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Toward Reflective Practice in Engineering Design Education*

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Today engineering design practices are radically changing through the development of collaborative work, which requires new specific skills. From an educational point of view specific courses have been set up, including projects and teamwork. However, few efforts have been devoted to the definition of a framework for analysing and characterising collaborative practices in engineering design education. Our aim in this paper is to propose a framework, based on four basic concepts, which allows the characterisation of specific collaborative situations in order to provide engineering students with a more accurate feedback. We stress here the importance of developing reflective practices as a basic skill for collaboration. Our research method is based on a longstanding qualitative analysis of groups of students working on a design game at a graduate level.

INTRODUCTION

THERE HAS BEEN a considerable upheaval in industrial practices over the last few years. Design activity is no exception and we can even say that with the setting up of new organisational structures based on concurrent engineering, design activity has radically changed. Thus new actors have arrived on the design scene, which were until now, in the wings. The very term 'designer' has become ambiguous given that structural and production engineers may be involved just as much in the design of a product as traditional design office engineers. The cast of actors participating in design is thus evolving and today there is no doubt about it that the scope of those involved is fluid and depends both on the type of product and the design stages. We can therefore consider that design is an activity shared [1] between several designers who do not always share the same knowledge and often have contradicting objectives. According to Mer [2] these actors belong to different 'worlds'. Designing a product is thus a question of getting these actors from different disciplines to work together with the aim of defining an artefact, i.e. the product.

DESIGN TEAMS

This teamwork often generates problems of co-ordination. This co-ordination depends on a temporal breakdown of the project, which is all the more complex the more participants are involved and the more complicated the product, but it also implies a structural breakdown of the product, which is not without its stumbling blocks. Among the means of co-ordination available, design meetings are highly effective and widely used.

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This article focuses especially on collaborative practices during these face-to-face meetings and we shall be looking especially at teaching methods to help students develop theoretical and practical knowledge that will enable them to adopt efficient behaviour in this type of situation.

Our contribution is a new approach to enhance training of fundamental competencies of design project work. It is based on a reflective practice activity. A framework for analysing design practices has been developed to serve as a means for learning about one's own practices in a collaborative design situation. Literature so far reports from experiences on teaching design based on reflections about results and sometimes practices from an instructor [3], peers [4, 5], or both instructor and peers [6], but we could not find experiences based on own students' reflective practice.

Why is it important to engage in reflective practice? Because:

- In an unstable universe managing action efficiently, especially if it is part of a collective movement, means being able to quickly react and adapt. Learning about one's own practices through success and failure is a positive and productive way to analyse the self.
- Each design situation is specific and it is not possible to dream up an efficient and universal practice model. What we have here is a means of making the invariance in collaborative design situations emerge in the form of practice analysis criteria.
- Designers have a certain amount of ethical responsibility, just as other professionals like doctors and architects, in choices that are made about the product and the way it meets needs, etc.

The reflective practice activity has been tested in teaching practice, supported by a design game.

Empirical observations have led us to formalise such a practice as a main part in engineering design education.

In the next section we present the context of the study, the curriculum, the type of students that were involved and the main purpose of the course where the game is used. In a third section we present the design game we use. This leads us to present in a fourth section our framework for a reflective analysis, which is the main outcome of the study. The conclusion stresses the importance of developing such tools to train the students in developing reflective practices for improving collaborative skills in engineering design.

TEACHNING/LEARNING CONTEXT

Students' background

The study presented here is based on the observation of a design game played by graduate students within the framework of a design course of a mechanical engineering school (ENSHM G) at the Technical University of Grenoble (INP G). In France, the curriculum of the students is articulated into two main periods throughout five years up to their final year engineering degree. The two first years are general and highly theoretical, and the last three are dedicated to the development of the core competencies of the various engineering fields. During these three years, at ENSHM G, specific courses in engineering design have been developed in order to infuse design experiences throughout the curriculum as Bucciarelli mentions in [7]. Among these courses, specific periods are dedicated to design exercises and projects. During the first year the total amount reaches 100 hours (homework excluded), when in the second year it is of 144 hours (in a single engineering project).

This engineering project involves an 'ill structured' problem and uses it to introduce the notion of project and collective work. This is now a common practice in many countries, and although it may take on many forms the basic idea stays the same: to train students to design complex objects involving a structural and temporal breakdown of the project. In this case structuring the problem is an important part of the exercise as well as planning the means to achieve the common goal defined by the group.

There are two objectives in this project: to define a product and to manage project. For students and teachers alike, the thing that is seen to be of major importance, and hence the primary goal, is the product. Its technical performances are therefore assessed using scientific and technical models studied during practical exercises. Project management, on the other hand, is often seen as simply a question of implementing the usual management tools. However, the real process is marked by individual work phases and group work times (project meetings, etc.). On the one hand there is a host of representation tools (functional expression tools, calculation tools, CAD tools, etc.), and, on the other hand, there are the project management tools (scheduling, Gantt, etc.). But how exactly are the design activities organised throughout all these different stages and tools? How can this action be efficiently co-ordinated during the collective working phases? And, finally, from a teaching point of view, what means should be implemented to allow learning based on effective practices?

This is why in the third year of the curriculum we have developed a course dedicated to the study of collaborative design practices. This is a relatively short sequence of 24 hours which aims at summarising the students' experience gained through the two previous years and developing specific skills in collaborative design through the use of a design game.

Course organisation

Course objectives. The objective of the course is to focus on the collaborative design issues and initiate the development of collaborative design skills. To achieve that, we develop a theoretical part in the form of two-hour lectures. The schedule is as in Fig. 1. After a brief introduction, we propose the Delta design game as a first step, without any theoretical premise, in order to allow the students to discover through the practice. A two-hour collective analysis permits building a shared feed back of this first experimentation. We use this sequence to point out some issues of collaborative work in design. The second part of the course is dedicated to a theoretical presentation of the analytical framework that we illustrate through various case studies drawn from empirical research carried out in the industry. The third part of the course is dedicated to another game, involving the design of a technological artefact. A four-hour sequence following this experimentation which provides the link with the theoretical concepts to the practical experience developed through the game. The lecture 4 is dedicated to the presentation and collective reflection on the concept of reflective practice, and a summary of our framework. The teams are composed of eight students (see Fig. 2 right-hand side). Most of the time role play comprises two students (e.g. the thermal engineer, the architect, etc.). The assignment is twofold: on the one hand they have to participate as designers, and on the other hand they must observe the group and their own practice in the group in order to report to the whole class. An observer (a teacher or a student) notes the activities of the group. The assessment of the course is carried out through an oral presentation of each group and a report by a team member. To complete the assessment a short individual examination is carried out at the end of the session.

The role-play. Through a game it is possible to recreate a collaborative design situation including all the elements of uncertainty and contingency involved in a real design situation, while avoiding

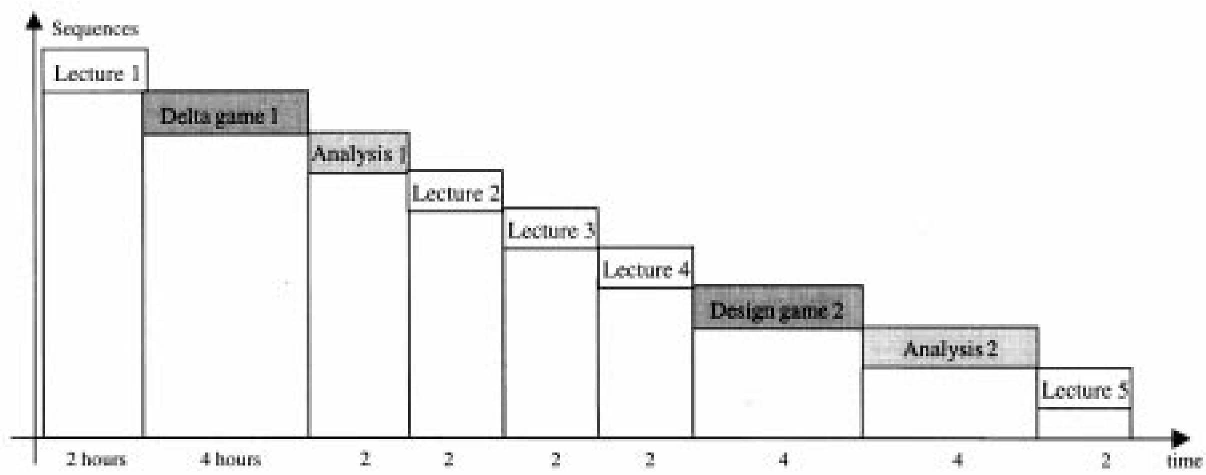

Fig. 1. The course structure.

the pitfalls of an overly complex and difficult-to-implement situation. (The game can always be stopped and started and the context adjusted whereas there is no control over the industrial process.) This is why a game was chosen as it involves an artificial design situation that can be managed and is easy to implement. We haven't done an exhaustive research of existing games. We have got the Delta Design game [8], created by L. L. Bucciarelli at the MIT, which is role play. Roles are defined through their objectives and their technical knowledge. The working universe of the game is not real. So there is no risk that a student's knowledge interferes with knowledge needed to play and modify the results of the game. Environmental constraints can be reduced to mainly focus on the course objectives.

Why do we use a game and not a real industrial project? For many reasons:

- The students do not have common or homogenous references relating to industrial design situations.
- The students are not specialists and have a very similar skills profile.
- Time training can be managed and limited.

Experimental context

The approach has been tested in teaching practice; the course has been running for five years. The observations and conclusions presented here result from this experience and are mainly empirical. It is particularly the case of the analysis framework which has been improved year after year and is reliable now. Its robustness comes from the number of teams having played so far.

DESCRIPTION OF THE GAME

As exposed before, we use an existing role play: the delta design game. We are now going to describe the objective, the required designing environment and team.

Objective: designing a house

The task to be accomplished by the players is to design a dwelling to meet, as best as possible, requirements relating to cost, resistance as well as customer taste. The designers of this game have been careful to minimise the possibilities of interference with participants' specific technical knowledge as far as possible. Only basic mathematical

Fig. 2. Building configuration example and team of eight.

knowledge is required. Thus the design takes place in a universe invented by the author: the Deltoïd plane. It is a flat, highly simplified universe created for the needs of the game (we shall describe it in detail in the following paragraph). Figure 2 shows an example of a possible building design and a team of students.

The requirements outlined in the specifications are as follows: minimum surface, one entrance, openings between all rooms, jagged internal layout with lots of nooks and crannies, upper limit for use of blue triangles, house life expectancy, internal temperature limits as well as limited hot and cold points and cost. The game lasts for two hours.

Description of the deltap environment

It is therefore a 2D world and, as shown in Fig. 1, the house will be defined by an assembly of triangles (called deltas) according to the specific rules: 'The view on a single sheet may not be quite what you expect, however, because in addition to lacking a Z axis, Deltoïd space has unfamiliar relations between the X and the Y axes as well. What we think as perpendicular is hopelessly skewed to a Deltan, and vice versa. In our units, a right angle on DeltaP measures 60° or $\pi/3$. Thus all sides of an equilateral triangle form lines considered perpendicular to all other' [8].

Furthermore, the units of measurement are specific to the DeltaP world. Distance, time, surface and currency are all specific to the delta world. Triangles have specific thermal properties (they generate heat if they are red and when blue are passive). Deltas are subject to gravity, which can change directions, and the cement between the deltas has a mechanical resistance limit. Their price varies in relation to the quantity, colour and possible factory pre-assembly. Thus described, the environment gives the players a representation of the problem, which is basically just the description given in the introduction to the game. Furthermore, each player has a description of the rules and methods specific to his/her job. A priori, the group has no shared knowledge before the start of the game.

Design team

The design team is made up of four designers, each one with expertise corresponding to his/her specific job and which is unknown to the other participants (see Table 1). A project manager is in charge of making sure that building time and cost requirements are met, a structural specialist must make sure that the structure is able to resist the field of gravity, a thermal engineer is in charge of internal temperature and checking hot and cold points. Finally, the architect represents the customer. S/he ensures that the 'aesthetic' specifications are met (shape, proportion and dispersion of blue, etc.).

Knowledge specific to each job is defined through different laws and calculation heuristics. Qualitative and quantitative rules compete, so the strategies developed by the participants are typical of complex design situations where heterogeneous point of view must be faced.

It should be pointed out that the major strength of the game lies in the intelligent way in which the constraints of each actor have been interwoven. Thus, for example, the architect will attempt to have as many smooth contours as possible while the thermal engineer aims for jagged contours. Similarly, the project manager will tend to reduce the size of the house for cost reasons while the architect will want a large house that is easier to sell. The project manager will perhaps find an ally in the structural engineer, as a small house will resist the force of gravity better and will be cheaper, and so on.

The process is not defined beforehand and depends greatly on the personality of the participants, just like in a real industrial project. The game consists in solving a design problem, so designers are confronted with a problematic situation [9]. This situation is described through objectives to be reached, scopes of requirement to be met and the roles of the actors. The fact that

Table 1. Different roles, objectives and product specifications

Roles	Individual objectives	Constraints	Product specifications
Architect	Form and function Aesthetic internal/external	Internal area/perimeter Colour distribution	Functional internal area Aesthetic
Structural engineer	Prevent the structure to collapse	Mechanical laws, gravity force, delta assembly joints resistance	Maximum load at anchor points Maximum internal moment
Thermal engineer	Keep average temperature acceptable Avoid hot/cold points	Thermal laws of single Deltas and conduction laws between Deltas and between deltas and environment.	Individual temperature rage Average internal temperature Maximum cool deltas
Project manager	Responsible for cost and lead time Minimise cost investments	Cost distribution of single elements and building blocks Building blocks production time	Total budget

behind each actor there is an individual means that the game will always be played out differently.

FRAMEWORK FOR A REFLECTIVE ANALYSIS

Why a reflective analysis and what is it?

Insofar as it is unlikely that any official theory will totally support the way in which activities are organised, regardless of the design situation and, what is more, in a collaborative context, one postulates along with Schön [9] that the learning process should be organised in the form of reflective analysis.

Each individual must think about their own practices in relation to those of the other members of their group. This thought process, which in this case is carried out subsequently to action but should eventually be initiated during the course of the action, should focus on the peculiarities of the situation in hand with a view to:

- analysing what was done during the period of action;
- the impact of these actions on the situation;
- any unexpected effects or 'intrusions' that were ignored.

Thinking about and criticising the unspoken but implicit facts or evidences that guided their actions should help the players to build up a certain amount of situated, contextual, knowledge that they can be incorporated into their personal knowledge repertoire [9] and used again later. A practitioner's repertoire, following Schön '*includes the whole of his experience insofar as it is accessible to him for understanding and action*'. This thought process should cover the problem and its construction, as well as possible solutions and their development. For anyone undertaking such reflective

Table 2. A framework for reflective analysis

Categories	Indicators, questions
Intermediary objects	What are the intermediary objects used? In what sequence? For which purpose? • to represent a solution principle, the results of a calculation, to explain, to show, to share, • to enrol or convince others • to assess and take decision What objects are used to memorise choices and their rationale? Does this memorisation addresses problem or solutions?
Criteria and Constraints	• What criteria are used during the discussion? • How does the collaborative design context influence the conjectures put forward and the implementation of criteria in the assessment of possible solutions? • How contradictory criteria, related to different domains, have be taken into account and handled? Who has brought these criteria into play: participant from the same domain or other participant? • Are these criteria prioritised? Is there any relationship between this hierarchy and the elements characterising their status (objectivity and subjectivity, qualitative and quantitative, etc. . . .)? • What constraint are put upon? • Are the constraints prioritised? What are the criteria used to do this? • How and why do these constraints change? Is the rationale of these changes explained and/or recorded? Are all the people involved aware of these changes? Do they correspond to the indications given in the specifications list? Where are the discrepancies, explicit or not?
Co-operation and co-ordination	• How was the game organised in terms of time breakdown (do any key phases emerge from the process?)? • How can each type of activity be qualified (which should highlight the alternation between individual and group activities)? • Have there been any attempts to implement well-known methods (value analysis, QFD, creativity methods, etc. . . .) or explicit, and even implicit, rules (taking turns to speak, temporal organisation of activities, etc. . . .)? • How does the social aspect influence procedures? Has a project manager emerged, have leaders alternated? Is there a link between the nature of the roles, the ability of players to create rules for action and their influence on the game's development? • How were decisions made (hierarchically, consensually, etc.)?
Knowledge and learning process	What have you learnt about: • the product, • the different domains and their impact on the design problem, • the design process, the 'how' to co-operate, • the organisation of the activities (the importance of relationships between the players, people to be included in the activities, etc.), • the formulation of the problem (explicit/implicit, pre-existing/developed in the course of action, fixed/dynamic, etc.), and the influences on this formulation (job-specific constraints). Which shared knowledge have you built? Did you formulate them? Did you record them? What is its nature: generic, local, in-action? Does it take form of a scientific law, a rule for action, . . .? What are its advantages, its limits, and the scope of its validity?

analysis, considering a new situation involves comparing it to a case in his/her repertoire, without knowing, initially, how the two situations look like or differ from each other. They might use the first situation as a reference and a model, to help understand and act. They are therefore able to act in the new situation as if it were the reference situation, whilst, at the same time, taking account of its peculiarities, similarities and differences.

So, at the end of the Delta Design game, it is suggested that the players undertake a reflective analysis of their practices in the situation specific to the game. It is suggested that they base their reflections on four categories (see Table 2):

- intermediary objects and graphics representation;
- criteria and constraints;
- co-operation and co-ordination;
- knowledge and the learning process.

Intermediary objects and graphics representation

Group design activities involve a large number of sketches, drawings and other representations of the product being designed. In this case, the word 'representation' is used to describe a graphic or material representation, in other words an artefact that is likely to facilitate discussions between the different participants in the design process. The object differs from the representation insofar as it has a cognitive dimension that is linked, of course, to the individual discussing it. An intermediary object [10] is both a representation of the product and a mediating support for the discussion about the product (see Fig. 3).

In our case especially, all the representations in the form of a set of deltas (concerning some deltas to explain a rule or the house design) are at the centre of discussions and act as intermediary objects. This leads us to define a first group of questions that allow the students to analyse their own practice (see Table 2) and help them to elicit (at least partly) their objectives, strategies, and rationale. A second group of questions addresses the reversibility of the process (Table 2). Reversibility is the ability of the system (people, objects, . . .) to re-consider product and problem configurations if an external element appears and modifies the design context (i.e. specification, constraint, action, . . .). This reversibility is much sought after (in the game, some teams feel the need to record solution configurations although this is not provided for in the rules) but, at the same time, it can hinder the convergence of the project.

Using this intermediary object category, we can grasp the actual design process. Relying on our observations, we found that the strategies adopted by the different groups for building their house could be clustered into two extreme models:

- The first can be called 'Learn in order to do': each specialist presents their constraints in a first approach using intermediary objects showing partial construction (see Fig. 3 right-hand side) then, in a second time the group builds (draft is often made by the architect) an initial house on which they all interact trying to integrate all of their specific constraints in an effort to get it right first time.
- The second may be referred to as 'Do in order to learn': the decision is made to build an initial house to see what it looks like and also to give each actor an opportunity to explain their own requirements. The objective here is not to build a house that meets the specifications first time round but to give each actor the opportunity to expose their constraints through the building of an initial house.

Of course none of the actual strategies adopted precisely reflects one or other of the two models presented above. In fact the strategies are built up rather on a patchwork of these two models. We believe there are two reasons for this:

- On the one hand, the principle of bounded rationality [11] prevents us from having an overall and exhaustive vision of the problem and also prevents us from fully applying the first model. Thus the actors often use graphic or material

Fig. 3. Examples of intermediary objects.

representations in order to assist them in their action and the design progresses by trial and error following an opportunistic strategy as many studies have already show [12]. For groups following the first strategy model, we do not see any reasoning or explanation of constraints without the construction of the house being present, even if it is only partial.

- On the other hand, there is no free object construction: each house, even if built to expose the different constraints as outlined in the second model, is the result of collective thinking leading to a search for improvements in order to make it comply with antagonistic constraints. It is thus costly from a time and cognitive point of view, rendering it difficult to destroy even when this is obviously necessary.

Constraints and criteria

A constraint is anything that restricts the designer's freedom, whether it stems from the customer's expectations (for example, for the purposes of our game, a minimum inside area of 100 QDs and an inside temperature of 55 to 65°), or from the design dispositions specific to each step in the life cycle (for example, in the game, the industrial manufacture of walls in the form of modules to reduce costs). A criterion is used during the course of action to assess a solution. In a collaborative design context, it is developed and defined jointly during the assessment process. The assessment of a solution in relation to a criterion requires a reference. This reference may be a constraint. For example, assessing the solution in relation to the inside temperature criterion requires us to consider the inside temperature constraint, which must be between 55 and 65°.

Mechanical design activities are almost systematically based on possible solutions, according to how the designers perceive the problem in hand. These possible solutions that, like Blanco [13] described as conjectures, are then intermediary objects assessed in relation to the criteria specific to the different design activities. In the game being studied, these intermediary objects are the different house layouts arranged within the available two-dimensional space. Which leads us to the questions (see Table 2) about criteria.

As one has just shown, these possible solutions, or conjectures, are the mediating elements (or intermediary objects) in most design activities. This leads us to suggest that these solutions are central to design activities. In the game, the initial problem is marked out by the constraints related to each domain. Now, the negotiation of constraints leads simultaneously to the definition and clarification of solutions and of the problem. One can therefore ask oneself questions (Table 2) about constraints and the problem expression.

During our observations, the different players' constraints are often antagonistic. As we have already explained, the collaborative work leads, in the majority of cases, to the iterative evolution of limits to individual constraints, or to new constraints that take account of everyone's expectations, as far as this is possible. The strong influence of the group is therefore visible, meaning that each player really tries to take account of the other group members' constraints, even if they are opposed to those related to his/her own activity. This can certainly be explained by the educational context in which assessment of the individuals' performance, or the image that the participants have of this assessment, depends primarily upon the product performance. This type of situation should not be found in industry, where people are assessed according to the job they do, and not on their performance in project groups. Nevertheless, constraints are prioritised. Some, for example, are knowingly ignored as aesthetic: 'It's better to make something solid than something attractive . . . honestly, if it isn't solid, no-one will buy it . . .', or changing gravity direction: 'they say it doesn't happen often . . . think about how long the house will last compared to the risk involved . . .'.

Although the criteria used to prioritise constraints are to a large extent implicit, they are governed by sets of values that go beyond the roles themselves, finding their roots in the personal values of the individuals involved. Therefore, priority is given to scientific or technical constraints, which are considered as objectives, rather than to subjective constraints; quantitative constraints are given more significance than qualitative ones.

However, some players take extra precautions when it comes to their constraints, especially the project manager with regard to cost. The potential variation in a cost factor k often incites a project manager to bring up too many constraints, in anticipation of this variation. A smaller cost becomes an ill-founded claim of quality whereas, at the same time, aesthetic arguments for example are neglected, although they may be valid.

Co-operation and co-ordination

Co-operation and co-ordination are two terms that are often used loosely, whereas in our case these two terms designate two clearly distinct realities.

Co-operation is used to define a situation in which a group of people work together towards a single goal. In a concurrent engineering context, co-operation fosters the early expression and recognition of all the specific constraints related to the different domains involved in the product's life cycle. More often than not, this takes place during project meetings or informal gatherings. Co-operation implies sharing information, resources and, to a certain extent, knowledge.

In the same way, co-ordination consists in working together. However, the aim is to arrange activities leading to a goal that may be of secondary significance in relation to a goal that is linked directly to the task. In this case, optimal resource management and organisation is required.

Finally, one can say that these two team-operating modes are based on two fundamental design requirements, namely:

- the need to find a middle ground between different points of view, so that a single object, the product, can be designed;
- the need to assign tasks to the different team members and to share the workload.

It seems important to us at this point to stress the significance of indicators (see Table 2) such as co-operation and/or co-ordination methods on the one hand and, on the other hand, how and in what way these methods affect the definition of solutions, the problem and the system's overall performance.

The rules of the delta design game do not include any specific means of co-ordinating activities. This remains the responsibility of the players. Moreover, during the game, procedure-structuring tools (schedules, resources, etc.) are not referred to in any way. Activities are co-ordinated according to roles and resources, and to the knowledge acquired during the course of the action. The fact that the game is very short encourages participants to acknowledge the need to co-operate. One can observe several teamwork sessions, interrupted by specific job-related evaluations.

Neither does the game provide for a job-related hierarchy within the group. However, a connection between the role played and the position adopted within the group does emerge, often showing itself in the leadership of the architect or the project manager. Notwithstanding the fact that those responsible for calculating structure or controlling temperature are more important from their own scientific point of view. One would suggest at this point that it is the scientific and technical aspects of these roles that make it difficult for their players to claim leadership. In particular, the ability to synthesise rules-for-action and a good level of reactivity are decisive factors in the power games played out within the groups.

One can therefore distinguish two types of activity co-ordination: in the one event, the architect or project manager assumes command, directs discussions, organises research, synthesises cross-learning processes and decides how the structure under construction will develop. In the other event, the leadership role is much more flexible and is taken on alternately by different members of the group. Each person participates spontaneously in the build-up of knowledge, taking into account the various professional opinions and the resulting impact on the house. Whatever the approach adopted, the agreement upon a final solution is governed by time considerations to a large extent, meaning that some members of the group might give up a certain number of their constraints. This is especially true with regard to subjective constraints—those of an aesthetic nature for example.

We can also notice that the organisation of activities is influenced by what the different players discover about their fellow team members' abilities, about how reliable (or unreliable) they are in their respective roles.

Finally, all our observations of the delta design game show alternation between two distinct working modes:

- collaborative working modes, where each actor talks about the constraints that s/he has to respect and where the group pulls together in order to build a house,
- individual working modes where each actor, focusing on his/her specific job, quantitatively assesses how well his/her constraints have been respected in the collectively built structure.

Knowledge and the learning process

Knowledge should be seen as co-creation, or the development of a personal relationship with the object of an interaction, the so-called object of knowledge. From this point of view, learning means creating or modifying one's personal relationship to this object of knowledge. The Delta Design game, like any collaborative design situation, requires all those involved to explain their personal relationship to, for example, the constraints specific to their job, and to modify them according to the common objective of designing a house and the constraints of the other players. This leads to what Hatchuel calls a cross-learning process [14].

It is suggested then some indicators form a reflexive analysis about knowledge acquired through group activity (see Table 2).

It would moreover be interesting to analyse how, for a given player, the obligation to explain his/her own knowledge, to teach it to the other people involved, may have changed his/her personal relationship with the objects used during discussions and, therefore, with the learning process.

This learning process, which must therefore be individual, results nevertheless in knowledge that we can qualify as being shared. Indeed, the different personal relationships created during activities are going to take on a common dimension. Analysis (see Table 2) can therefore focus on this common dimension, its advantages that concern, in particular, an increase in group work efficiency through the re-use of shared knowledge, its limits, and the degree of validity of the shared knowledge (which may be very local and contextual).

This question of validity also leads us to examine the nature of the knowledge: can it be described as generic, local or in-action knowledge [15]? Can in-action knowledge, which is often informal or too costly to formalise, result in the development of formal, local or generic knowledge that could help people to understand why action is successful and therefore to perform it again? Conversely, how has generic or local knowledge been transformed or converted into rules for action? What are the advantages (reactivity) and limits (conceptualisation) to these transformations?

The arguments developed to build, improve and assess during the group working times differ from those used in the individual working times: people working in the same field share scientific models and rules-for-action; for collective working times rules-for-action and a shared working space (knowledge, values, etc.) have to be first of all set up.

Furthermore, with the structure of the houses not being continuous, each specialist has to take into account the specific characteristics of each element in the construction in order to validate his/her constraints before looking at the structure as a whole. With the laws of each specialist being based on local data, evaluating the house means making a detailed and precise observation of the structure. These laws may lead to long and fastidious calculations. This is particularly true for jobs where analysis is required (structural and thermal engineer and, to a lesser extent, the project manager), leading the actors in these fields to translate the specific laws into qualitative rules (we call them rules-for-action) that can be quickly implemented and shared by all the actors during the collaborative working times.

For the quantitative evaluation, some actors (structural and thermal engineers) need stable configurations on which to base long calculations while others (architect, project manager) assess things quickly and tend to make rapid changes to the structure.

These different working methods, based on two different timings, lead to two types of situation, which can moreover be put together:

- the participants are unable to translate their laws into rules-for-action: they are therefore not reactive and their constraints are not taken into account during collaborative working times;
- these same specialists are unable to impose long enough stability times on the group to be able to perform the necessary calculations.

The consequences are that the specialist actors are excluded from the core of the group dynamics: their specialist constraints are not taken into account and they learn less from the others. It is thus no longer possible during the action to build up knowledge and inter-specialist rules based on cross-specifications that reduce the other specialist actors' scope for action or dominance.

CONCLUSIONS

Today, designing a product is a collaborative effort. Design teams, gathering actors involved in the whole product life cycle, must integrate various kinds of knowledge and constraints which are often heterogeneous and most of the time contradictory. Design teams evolve dependant both on the type of product and the design stage. Design activities include individual and collective working times like face-to-face meeting. Designers have to co-operate and to co-ordinate their activities. This co-ordination can't be fully defined beforehand, and can only partially be included in procedures because it depends on technical, human, social and economical context. During face-to-face meetings designers build new knowledge, i.e. develop new relationships with the object they collectively interact with—about the product, but also about the design process and other domains. The formulation of the problem and its evolution, its decision-making process and its social aspects are also influences. In this paper we have proposed a training situation that helps students to develop skills that will enable them to adopt an efficient behaviour in collaborative situations. This training situation concerns graduate students and is complementary to project-based teaching situations. We propose the use of a game, the Delta Design game, to train the students for developing reflective practices. A framework for analysing design practices has been developed to serve as a means for learning about one's own practice.

After having formalised our analysis framework we aim now to more finely develop observations on the actual implementation of this framework. A future work will be to set up a more structured protocol in order to record quantitative data on the use of the Delta game. It might be interesting the have more quantitative evidence on the creation of shared knowledge or on the actual design process.

Besides, one of the limits of this game stems in the very odd design context. The Delta planet is not realistic enough for allowing to fully build connections with real design situations, especially referring to technical domains. This is why in the next stage (see Fig. 1) we propose during the course to play another game, more realistic in terms of product and roles and more open to the creation of specific intermediary objects (mainly sketches).

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