INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED'07
28 - 31 AUGUST 2007, CITE DES SCIENCES ET DE L'INDUSTRIE, PARIS, FRANCE

USING ANALYSIS OF COMPUTER-MEDIATED SYNCHRONOUS INTERACTIONS TO UNDERSTAND CO-DESIGNERS' ACTIVITIES AND REASONING

Kristine Lund[1], Guy Prudhomme[2], Jean-Laurent Cassier[2]

[1]ICAR (Interactions, Corpus, Apprentissages, Représentations), University of Lyon, CNRS, École Normale Supérieure Lettres & Sciences Humaines, 15, parvis René Descartes, BP 7000 69342 Lyon Cedex, France
[2]G-SCOP (Sciences de la Conception de l'Optimisation et de la Production de Grenoble), University of Grenoble, BP 53 38041 Grenoble Cedex 9, France

ABSTRACT

Our global objective is to understand designers' activities and reasoning during periods of synchronous collaborative work in order to provide supporting methods and tools. In this paper we present a first step in this direction. As collaborative design in such a context involves computer-mediated synchronous human interactions, we based our study on a theoretical approach for interaction analysis coming from the human sciences. The analysis of interactions issued from 1) a design experiment we carried out in an educational environment and 2) an observation of a design study in industry (in progress), led us to propose the transposition of an analytical framework of debate (Rainbow) to one of collaborative design (Rainbow-D). This framework will aid us in understanding how designers' co-construct their interactions, allowing us to form hypotheses about improving these processes through the modification of methods and/or tools designers use.

Keywords: conversation analysis, interaction analysis, design experiment, computer-mediated human interactions, argumentation

1 INTRODUCTION

In industry, the activity of design is increasingly composed of periods of synchronous collaborative work, oftentimes carried out at a distance. Mainly in the form of "project reviews", these periods consist of computer-mediated interactions between designers who give arguments concerning the product being designed. Researchers that study design processes employ two main methodologies: ethnographic observation [1], and different types of experimental studies [2], some of which involve coding dialogue [3], [4], [5]. If one chooses coding dialogue to understand the activites and the reasoning of designers during such synchronous periods, an analysis framework specific to such argumentative situations must be elaborated.

However, merely understanding *how* designers work in teams of two or more can be seen as part of a larger research methodology such as the one proposed by Blessing & Chakrabarti, [6] where the final objective is to improve the industrial design process in measurable ways, often by the introduction of improved guidelines, methods or tools.

Blessing & Chakrabarti [6] make two points, interesting for the research presented here. Firstly, while each discipline has its specific research methods, underlying paradigms and assumptions, many of these methods are either poorly or unsuitably applied in research on design. Secondly, transforming the findings of descriptive studies into implemented support for design is problematic because the findings characterize existing processes and not the hypothetically improved processes. If difficulties are uncovered in existing processes, the question becomes how to alleviate them in the new proposed process. It may not be immediately evident what to change, and proposed changes must be evaluated, signifying another study. This second study can never be strictly identical to the first, thus posing problems for cause and effect chains and validation in general [7].

In this article we propose a first response to these two criticisms of research in design. Firstly, we will present the theoretical framework and assumptions underlying 1) conversation analysis and 2) interaction analysis and the relationship between them. This will lead us to present our methodology of analysis for computer-mediated synchronous human interactions of debate that we adapt to studying design. In addition, we will compare the notion of a design experiment in educational psychology and in research on design in a general methodological framework. In this way, we hope to introduce a theoretically grounded method of computer-mediated interaction analysis to the field of research in design and respond to the first point of Blessing & Chakrabarti. Secondly, we will describe an initial empirical study during which interaction analysis was carried out on the computer-mediated interactions of student co-designers in a university setting. A second complementary analysis of an observational study at Volvo IT (Information Technology) is in progress. In this article, we will show how the analysis method Rainbow — originally elaborated for studying argumentative pedagogical debates — can be transformed into Rainbow-D (D for design), with the goal of contributing to understanding co-designers' activities and reasoning in our particular argumentative situation. Finally, we will hypothesize about how these results could help us improve co-design and how this improvement could be measured.

2 THEORETICAL AND METHODOLOGICAL FRAMEWORK

There are currently a number of approaches employed in the analysis of human-human interactions that are grounded in a variety of theories. One of the principal approaches is Conversation Analysis (CA) [8], [9]. Another is Interaction Analysis (IA), based in part on CA [10], [11], [12]. Although there is some controversy surrounding notions of context, for example [13], thus creating different currents of CA research that are seen as varying from orthodox CA, Interaction Analysis is nevertheless not as stable as CA. This is due to its more varied methodological applications and theoretical foundations as well as it being applied to both the analysis of video recordings and computer mediated traces of human activity. In the following two sections, we will briefly examine the theoretical assumptions of CA and IA, in the light of how they address the issue of the co-construction of knowledge between humans in interaction. This will prepare a discussion of our analytical and methodological approach of the study of interactions between co-designers and how it helps us to understand their activities and reasoning.

2.1 Conversation Analysis and the interpretation of meaning

The defining focus of CA — originating in the mid 1960s within sociology in the work of Harvey Sacks and colleagues — is "…the organization of the meaningful conduct of people in society, that is, how people in society produce their activities and make sense of the world around them (p. 64)" [9]. The main goal of CA is thus to render explicit the different (shared) methods or procedures people use to be understood by others. According to Harold Garfinkel — the founder of ethnomethodology — and Sacks, social reality is not a pre-existing piece of data, but is rather constantly created by social actors themselves [14]. Linstead writes of ethnomethodology as "…revealing social order as a dynamic, contingent 'ongoing accomplishment (p. 399)", as opposed to determining the set of stable laws that underpin social order [15]. Instead of making the hypothesis that participants follow pre-established rules known by members of society, the interest of ethnomethodology lies in demonstrating how participants actualize the procedures with which they constantly interpret social reality [16] and thereby display the orderliness of the social world [17]. It follows that oftentimes CA researchers prone "unmotivated observation" [18], in other words, the act of listening to or viewing — without any particular agenda — audio and/or video tapes so that a prescribed orientation does not pre-select the range of phenomena to discover within the interaction.

Given all this, can CA help us in our first quest — understanding how co-designers construct knowledge? In theory, yes, but there are some problems, one of which, in particular, shall concern us here — the work of interpretation of discourse in interaction [19]. According to Kerbrat-Orecchioni, this involves extracting the meaning of discourse in a given context by a given participant. It means understanding how participants understand each other's utterances. In CA, as this is done from the point of view of the participants (see arguments above), the analyst must interpret talk as if he or she were positioned as the participant who is hearing the other participant's utterance, at the point in time it was uttered. Yet, the analyst should not take into account interpretations other than those made 'publicly available' [20] by the participants themselves. In other words, the context of the interaction is created through the talk itself with the help of elements that are expressed as pertinent by the participants. This seems problematic for understanding how co-designers construct knowledge for one

main reason. Firstly, if CA examines social reality on participants' own terms [21], on what grounds can we take our own interpretation of what was going on in the interaction to be the same as the participant's interpretations [17]? To what extent are interpretations 'publicly available' for the analyst? When we mobilize lexical and referential knowledge in order to interpret, is this knowledge really present in the discourse we are analyzing? Or is it part of our knowledge of the world, that we call upon? Designers have an extensive shared knowledge base involving methods of fabrication, characteristics of materials, criteria for evaluating proposals, etc. and without mobilizing — as an analyst — this knowledge base, albeit in an implicit manner, the meaning of dialogue remains opaque. As Arminen [22] puts it, "…in institutional settings an agent may orient to expert knowledge or organizational procedures taken for granted for the practice in question, but not known to outsiders (p. 435) ". In other words, in order to understand the context sensitive activities, the analyst must evoke the pertinent contextual knowledge in order to access the deeper institutional practice.
In the next two sections, we will examine the theoretical assumptions underlying Jordan & Henderson's [10] Interaction Analysis as well as our own approach in order to show how the latter is more adapted to our goal of understanding how designers co-construct knowledge, although both share elements with CA.

2.2 Interaction Analysis and participants' understanding

Jordan & Henderson [9] provide the following definition of Interaction Analysis:

> "Interaction Analysis as we describe it here is an interdisciplinary method for the empirical investigation of the interaction of human beings with each other and with objects in their environment. It investigates human activities such as talk, nonverbal interaction, and the use of artifacts and technologies, identifying routine practices and problems and the resources for their solution (p. 39)"

According to these authors, the roots of their version of IA lie in ethnography, sociolinguistics, ethnomethodology, conversation analysis, kinesics, proxemics and ethology whereas the domain of analysis of interactions in general are concerned with yet other theoretical and practical persuasions, among them symbolic interactionism, phenomenology, social psychology and various schools of therapy. IA in a larger sense, therefore has a much wider possible theoretical grounding than conversation analysis.
But how is cognition and context treated by these types of IA? In Jordan & Henderson's IA, video technology is at the center; audiovisual recordings are primary records and the replay of interactions is necessary. In the context of ethnographic fieldwork, researchers in collaborative work groups analyze a chosen videotape. Analysts do not use predetermined categories to analyze segments of videotape, but rather expect that such categories will "emerge from [their] deepening understanding of the orderliness of the interaction as participants on the tape make this orderliness visible to each other (p. 43)" [10]. This is quite similar to orthodox CA. But if researchers in IA do not use predetermined categories, they do, however, use foci for analysis or ways of looking at videotape that have proven productive. These include looking at the structure of events, the segmentation of interaction, the temporal organization of activity, rhythm and periodicity, turn-taking, participation structures (i.e. the extent to which co-present individuals share a common task orientation and attention focus), trouble and repair, the spatial organization of activity, and finally artifacts and documents.
Jordan & Henderson's IA differs from CA in that intentions, motivations, understandings and other internal states can be talked about — accounting for such cognitive related phenomena is often discouraged in orthodox CA and treated as "mentalist" — as long as there is evidence of them on the tape (e.g. beginning writing on the upper left of a white board illustrates an intention to write a great deal; being able to quickly note how a problem was solved during a demonstration illustrates comprehension while not being able to note it down, needing to ask further questions or to repeat the wording illustrates difficulty).
Frolich, [23] speaks of Interaction Analysis (IA) as providing information on the sequential organization of technologically and socially mediated activity. He sees IA as an extension of CA that examines visual as well as verbal conduct in technologically rich settings in order to understand the influence of other things as well as people on personal and interpersonal behavior. This is closer to our own view on Interaction Analysis, presented in the next section.

2.3 Analysis of computer-mediated interactions

Two of the main communities in which researchers do analyses of computer-mediated human interactions are CSCL (Computer Supported Collaborative Learning) and CSCW (Computer Supported Collaborative Work). CSCL has emerged in relation to different paradigms of instructional technology and Koschmann [24] has noted a large variety of learning theories present in the literature. Unsurprisingly, as knowledge, interpretation of the meaning of speech and actions and understanding what students know are central to research in instructional technology, methods of analysis specifically focus on these elements. In CSCW, the focus is on the use of technology in the workplace situations, and although learning is not targeted per se, knowledge, meaning and understanding remain central and similar theoretical frameworks (e.g. Activity Theory) and methods of analysis are implemented.

In what follows, we briefly present the Rainbow framework [11], developed within the European project SCALE[1] for the analysis of pedagogical interactions where dyads debate open-ended questions. It is this original framework that we present in a version modified for the analysis of interactions about design (Rainbow-D), further on in the paper. The target audience is thus the researcher who is interested in discovering how designers use argumentation to co-construct a solution.

There are seven main analytical categories in the framework, each corresponding to a different color (red, orange, yellow, green, blue, indigo, violet) — hence the name Rainbow (cf. Figure 1).

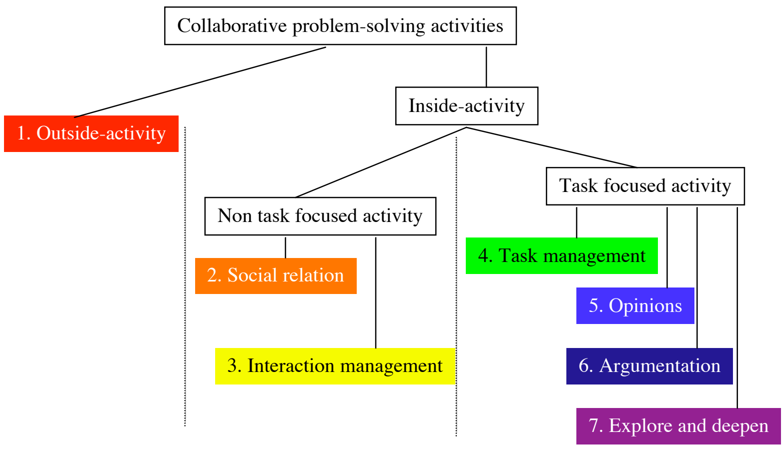

Figure 1. Rainbow: a framework for analyzing computer-mediated pedagogical debates

Category 1 (outside-activity) is distinguished from the others from the point of view of the researcher who provides the students with a particular collaborative activity, for example arguing in favor of allowing genetically modified organisms (GMOs). All activity falling within the interaction imposed by the researcher is inside-activity. Non-task focused activity concerns category 2 (social relations, e.g. annoyance with a partner's manner of debate) and category 3 (management of the interaction itself, e.g. coordination: « go ahead », communication management: « do you understand? », and time management). Task-focused activity is managing the task and debating; this 4th category includes all aspects of task control: discussion methods, the progression of the task, the direction of debate and the topics to be dealt with. Categories 5, 6 and 7 concern the *task* of debating, writing or producing argument graphs about the topic. Category 5 (opinions) refers to agreement, disagreement, belief or acceptance with respect to the topic of debate. Category 6 (argumentation) includes expressions of arguments for and against a thesis (i.e. a particular claim: "GMOs should be authorized"). Finally, category 7 (explore and deepen) involves arguments that build on other arguments, discourse that questions or supports an argument for or against a thesis or discussion of the meaning of an argument

[1] SCALE (Internet-based intelligent tool to Support Collaborative Argumentation-based LEarning in secondary schools) was financed by the European Union "Information Societies' Technologies (IST) programme (IST-1999-10664) of the 5th framework between 2001 and 2004; http://www.euroscale.net, http://drew.emse.fr.

(examples, specifications). Figure 2 shows short definitions for each of the seven categories.
Rainbow is a functional framework. This means that analytical categories relate to what the researcher views the participants' utterances are accomplishing in relation to the task. In terms of the theoretical assumptions discussed above, an analyst applying the Rainbow framework attempts to put him or herself in the position of the participant and seeks to see how utterances are interpreted by subsequent participant interventions in order to categorize them. Rainbow functional categories are thus analyzed contextually and retroactively.

Categories	Definition
1. Outside activity	Any interaction that is not concerned with interacting in order to carry out the researcher-defined task, including socio-relational interaction that does not relate to interacting in order to achieve the task.
2. Social relation	Interaction that is concerned with managing the students' social relations with respect to the task (debating about X), e.g. greeting, leave-taking, politeness, expressions of frustration with the way the partner is interacting, etc.
3. Interaction management	Interaction concerned with managing the interaction itself: who will speak or not and when (coordination), establishing contact, perception, understanding, attitudes (communication management), topic shifting, time management.
4. Task Management	Management of the progression of the task itself: planning what is to be discussed, establishing whether the problem is solved or not.
5. Opinion	Interaction concerned with expressing, making explicit, opinions (beliefs, acceptances,…) with respect to the topic debated: expression of opinions at opening and closing of phases of argumentative discussion.
6. Argumentation	Expression of (counter-)arguments directly related to a thesis (e.g. GMOs should be stopped).
7. Explore and deepen	Interaction concerned with (counter-)arguments linked to (counter-)arguments. Argumentative relations and meaning of arguments themselves (elaboration of them, definition, extension, contraction, i.e. any discursive or conceptual cooperation performed on content of arguments themselves).

Figure 2. Brief definitions of Rainbow function categories

The analyst does indeed code an interaction with pre-existing categories (demonstrated as pertinent in the literature), but these categories are quite large and leave room for discovering the emergence of finer grained interactive phenomena within them. Although we recognize that utterances are often multi-functional ("Your graph is messy" can both be an opinion as well as an implicit request to make the graph neater), if categories are to be counted in order to obtain descriptive analyses, then a dominant pragmatic function must be chosen for each utterance. For example, the utterance "I can tell you how famine won't stop with sterile seeds" can have several functions: an interactive management function by requesting the floor and an argumentative function against GMOs stopping famine. The analyst can either cut the utterance into two or choose, say, the argumentative function as being dominant. If it is necessary to do so in order to understand participants' exchanges, the Rainbow analyst also takes into consideration contextual information that is not always explicitly 'publicly available' in the dialogue (see the Rainbow-D section for an example from our corpus).
Rainbow is a descriptive framework rather than a normative one; an analysis of a particular interaction done with Rainbow gives a description that can be compared to a normative vision of the general interaction type, if one is thought to exist. Rainbow is a comparative framework; different CSCL tools (e.g. chat and argument graph; for a description of the latter, see the section below on our corpus) can be analyzed with Rainbow. Pedagogical results of experimental conditions during interactive debates can be compared quantitatively (chat vs. Graph+chat) and qualitatively (further semantic and pragmatic analyses of the nature of argumentation). Finally, validation requires inter-subjective agreement; analysts must agree on how they will treat pragmatic function and this should align with how the participants themselves treat it in subsequent dialogue.

2.4 General methodological framework

Depending on the field of research, the terms "design experiments" [25], [26] or even "design research" [27], [6], are used differently. In research on education, they refer to the methodology used when a researcher attempts "…to engineer innovative educational environments and simultaneously conduct experimental studies of those innovations (p. 142)" [25]. Since Brown and Collins, researchers have engineered educational environments from technical, pedagogical and procedural points of view for specific goals such as favoring argumentative and explicative interactions [28], affecting discourse processes with the use of lecture notes [29] promoting conceptual debate [30], or by enhancing reasoning in science by electronically managing peer discussions [31].

These specific goals are usually considered to favor participants' learning. Evaluation of learning is carried out in two main ways: quantitatively and qualitatively. Firstly, pre- and post-tests on taught knowledge can be given to participants and the scores compared. In this case, learning is considered to have taken place if participants' scores show a statistically significant increase after they experience the engineered environment. Secondly, participants' verbal and graphical interactions, often mediated by computer, can be automatically traced directly from the system [32] and/or transcribed (if they are oral) [33]. In this case, the quality of the interactions themselves is evaluated, according to specific criteria, hypothesized to favor learning.

Unsurprisingly (especially in the context of the ICED conference), in addition to referring to the design of experiments using educational technology, "design research" also refers to research on design itself. In this case, "design experiments" have the objectives of understanding the engineering product design process, proposing design methods relevant to this process that are adapted to industrial practice and finally developing tools to assist designers. Here, researchers have engineered different aspects of the design process, but as Blessing and Chakrabarti [6] point out, the three goals of 1) understanding designers' reasoning and actions, 2) providing tools and methods for designers and 3) evaluating how these tools and methods change designers' reasoning and actions are rarely present in a single research project, even if initial understanding comes from a literature review. This is often due to differences in how research and industry function or simply to time constraints. Complete design projects addressing the three questions are lengthy and research papers are often written up on only the first and/or second questions, leaving evaluation by the wayside.

Design experiments in research on design are thus similar to experiments by the same name in research on educational technology. In both cases, a complex process involving the use of technology and human interaction grounded in institutional settings is studied using a variety of methodologies and techniques for evaluating results, although design experiments in educational technology include evaluation of tool usage, scenarios and final goals more consistently than research on design does.

According to Ahmed & Wallace [34], no clear theory of how designers design has been developed. In addition, Okudan, & Rao [35] note that 1) the effect of the design process employed by individual members on the collaborative process is not understood; 2) There is a lack of modeling effort for the collaborative design process, which limits the process improvement and finally 3) most software tools developed ignore the human perspective regarding design information processing and focus more on system design and implementation. In contrast, in the field of educational technology, interaction analysis has provided much insight to how humans use technology to solve problems. We thus propose in this paper an example of computer-mediated interaction analysis in order to understand how designers cooperate during a design task. We will also form hypotheses about how this understanding can be evaluated. The next section will describe the design situation in terms of the technical problem the designers were asked to solve, the set-up of the design scenario and the resources at the students' disposal.

3 THE DESIGN SITUATION STUDIED

The objective of industrial product design is to propose a solution for the product and for the production process, but also to define the needs and constraints relative to the product life cycle in the form of a specifications document. In the context of Concurrent Engineering, this is done by a group of designers, belonging to different expert groups (mechanical, electrical engineers, etc.) and regrouped in what we call a project platform. Such a design situation includes: a design task (goal and conditions in which work should be carried out), a design product (entity on which designers work), actors (people participating in the design), but also a constrained environment provided by the industry (organization, politics, strategies), by the available technical means and by the project organization.

Conducting an experimental approach to research on design leads us to a paradox: an authentic design situation in an industrial context is complex, non replicable and difficult to manage as the parameters that define it are interconnected, conjointly defining the situation. However, it is possible to construct collaborative design situations similar to the workplace in the context of university students' courses,

situations that are somewhat simplified and more manageable, although still not reproducible in a way that controlled laboratory experiments would be.
The design situation described in the following sections is a collaborative design experiment in an educational context we construct as comparable to a natural situation. Once we will have analyzed this situation from an interaction point of view, we will move to observing natural situations in the workplace and attempt to obtain sufficiently comparable data so that we may validate our initial interaction analysis. This will be done with video data obtained from a Volvo design situation.

3.1 The technical problem to solve

The technical problem we chose was given to the students by way of an initial specifications document that presented a summarized principal scheme (cf. Figure 3) and described the mechanical, economic and functional specifications.

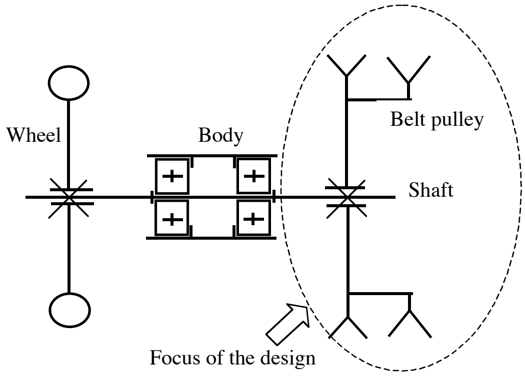

Figure 3. The schema of the product to design

The product to design consisted of an element that introduced a rotation of a wheel by the means of a double pulley that allows firstly for recuperating the mechanical power from an electric motor and secondly, for transferring part of this power to another similar system. We focus in particular on the design of the double pulley and on its liaison with the shaft. The constraints of the specifications document are as follows:

- technical: the power to transmit is equal to 8 kW, with torque that can be superior to 320 Nm, a life cycle of 24 000 hours.
- economic: the global cost (the direct cost of the components, but also indirect costs, relative for example to ecological considerations, fabrication, assembly or maintenance, etc.).

3.2 The set-up of the design scenario

The situation is a "project review", typical in industry. During a project review, designers confront their respective solutions and assess them according to constraints stemming from their expertise. They are required to come to agreement in a limited time, on a particular solution.
Three students in the second year of the Master's program in mechanical conception at the University of Grenoble, France, were the design actors. These students, voluntary and interested in participating, had good knowledge of design and in the production of mechanical systems. They had a common technical background due to their post-secondary studies, so we attributed identical technical roles to all three students. They were located in three different rooms on separate computers, corresponding to three distant geographically separated research units of the same company.
A project review situation generally occurs as a step in the course of evaluating the design process. The actors gather to submit, discuss or confront the work they have carried out on an individual basis. The goal is to validate intermediary designs and make decisions on the orientation of the project.
In order to put our three students into a similar configuration, we defined three main stages in our design experiment:

- Phase 1 (1h) was a preliminary stage of individual work meant to prepare them for the collaborative project review. At the end of this stage, each designer handed in: a schema and/or a description of the proposed solution, a representation of the technical problem that this solution solved and finally, a list of the advantages and disadvantages of the proposed solution.
- Phase 2 (45m) was the design review situation where the project review interactions occurred. The designers, working over the network, exchanged their arguments in order to attack or

defend a claim concerning a preferred solution. At the end of this phase, they produced: a description of the solution they agreed upon and a description of the constraints (function, criteria, level) that this solution took into account. Their collective interaction was automatically recorded (see next section for details).

- Phase 3 (15m) was the final stage of individual work after collective confrontations and decisions. Each designer was asked to provide: a schema and/or a description of the individual designer's personal solution after review and a description of the constraints (function, criteria, level) that this solution took into account according to his own opinion.

In order to make sure that the preparatory phase was effective, we defined three possible solutions: A, B, and C (cf. Figure 4). They were given to the students at the beginning of the experiment in the form of three figures. The students could choose one of them, propose a hybrid solution or invent an entirely new one.

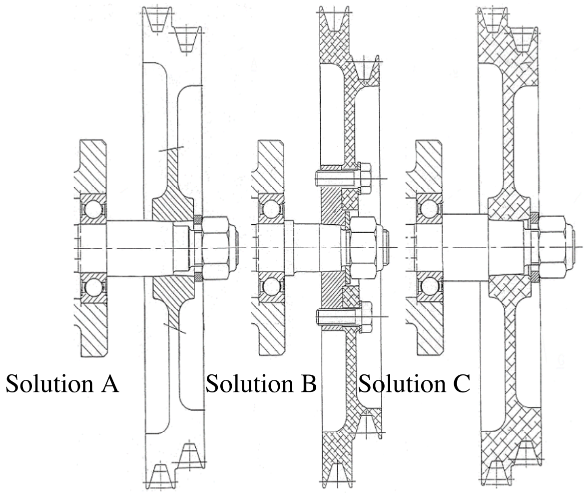

Figure 4. The three initial solutions given to the designers

Each stage required the students to submit a deliverable regarding the task, designed to guide their work. In addition, we obtained their productions, crucial for our analyses.

3.3 The resources at the students' disposal

Since the duration of our experiment was quite short, it was not feasible to give the designers CAD tools. We preferred limiting their design work to the production of principal schemas on paper.

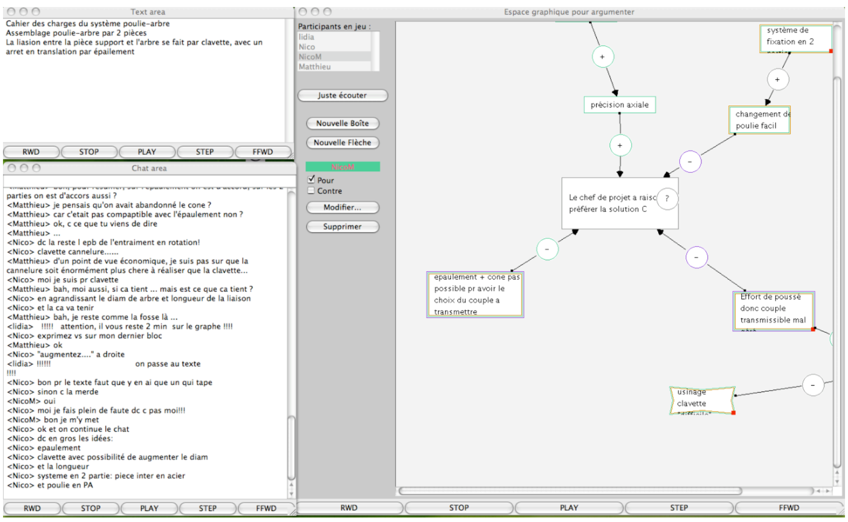

Figure 5. A screen copy of the DREW platform

However, we provided the designers with tools for evaluating the technical performances of the solutions: five spreadsheet documents allowed designers to determine specific values as a function of

geometrical parameters and the chosen material. The interaction in Phase 2 was mediated with the DREW (Dialogical Reasoning Educational Webtool) platform [32] (cf. Figure 5), discussed below.
Even though DREW was not developed for collaborative *design* situations, it provided the communicational means and *argumentative support* for the project review debate. DREW is composed of different modules, three of which were employed for the experiment described here (cf. Figure 5): a synchronous chat (support for the discussions between the three designers: bottom left), a shared text editor (for describing the common solution and the table of constraints: top left), and an argumentation diagram tool: right. This last module consists of an interface for constructing argumentation diagrams that include one or more theses (phrases in boxes) and arguments that attack or defend them (other phrases in boxes that point to the thesis in question). An example from our experimental design situation is shown in Figure 5 in the original French. Prior to the experiment, the three designers received training on how to use DREW and thus any initial problems they had were dealt with before we recorded their interaction.

4 CORPUS OBTAINED

In this section, we present the elements of the corpus we gathered during the collaborative design experiment described above. In addition to supporting communication and argumentation, DREW captures the designers' interactions into XML trace files, chronologically saving their graphical and verbal exchanges. This is crucial for later interaction analysis.
Figure 6 shows such a sequential recording, augmented by an initial Rainbow analysis we performed. The first column is the intervention number (591 total interventions). The second shows the date and time, the third column reveals the designer in question, the fourth column shows the actual content of the designer action and finally the fifth column tells us which tool the designer used. The last column shows the Rainbow categories we attributed by hand and through consensus. As our goal was to explore using Rainbow for the analysis of a new interaction type (collaborative design) in order to extend the framework, inter-coder reliability was not performed.

N°	Time	Designer	Chat or Argument Graph intervention content	Tool	Rainbow
100	15/04/05 10:26	Bob	i don't like solution c	chat	**5. Opinions**
101	15/04/05 10:27	Bob	y:because you don't have a good torque	chat	**6. Argument**
102	15/04/05 10:27	Alan	ah well i like that solution	chat	**5. Opinions**
103	15/04/05 10:27	Bob	if there's a drive shaft shoulder	chat	
104	15/04/05 10:27	Bob	we'll have	chat	
105	15/04/05 10:28	Bob	good precision but we won't be able to manage the pushing effort	chat	**6. Argument**
106	15/04/05 10:28	Bob	unless the tooling is really precise	chat	**7. Explore and deepen**
107	15/04/05 10:28	Bob	do you see what i mean?	chat	**3. Int. Management**
108	15/04/05 10:28	Bob	makes the box Bob.731.1	grapher	
109	15/04/05 10:28	Bob	begins editing the argument Bob.731.1	grapher	
110	15/04/05 10:28	Alan	we're supposed to argue on the graph aren't we?	chat	**4. Task Management**
111	15/04/05 10:28	Bob	edits argument Bob.731.1 : Name = pushing effort so transmissible torque not well managed Commentary = Could you add something more?	grapher	
112	15/04/05 10:28	Bob	ends editing the argument Bob.731.1	grapher	**6. Argument**

Figure 6. A partial extract of the designers' computer-mediated interaction using both the chat and the argument graph

The part with a bold outline illustrates how Bob adds an argument (a box with text) to the graph: "pushing effort so transmissible torque not well managed". Bob does not include a comment. He will later mark this argument as being against acceptance of solution C, the thesis (not shown). We notice that Alain says "we're supposed to argue on the graph aren't we?", but Bob is already adding his argument to the graph. For this short extract, no new categories were needed. Note that category 6. is attributed to the last element of the intervention series that makes for a semantic whole (intervention n° 105 (103-105) for the chat and intervention n° 112 (108-112, excluding 110) for the grapher). In fact there are two arguments: one in favor of a drive shaft (precision) and one against (pushing effort).

This trace file was the principal object of our analysis for the work in this article. Although we will not present their analysis here, other elements also gathered included a paper and pencil drawing from each designer and a description of the solution chosen by him as well as a description of the constraints that this solution takes into account. Designers were asked to modify these documents after the collaborative interaction and this result was also collected. After the experiment, each designer was individually interviewed and these interviews were transcribed.

5 DESIGN INTERACTION ANALYSIS FRAMEWORK: RAINBOW-D

Our analytical objective was to perform Rainbow analysis on our designers' computer-mediated interaction trace in order to extend the method — originally elaborated to analyze pedagogically oriented argumentative debates, — to the analysis of collaborative synchronous design. Our motivation for doing so was firstly our belief that designers' interactions included a great deal of arguments for and against different solutions (cat.6), opinions about them (cat.5), and justifications for them, etc. (cat.7). However, Rainbow was developed for analyzing debate where argumentation is the task *per se*. In the case of collaborative design, argumentation is indeed fundamental, but we claim that the core task around which argumentation is based is the proposition of elements of the solution for designing the product and the evaluation of these elements. We therefore propose a slight modification of categories 6 and 7 (including subcategories), which form the *task* under analysis; other Rainbow categories remain the same. As a bonus, Rainbow-D retains the seven-color scheme. Figure 7 shows definitions and examples for the initial proposed modified framework.

Categories	Definition	Examples taken from our corpus
6.1 Argument mobilizing (part of) solution	The suggestion of a solution element that is argumentatively oriented for the product being designed.	Chat element: "i think we should keep the drive shaft shoulder [4 the axle precision]" Graph element: "solution with drive shaft shoulder"
6.2 Argument mobilizing criterion	An argument mobilizing a particular criteron for a solution element of the product being designed	"we'll have good precision, but we won't be able to manage the pushing effort"
7.1 Explore and deepen (part of) solution proposition	Different types of justifications of arguments in terms of solution elements, (e.g. breaking down the solution element into component parts, choosing the physical material of different parts of the solution)	The solution with shaft shoulder and cone ; with shaft shoulder and key
7.2 Explore and deepen criterion	Different types of justifications of arguments in terms of criteria for satisfying a solution element.	"unless the fabrication is really precise" "and tooling is not that expensive after all"

Figure 7. New categories for Rainbow-D (D for Design).

Concerning the new category 6, both chat elements and graphical elements can be coded as either argumentatively oriented solution elements or arguments mobilizing criteria for evaluation. However, as the chat example of 6.1 shows in Figure 7, the choice of a dominant pragmatic function for each intervention is not always obvious. Here, the example "i think we should keep the drive shaft shoulder 4 the axle precision" consists of an opinion, a proposition for the design *and* an argument (that is not completely made explicit) in favor of the proposition. Alternatively, utterances can be separated. In addition, we see that the analyst must reference contextual knowledge not explicitly present in the dialogue to understand how keeping the drive shaft shoulder is good for axle precision in order to know it is an argument. Category 7 is a first attempt at typifying discursive operations performed on arguments that employ constraints to respect and criteria to satisfy for proposed solutions.

6 CONCLUSIONS

In accordance with Blessing & Chakrabarti's [5] criticisms on design research mentioned in the introduction, our first goal was to render explicit the underlying paradigms and assumptions of an analysis approach when transposing it from the intersection of two disciplines (language sciences and educational psychology) to another (research on design). We have thus described the theoretical foundations of conversation and interaction analysis and their influence on the analysis of computer-mediated human interactions. Secondly, we have proposed an extension of a particular analytical method: the Rainbow framework, originally elaborated for analyzing pedagogically oriented societal debates. Our application of Rainbow to a corpus issued from a semi-experimental design situation (inspired by an industrial project review) allowed us to suggest analytical categories specific to design and therefore extend Rainbow to Rainbow-D (for design). Our current task is to apply Rainbow-D to a new corpus (the Volvo corpus referred to earlier) in order to appreciate to what extent we are able to account for designers' interactions in an authentic project-review industrial situation. As DREW was not used in this new corpus, we expect differences in how the participants structure their argumentation. Once our analytical method has been validated (through inter-coder reliability), we will be able to perform descriptive analyses on our corpus and understand how designers' co-construct their interactions through their use of social and physical resources. It is only through this characterization of existing processes of activities and reasoning (using the aforementioned foci for analysis) that we will be able to form hypotheses about improving these processes through the modification of methods and/or tools. Finally, a new industrial interaction embodying our modifications will be recorded; we will apply Rainbow-D to it and compare the results to the initial Volvo corpus in order to evaluate our proposed modifications. In our view, Rainbow-D is a first step towards understanding the activities and reasoning of designers although we plan on performing more detailed qualitative analyses on how participants organize utterances classed within particular categories, notably 7. Explore and deepen, the heart of argumentative debate on product design.

ACKNOWLEDGEMENTS

We thank Michael Baker for discussion and his insight on the transposition of Rainbow to Rainbow-D.

REFERENCES

[1] Bucciarelli L.L. *Designing Engineers*, 1996 (MIT Press, Cambridge).

[2] Pahl G., Badke-Schaub P. and Frankenberger E. Résumé of 12 years inter disciplinary empirical studies of engineering design in Germany. *Design Studies*, 1999, 20(5), 481-494.

[3] Cardella M.E., Atman C.J. and Adams R.S. Mapping between design activities and external representations for engineering student designers. *Design Studies*, 2002, 27(1), 5-24.

[4] Parent A. Analysing design oriented dialogues: a case study in conceptual data modeling. *Design Studies*, 1997, 18(1), 43-66.

[5] Fleming D. Design Talk: Constructing the Object in Studio Conversations. *Design Issues*, 1998, 14(2), 41-62.

[6] Blessing L. and Chakrabarti A. DRM: A Design Research Methodology. In *The International Conference on The Science of Design - The Scientific Challenge for the 21st Century*, INSA, Lyon, France, March 2002.

[7] Salomon G. Transcending the Qualitative-Quantitative Debate: The Analytic and Systemic Approaches to Educational Research. *Educational Researcher*, 1991, 20(6), 10-18.

[8] Sacks H., Schlegloff E.A. and Jefferson G. A simplest systematics for the organization of turn-taking in conversation. *Language*, 1974, 50(4), 696-735.

[9] Pomerantz A. and Fehr B.J. Conversation analysis: An approach to the study of social action as sense making practices. In *Discourse as Social Interaction,* 1997, 64-91. (Sage publications, London).

[10] Jordan B. and Henderson A. Interaction Analysis: Foundations and Practice. *The Journal of the Learning Sciences*, 1995, 4(1), 39-103.

[11] Aviv R., Erlich Z., Ravid G. and Geva A. Network Analysis Of Knowledge Construction In Asynchronous Learning Networks. *JALN*, 2003, 7(3), 1-23.

[12] Baker M.J., Quignard M., Lund K. and Séjourné A. Computer-supported collaborative learning in the space of debate. In *The International Conference on Computer Support for Collaborative Learning*, Bergen, June 2003, pp.11-20. (Kluwer Academic Publishers, Dordrecht).

[13] Bilmes J. Problems and resources in analyzing Northern Thai conversation for English language readers. *Journal of Pragmatics*, 1996, 26(22), 171-188.

[14] Garfinkel H. and Sacks H. On Formal Structures of Practical Action. In *Theoretical Sociology: Perspectives and Developments*, 1970, pp.339 (Appleton-Centry-Crofts).

[15] Linstead S. Ethnomethodology and sociology: an introduction. *Sociological Review*, 2006, 54(3), 399-404.

[16] Coulon A. *Ethnométhodologie [Ethnomethodology]*, 1987 (Presses Universitaires de France, Paris).

[17] Hammersley M. Conversation analysis and discourse analysis: methods or paradigms? *Discourse & Society*, 2003, 14(6), 751-781.
[18] Schegloff E.A. Naivete vs sophistication or discipline vs self-indulgence: a rejoinder to Billlig. *Discourse & Society*, 1999, 10(4), 577-582.
[19] Kerbrat-Orecchioni C. La place de l'interprétation en analyse du discours en interaction" [The place of interpretation in the analysis of discourse in interaction]. *Revue de Sémantique et Pragmatique,* forthcoming.
[20] Heritage J. *Garfinkel and Ethnomethodology*, 1984 (Polity Press, Cambridge).
[21] Schegloff E.A. Whose text? Whose context? *Discourse & Society,* 1997, 8(2), 165-187.
[22] Arminen I. On the context sensitivity of institutional interaction. *Discourse & Society,* 2000, 11(4), 435-458.
[23] Frolich D.M. (1993). Adding Interaction Analysis to the User Research Portfolio. In *Rethinking theoretical frameworks for human computer interaction, InterCHI'93*, Amsterdam, April 1993.
[24] Koschmann, T. Revisiting the paradigms of instructional technology. In *Meeting at the Crossroads, The 18th Annual Conference of the Australian Society for Computers in Learning in Tertiary Education*, Melbourne, 2001, pp.15-22 (The University of Melbourne, Melbourne).
[25] Brown A.L. Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *The Journal Of The Learning Sciences*, 1992, 2(2), 141-178.
[26] Wiegers T. and Vergeest J.S.M. Extraction Of Cad Tool Requirements From Industry And From Experimental Design Projects. In *Proceedings of 2001 ASME Design Engineering Technical Conferences And Computers and Information in Engineering Conference Pittsburgh*, Pennsylvania, September 2001.
[27] Collins A., Joseph D. and Bielaczyc K. Design Research: Theoretical and Methodological Issues. *The Journal Of The Learning Sciences*, 2004, 13(1), 15-42.
[28] Baker M.J. and Lund K. Promoting reflective interactions in a computer-supported collaborative learning environment. *Journal of Computer Assisted Learning*, 1997, 13(3), 175-193.
[29] Sawyer R.K. and Berson S. Study group discourse: How external representations affect collaborative conversation. *Linguistics and Education*, 2004, 15(4), 387-412.
[30] Baker M.J., Quignard M., Lund K. and Amelsvoort M. Designing a computer-supported collaborative learning situation for broadening and deepening understanding of the space of debate. In *The Fifth Conference of the International Society for the Study of Argumentation, ISSA 2002*, Amserdam, June 2002, pp.55-61 (Sic Sat Publications, Amsterdam).
[31] Nicol D.J. and Boyle J.T. Peer Instruction versus Class-wide Discussion in Large Classes: a comparison of two interaction methods in the wired classroom. *Studies in Higher Education,* 2003, 28(4), 458-473.
[32] Corbel A., Girardot J.J. and Jaillon P. DREW: A Dialogical Reasoning Web Tool. In *The International Conference on ICT's in Education*, ICTE 2002, Badajoz, 2002.
[33] Roschelle J. and Teasley S.D. The construction of shared knowledge in collaborative problem solving. *Computer Supported Collaborative Learning*, 1995 (Claire O'Malley) pp. 69-96.
[34] Ahmed S. and Wallace K. M. Identifying and Supporting the Knowledge Needs of Novice Designers within the Aerospace Industry. *Journal of Engineering Design*, 2004, 15(6), 475-492.
[35] Okudan, G.E. and Rao, G. (2005). Collaborative Conceptual Design Thinking and Software Aids: A Review. In *International Design Engineering Technical Conferences & Design Theory and Methodology Conference, IDETC/CIE 2005 ASME 2005*, Long Beach, California, September 2005.

Contact: K. Lund
University of Lyon
Laboratory ICAR
École Normale Supérieure Lettres & Sciences Humaines
15, parvis René Descartes
BP 7000 69342 Lyon Cedex, France
Phone (33) (0)4 37 37 63 16
Fax (33) (0)4 37 37 62 65
Kristine.lund@univ-lyon2.fr
http://icar.univ-lyon2.fr