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DESIGNING INTERFACES: A SKILL DESIGNERS SHOULD / MUST LEARN.

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Abstract:

The purpose of this paper is twofold.

The first objective is to specify a skill, peculiar to the distributed design of an industrial product: the ability to design the interfaces between two substructures of a machine that are designed by different people. This skill should be taught in new designer's training courses. Indeed, a team of designers has to solve the problems of compatibility of their substructure with that of the others. Thus, it is necessary that the teams of designers decide on the parameters determining the interface and that they pass them on to each other. We propose an interfaces typology.

The second objective is to expound the method and the results of a PhD in Didactics of Technology, achieved in 2002. It characterizes the students' difficulties with relation to this interface-designing ability while they were following a design training course. Four categories of difficulties have been identified, and relate to: coordination, taking other people's work into account, correct use of remote communication tools, and use of an easy-to-understand, univocal language.

Key words: Agility in Design, Students' Difficulties, Distributed Design, Interfaces

1 Introduction: New Work Organizations Require New Designing Skills

Some new organisational schemes have emerged in industrial companies over the last decades: concurrent engineering, project teams and subcontracting. And it influences the organization of the designers' work.

In the activities of concurrent engineering, one usually makes a distinction between "distributed design" moments, and "co-design" moments [2, 6, and 7]. In the distributed design situations, the actors cooperate, simultaneously but not jointly. They accomplish some tasks which were previously allocated to them and thus work towards their *own* objectives. The problems have to do with the internal working of a technical subset. These phases of distributed design are punctuated by meetings concerning the progress of the project, during which the achievements of each team are confronted, discussed and made coherent. These pooling sessions are the co-design phases. The problems are those that crop up when one

wishes to integrate a technical subset in the machine environment , and when one imagines the following life stages of the product: manufacture, assembly, use, and recycling.

Three distinct designing skills thus seem to result from such an organization:

- The Ability to explain one's own design problems to specialists of other fields of action on the product (in particular, manufacture), and the ability to understand the specific technical problems explained by these specialists.
- The Ability to design the interfaces between various parts of the machine that are designed by various people, *i.e.* to make sure that these parts are compatible.
- The Ability to design inside the group a part of the machine which the whole group is in charge of. This ability is difficult to take into account in universities given the individual character of the studies and the qualifications.

Our study focusses only on the second one : the ability to design interfaces. The purpose of the following section is to specify this ability.

2 An Ability Peculiar to Distributed Design: Designing Interfaces

We have chosen a model of distributed design, in which the work is distributed between several teams of designers, according to the various substructures of the machine being designed. This distribution is done for example in the car industry, to design a car, the projects are broken down into standard subsets: instrument panel, air-conditioning, instrumentation, base, driving cradle, nose gear, rear wheel-axle unit, and braking (in the French firm Renault [5]).

During the machine-designing process, some periods of time must be devoted by each team to solving the problems of compatibility of their own substructure with that of the others. These problems only relate to some characteristics of the substructure, *i.e.* structural elements, components or/and dimensions. The term "interface between two substructures" that we use encompasses all these characteristics. And to design the interfaces (*i.e.* to solve the problems of incompatibilities), the teams of designers have to make some decisions in which they specify the parameters determining the interface, and have to pass them on to each other. These parameters constitute the information needed to define the entire interface. In table 1, we propose a typology of the possible interfaces between two substructures of a mechanical part of a machine, the corresponding incompatibilities that should be avoided, and the parameters determining these interfaces. The play (for working and assembling) consists in space which must be left free by one team of designers or the other, for a part of the other teams. Junction surfaces separate two parts of the machine designed by two different teams. Lastly, the internal environment of the machine (lubrication conditions, temperature conditions, etc.) has to be chosen in a coherent way by the various designers, and all the technical solutions adopted have to be compatible with this internal environment.

Type of Interface		Possible Incompatibilities	Parameters to Be Defined
Play	Working play	Static interference: two components at the same place	Positions and volumes of components
		Difference in the shape of the theoretical contact surface between two components which have a relative movement	Shape (geometric shape type and dimensions) of theoretical contact surface and play.
		Difference in the position of the theoretical contact surface between two components which have a relative movement	Position of theoretical contact surface
		Working collision	Envelope surface of the trajectories of a moving component's points, when the machine works
	Assembling play	Assembling collision	Envelope surface of the trajectories of a moving component's points, during the assembling process. Dimensions of the conduits
Junction surfaces	Imaginary junction surfaces (cuts a component in the material)	Difference in the shape of imaginary junction surface	Shape (geometric shape type and dimensions) of theoretical junction surface.
		Difference in the position of imaginary junction surface	Position of theoretical junction surface.
	Fastening joint surfaces (between two fastened components)	Difference in the shape of fastening joint surfaces	Shape (geometric shape type and dimensions) of theoretical contact surface
		Difference in the position of fastening joint surfaces	Position of theoretical contact surface
Internal environment	Incoherent internal environment	Components for lubrication and oiltightness	

Table 1. Proposal of a typology of possible interfaces between two substructures of a machine. Their corresponding potential incompatibilities, and the parameters that determine them.

3 Difficulties Peculiar to the Designing of Interfaces

The second objective of this paper is to expound the method and the results of a PhD in Didactics of Technology achieved in 2002. It characterizes the students' difficulties with relation to this interface-designing ability, while they were attending a design training course.

We start by describing the characteristics of this design training course, called "CoDiMI", which we already presented in detail at the 7th conference on Integrated Mechanical Design Aip-Primeca, in April 2001 [6].

3.1 The Design Training Module "CoDiMI"

The training process is shaped like a simulation of professional activities of distributed design. Since the academic year 1998-1999, it has been a twenty-hour module for a "Licence de Technologie Mécanique" (a degree awarded after one year of a Master program in Mechanical Technology) at the "Ecole Normale Supérieure de Cachan", in France.

For this module, 80 students get into groups of 2 or 3 people. Each group works with another group simultaneously, but remotely, in another building in the university. The two

groups that constitute such a work unit can communicate via electronic chat and videoconferencing (figure 1). The videoconference device is equipped with a camera over the table which makes it possible to retransmit the image of a document. In addition, they have access to the software Mathcad and to a database on the existing dosing pumps.

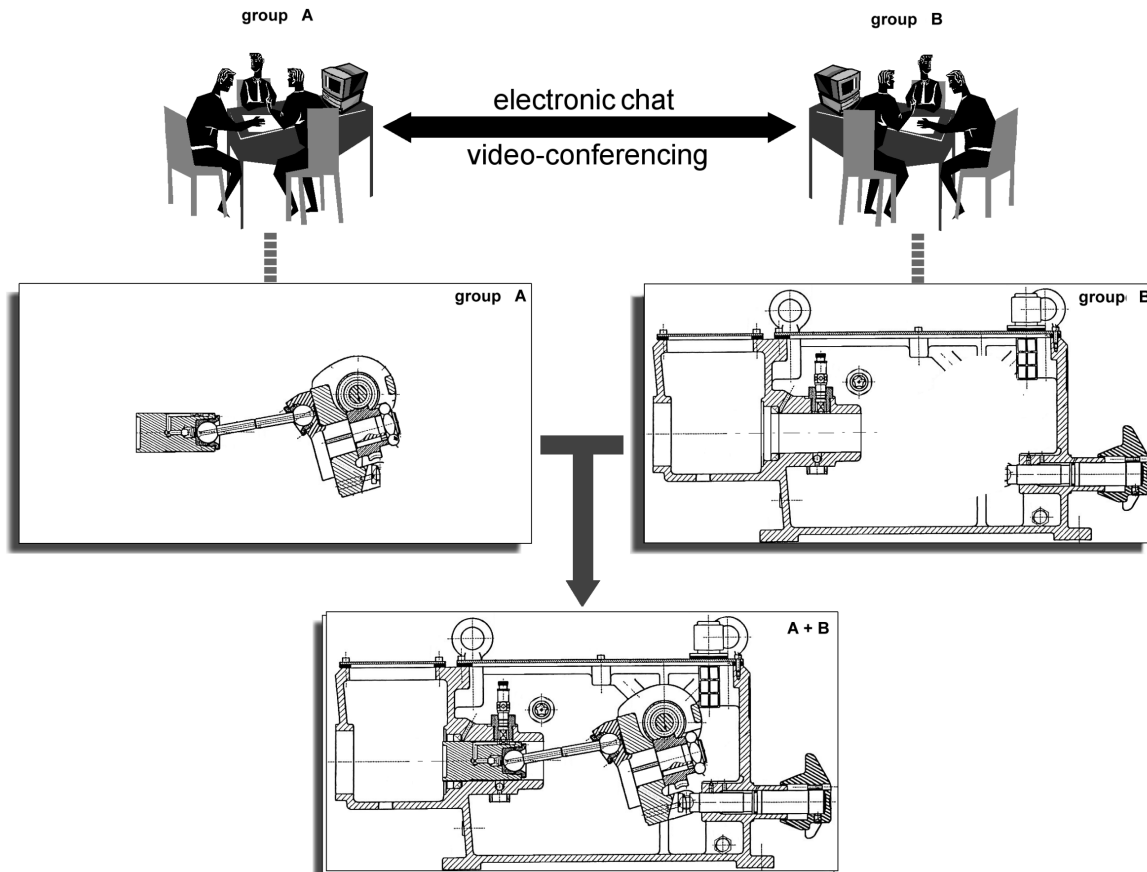


Figure 1. Two groups of 2 or 3 students work together, remotely. They constitute a "work unit". They can communicate via electronic chat or during videoconferences. Either group is expected to design and draw a partial plan of the machine, which must complement the twinned group's one.

The students have to design the preliminary draft of a dosing pump which will send methanol from an oil rig to the bottom of an oil well. Methanol is used in fact as antifreeze and makes it possible to avoid plugs while the oil, which freezes because of the expansion of gases that it contains, goes up. The pump must provide an adjustable flow of 5.3 gph (20 lph) maximum, under a maximum pressure of 5.8 psi g (400 bar g). During the first four hours, Each group works on retrieving information regarding existing dosing pumps, without the twinned group. Then, during the next sixteen hours (twice eight consecutive hours), the twin groups work remotely together according to a distributed design protocol . One deals with the transmission chain, composed of the following substructures: the electric motor, the elastic joining, the speed reducer, the drive mechanism, the slide and the liquid end. The other one deals with the design of the casing and of the flow adjustment system. Either group produces the draft plan of the part of the dosing pump for which it is in charge of, on graduated tracing

paper (see figure 1). Except during the lunch break, the students can communicate only through videoconferencing and electronic chat.

The observations which henceforth report relate only to the last eight hours of distributed design.

3.2 Reconstruction of Decisions and Exchanges about Interfaces

The data corpus used to spot the students' difficulties consists in the full recording of their communications: electronic chat and videoconferences. The texts exchanged through electronic chat and the written retranscriptions of the videoconferences were analyzed to reconstruct the decisions and the exchanges concerning the interfaces, precisely where the students drew incompatible technical solutions. For each of these interfaces, the determining parameters were first identified; and then we located the exchanged information which relates to these parameters.

The monitoring sheet presented in figure 3 reconstructs the decisions and the exchanges concerning the necessary working play between two parts (*Part A* and *Part B*, see fig 2) of the mechanism (*Part A* being designed by the group A3, *Part B* by the group B3). This play does not exist on the plan drawn by the groups A3 and B3.

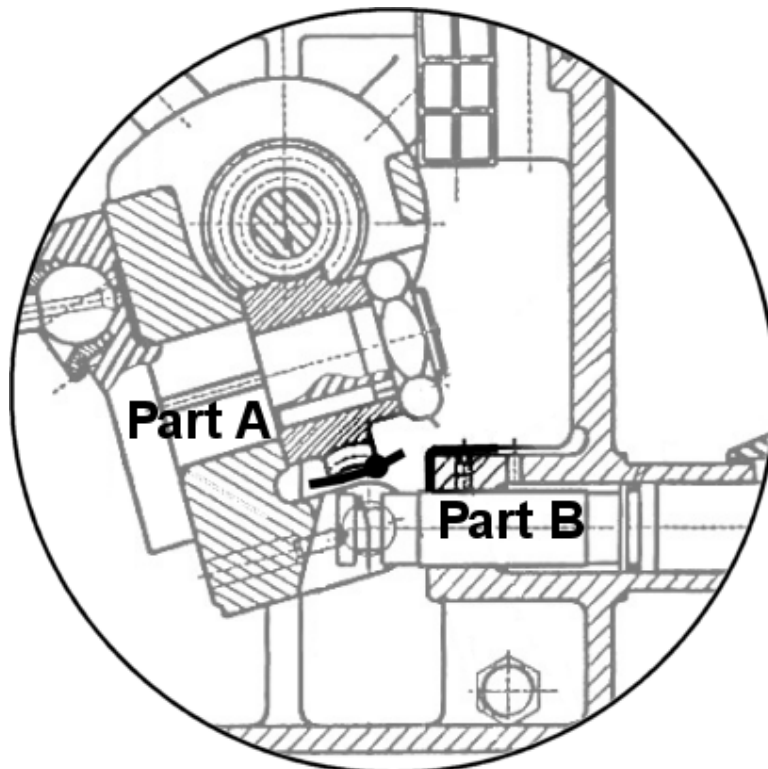


Figure 2: Detail of a plan of a dosing pump: the trajectory of the extremity of part A does not intersect with the external face of part B during the flow adjustment

<p>Compatibility Mistake: the toothed wheel, drawn with a 7,5° angle from the casing face, collides with the casing during the flow adjustment (maximum angle = 15°).</p> <p>Interface Concerned: The play between the toothed wheel and the casing, necessary for the angle of the toothed wheel during the flow adjustment.</p>	
History of Decisions and Exchanges	References
A3 states the fault to be avoided: the collision of the plate with the casing, in top of the casing, when the plate turns. B3 proposes an approximate safety leeway.	VISIO.1[60-65]
A3 and B3 define the radius of the wheel and the dimension of the adjustment system to avoid the collision of the toothed wheel with the adjustment system, when the plate turns with a 15° angle	VISIO.1[86-116]
A3 draws the drive mechanism, in particular the toothed wheel	VISIO.6[420-425]
<u>B3 requires the coordinates of the extreme point of the drawn wheel (it is drawn with an 7.5° angle). A3 gives them</u>	VISIO.6[420-425]
<u>B3 draws the casing in order to leave some space for the wheel with an only 7.5° (but not 15°) angle</u>	VISIO.8[462]

Figure 3. Decisions and Exchanges of the A3 and B3 Groups, about one interface they drew with a mistake: the trajectory of the extremity of part A (see figure 2) does not intersect with the external face of part B during the flow adjustment.

3.3 Investigation of Difficulties Peculiar to Interface Designing

Compared to the local design of a machine, the remote and distributed design imposed on the students by the design training module "CoDiMI" is characterized by the need to make compatible two parts of the machine designed by two different teams. The interface-designing activity can be examined from 4 different angles.

① First, the coordination between the twin groups. The latter is necessary to dispel the indetermination due to the fact that, at some point, a student does not know the solutions that have been chosen for another part of the machine by another student (because it is not designed yet or is still in process of designing) though he needs it to carry on his own work. We tackled this aspect thanks to some concepts taken from analyses of professional designing. Thus, in a firm, two strategies of coordination exist. The first one consists in waiting for a designer to have entirely designed a part of the machine, before designing the parts that depend on it. It goes with a planning of the design of all the substructures of the machine, according to the information needs regarding their interfaces. The second coordination strategy consists in making *a priori* hypotheses about the interfaces between the substructures which various designers are in charge of, by defining, for example, a reserved space [7]. The designers start with this decision, even if they can still negotiate this reserved space later on. The indicators we will use concerning coordination must allow us to check if the students have a common coordination strategy, among the two preceding ones, and if that had consequences on their results.

② The second aspect under consideration is the taking into account of the work of the twinned group when designing a substructure of the machine. To analyze this aspect, we have used some concepts developed by Yves Cartonnet [1]. Taking the technical solutions of the

twinned group into account occurs twice during the local design of the substructures: when anticipating a technical problem, in particular an incompatibility with a substructure designed by the twinned group; and when simulating in order to check that a suggested technical solution is compatible with those of the twinned group.

③ The third aspect of the remote distributed design that we analyze is the use of remote communication tools: electronic chat software and videoconference device. We use the concept of "instrument" developed by Pierre Rabardel [6]. Used in Pierre Rabardel's meaning, the effective use of the communication tools -as artefacts- requires that the students have built cognitive schemes. With these schemes, an artefact becomes an "instrument" for action. The researcher distinguishes two types of schemes. The "use schemes" are mental constructions which allow the perfect command of the procedures peculiar to the use of an artefact. The "instrumented action schemes" are those which make it possible to incorporate the appropriate use of the artefact in a more complete action. We use indicators of difficulties for either scheme, to see whether they are used by the students, and if that is a source of mistakes.

④ Lastly, the fourth aspect that we study is the use of an easy-to-understand and univocal vocabulary to communicate remotely. It is necessary so that communicated information is well interpreted and correctly used.

The indicators listed in table 6 take these 4 aspects into account.

	Corpus of data	Indicators: The students ...	Results
Mistakes	42 pairs of drawings (years 1999, 2000 and 2001 classes)	... have drawn at least one incompatibility	31 WU* /42 (74%)**
① Lack of Coordination	14 WU* during 8 hours (year 2000 class): - Electronic chat text, - Written retranscription of videoconferences.	... have neither expressed nor applied any coordination strategy	8 WU /14 (57%)
		... were stopped because awaiting information from the twinned group	3 WU /14 (21%)
		... have added a modification at the last minute because of a drawn incompatibility	1 WU /14 (7%) (1 mistake /23)
② Not Considering the Others' Work		... haven't communicated about an interface, and have drawn an incompatibility	6 WU /14 (43%) (10 mistakes /23)
		... have communicated and have both decided the parameters determining an interface, but have drawn an incompatibility	4 WU /14 (29%) (4 mistakes /23)
③ Misuse of Communication Tools		... have implemented a bad procedure, which caused the drawing of an incompatibility	2 WU /14 (14%) (2 mistakes /23)
		... have communicated information about geometry without using the videoconference device, which caused the drawing of an incompatibility	3 WU /14 (21%) (3 mistakes /23)
④ Use of Incomprehensible or Equivocal Vocabulary		... have used an incomprehensible or equivocal vocabulary, and have drawn an incompatibility	2 WU /14 (14%) (2 mistakes /23)

* WU = Work unit made up of two student groups

** Among the year 2000 class sub-population, 23 incompatibilities were drawn.

Table 2. Data, Indicators and Observation results that made it possible to characterize the students' difficulties in designing interfaces.

3.4 Results: Observed Difficulties

Table 6 and figure 3 highlight the difficulties that were encountered by the students, and that are peculiar to interface-designing (year 2000 class: 14 work units).

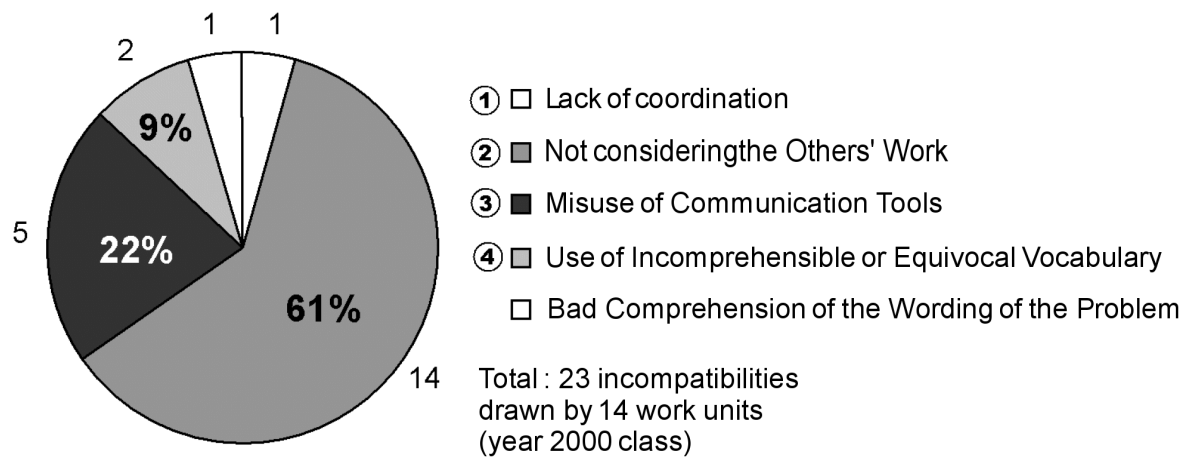


Figure 4: Synthesis of Observed Difficulties which Caused Mistakes on the Plan.

① The first result is that only few students organize their work explicitly according to the problems of compatibility at the interfaces. But that causes only one mistake, for one work unit (1 mistake out of 23).

② The second result is that the great majority of the mistakes made by the students are due to the fact that they don't take their twinned group's work into account, during the design of their own substructures. Often (in 6 work units out of 14), the students have not even anticipated the possibility of an incompatibility, and have never expressed it.

③ With regard to the bad use of the communication tools, the mistakes are three times less frequent. They can be divided into two types. On the one hand, those which correspond to a lack of mobilization of the use schemes, which result in inefficient procedures (observed twice, see table 6). For example, a group changed the lens of the camera of the videoconference device and was then incapable of making out clearly the drawing shown by their twinned group. This caused a bad interpretation of dimensions and the drawing of incompatible solutions. On the other hand, the lack of mobilization of the instrumented action schemes. They correspond to the unsuited use of the electronic chat software, with no use of the videoconference device, to communicate the geometrical description of a technical solution (observed three times).

④ Lastly, in only one work unit, we observed that the use of an ambiguous vocabulary, used to describe a technical solution, led to a wrong interpretation and a mistake.

4 Conclusion: Implementation Prospects and open question

We have tried to increase and improve the empirical knowledge on what can really happen with students in new design training courses. In addition we are planning to implement this work in the following way.

The application would consist in helping teachers diagnose the difficulties of some students who would be put in a training situation similar to the one we have described. The indicators which we have developed would then be used as signs of the students' difficulties, among those which we have identified. A diagnosis diagram can represent the difficulties and the indicators of difficulties, as shown in figure 5. When the teacher notes a difficulty, he can then decide :

- to resolve this difficulty by intervening (in the group), because he chooses that overstepping the difficulty is not the most important thing to learn,
- to give some tools to the student to help him overstep the difficulty, hoping he will learn how to use them and later overstep such a difficulty alone,
- to leave the student in a difficult situation, to let him it overstep alone, or to make a reflexive analyse later on, based on indicators about the mistakes they have drawn and the texts they have communicated.

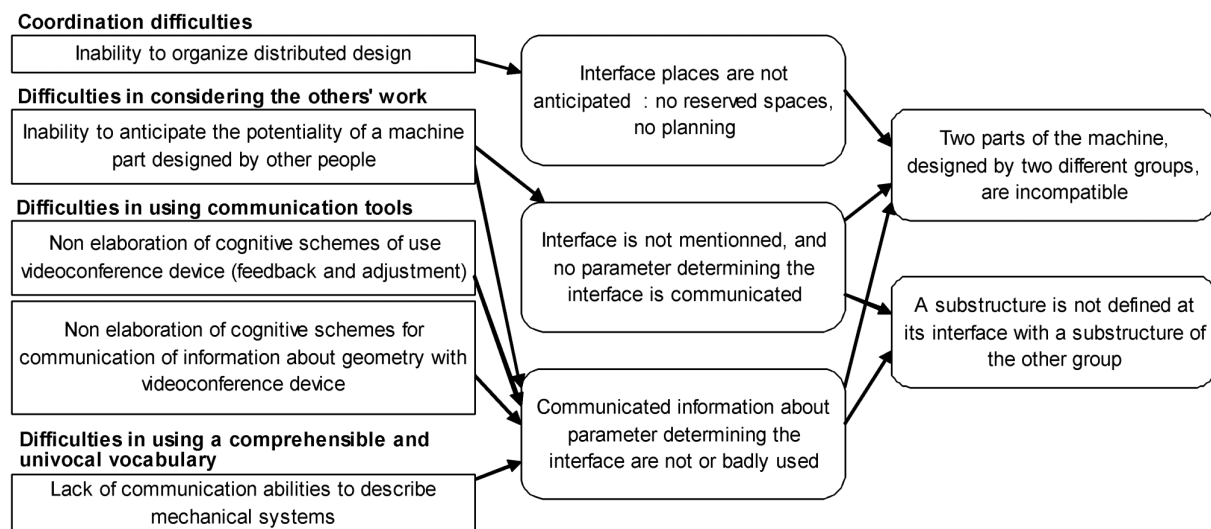


Figure 5. Diagnosis Diagram of the students' difficulties concerning Interface-Designing

To conclude, we have considered that, in industry, designing interfaces is in charge of teams of designers. In fact, a part of this task is in charge of teams of designers, and the other part is the job of one person, called "integrator" or "architect". In addition, designers and "integrator" can be helped by computer simulators. For example in the firm Daimler, each night, a computer gathers everything that has been worked by designers together in the global 3D-model of the car, and goes through a checklist of interface-problems by simulating. Then designers begin the day with reading a list of interface-problems which concern his substructure.

So we have dealt with only a part of training problems. What about the training of these "integrators"? Should they follow peculiar training courses? And how can we introduce interface-problems simulators during distributed design project at University?

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