not obligatorily "Design Objects". For example, in the third situation, the indexer drawing made by the manufacturing actor (3.7) was used only to transmit the knowledge of this object. It was not used for the definition of the product itself. In contrast, in the second situation case, a “Design Object” was used as a "Knowledge Object". Indeed, to define the jaw covers, the manufacturing actor used the product drawing itself (the vise) (2.11).
We also ask ourselves about a description mode according to structural, functional and behavioural aspects of the explanations. In the first situation, the transmitter had to use a verbal transmission (1.2) then a graphic one with a structural description (1.6), then a verbal behavioural description (1.8) and finally a functional description of the artefact subject of the knowledge (1.8), before the validation by the transmitter (1.10). The other situations are less evident.

5. Conclusion

Distinguishing between information and knowledge is necessary to understand the knowledge sharing process between the designers. Knowledge is an interpretation of the information by designers. This confer them capacity to act. Their action makes it possible to validate knowledge acquisition (either individual or collective). In addition, knowledge sharing situations occurring during the design process require externalising and combining individual knowledge so that a collective knowledge emerges. This emergence results from a collective process in which the interactions between the designers are more complex than a simple transmission.
From the concepts found in literature and our observations, we proposed a knowledge sharing model that implies stages of release, transmission, absorption, intermediate validation, action, and final validation. This model makes it possible to describe the observed situations. Some of these situations reveal only a partial knowledge sharing, for example after a decision of the transmitter to make the action himself (the validation cannot then be done).
Also, our study highlights the importance of the role dynamics. We assume that it is a precondition to the engagement of knowledge transmission actions. According to this assumption, to be valid, a knowledge sharing process is characterized by, at least, a preliminary release, the instituted existence of transmitter and receiver roles, and the absence of validation. Without these characteristics, the process cannot proceed. The contents of transmitter and receiver roles are specified; in particular, a new responsibility is assigned to the actor having the transmission role: to validate the knowledge sharing process.
ransmission modes observed appear also interesting to investigate. Indeed, we showed that verbal transmission was not sufficient. It must be relayed by an explanation based on an object, which we called *Knowledge Object* in reference to the concept of *Design Object*. It will be advisable to clear up

possible differences between these two types of objects even if a Design Object can be used for knowledge sharing.
The study we carried out in this paper is only a qualitative and exploratory one. A validation on a broader panel of situations including situations with more than 3 actors is engaged. The relevance of the model for the specification of supports appears to be proven, in particular by the possibility of extracting from this work a UML model and use cases scenarios very close to reality.

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