Expert user-centred design, a cooperative product development approach

Rahi Rasoulifar, Guillaume Thomann, François Villeneuve

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Rasoulifar R.
G-SCOPLaboratory,University of Grenoble,46, av Félix Viallet – 38031 Grenoble Cedex, France

Thomann G.
G-SCOPLaboratory,University of Grenoble,46, av Félix Viallet – 38031 Grenoble Cedex, France

Villeneuve F.
G-SCOPLaboratory,University of Grenoble,46, av Félix Viallet – 38031 Grenoble Cedex, France

Abstract
User integration into the design process has brought challenges to the design theories and practices. Numerous design methods exist concerning the user integration, like the user-centred design (UCD), but no special attention paid the user expertise. Nevertheless, in design of user dependent product such as surgical and aviation navigation, the user plays an active role in the design progression. An aim of our study was to understand if the new contribution of the user can affect the design process, and needs more consideration. The design process of a surgical instrument was investigated, in which the surgeon took the role of expert user. A case in minimally invasive spine surgery has been studied and the results showed a strong contribution of expert user. Finally, a new model for expert user-centred design has been proposed.

Keywords: *User-Centred Design (UCD), collaborative design, scenario, user integration*

1 Introduction

Since the industrial competition started in nineteenth century, designers realized the importance of users' choice decision and tried to understand it and to apply it into the design process. Nowadays, new multitask highly user dependent systems like aviation and surgery, necessitate a new consideration of the user and the user needs.

How to involve and to integrate the user in the design process has been studied under the title of collaborative design, human-centred design and usability engineering ([1] [2] [3] [4] [5]). The ISO 13407 formalized the theories about user involvement called User-Centred Design (UCD) as a standard [6]. Jokela modelized the intercommunication of the user with the usability in cycling process of UCD [7].

Until now, most of design studies concerning user needs have been based on novices or, at best, accessible users of relatively modest talents [8]. The reason is somehow obvious: it is easier to obtain such people as subjects of study and they seem to provide enough data. If studies of user integration are limited to studies of rather inexpert users, then it is obvious that the contribution of user to the design process will be limited.

This subject brings out both industrial and research aspects. In the industry, designers commonly put themselves in the place of users, seeking to understand what they may need. Nevertheless, new high-tech and special featured products reveal that the role of professional users and the importance of their integration in the design process are no longer negligible.

In the design research, the concept of user integration is different from considering user's needs and requirements by existing methods. In some instances, it is necessary to study outstanding, or exceptionally good users, to develop a professional product. In this research we have chosen the surgeon as an expert user in the design process of innovative surgical instrument, in order to gain an insight of the cognitive interaction and the nature of expertise in the design process.

The aim of this paper was to discuss the existing user supportive models, and to propose new aspect of collaborative design, and to make it appropriate for integrating an expert user into the design process. To follow this claim, the article starts with a detailed review on existing researches of user integration in the product development process, known generally as User-Centred Design (UCD). Section three describes our methodology of our research. Section four is about the case of application, and results. Section five addresses main findings in form of a new model for expert user integration.

2 Literature review

In engineering design, the nature of the design process is identified as the collaboration of a group of actors using interaction tools to solve a problem, or, to shift from a problematic situation, in which the needs are unsatisfied, to an objective situation in which they are ([9] [10] [11] [12] [13]). Thus, design activities are distributed in particular among the different actors involved in the product life-cycle, and the integration of those actors from the earliest stages of design is explicitly intended [14]. It is critical to the success of a company to understand and to meet the requirements of their customers and end users, in the product design. Nevertheless, there is no appropriate design tool realizing a complete coherence between user needs, professional needs and design solutions [15].

Far from (mechanical) engineering design domain, amazingly the idea of user involvement in the design process was initiated by the studies in human-computer interactions, and widely accepted as a principle in the development of usable and useful products and systems[16] [17]. User-Centred Design (UCD) was introduced in the format of the standard ISO 13407: Human-Centred Design Processes for Interactive Systems, and several methods for capturing user requirements during the early design stage were proposed [6] [7] [18]. Figure 1 shows the UCD process model proposed by the standard.

So far, the user was not really a part of the team, but is spoken for the designer by the intermediates. By

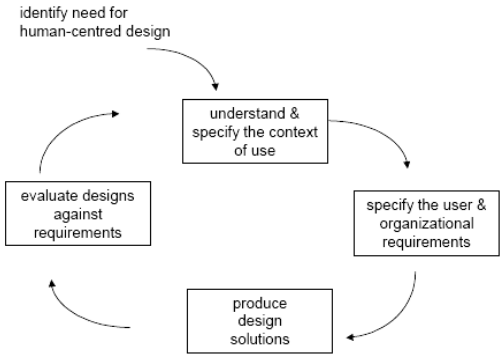

Figure 1: Processes for user-centred design in ISO 13407

the end of 1999, many participatory experiences showed that the roles of the designer and the researcher blur and the user becomes a critical component of the process. It was a shift in attitude from designing for users to one of designing with users [19]. This new concept is called differently such as user-design, post design and participatory design [20]. Clement et. *al* outlined three basic requirements for participation: 1) Access to relevant information, 2) The possibility for taking an independent position on the problems, and 3) Participation in decision making [21].

Design processes that involve user participation have evolved among several design uses and professionals, in both product and software engineering ([1] [2] [3] [4] [5] [22] [23]). The new rules call for new tools. Users want to express themselves, and to participate directly and proactively in the design development process [19].

Thus, participatory methods had some efforts from product developers to adapt and extend elements of the participatory design approach. Some of these issues are mentioned as low-fidelity mock-ups and prototyping, increased engagement and communication with potential users, and an emphasis on site visits and understanding the work context [24].

However, the problem in many participatory design projects is that user participation is commonly based on, for example, description of current work practices

and testing or evaluating of existing products, but users' design-related ideas and decisions are left out [25]. Iterative and adaptive processes in creativity are in conflict with typical design development methods [26]. The absence of a common vocabulary can limit the dialogue between designer and user [18]. Moreover, most of design studies concerning user needs have been based on novices or, at best, accessible users of relatively modest talents. The reason is somehow obvious: it is easier to obtain such people as subjects of study and they seem to provide enough data.

Hence, such a discussion implies that the integration of "special user" in the design process can not be covered by actual propositions and methods. Researchers reviewed some experiences of using 'lead user' method [27]. Others studied the lead users in co-creative activities [28]. Colleagues proposed (each) user is a part of the design team as 'expert of their experiences' [29]. The concepts of experts and expertise are debated within the field of epistemology under the general heading of expert knowledge. In contrast, the opposite of a specialist would be a generalist, somebody with expertise in many fields. The word experience means direct observation of or participation in events as a basis of knowledge and the fact or state of having been affected by or gained knowledge through direct observation or participation (Merriam-Webster). Expert is the person who supposed to have the experience.

When designers design for a use situation, they usually put themselves in the role of the user [30]. A designer or an engineer can hardly be representative for the user, and this role is almost invalid in case of expert users with professional knowledge. It is also necessary to give more attention in user cognitive ability as the key element in information processing. According to the studies of user background effect on the evaluation of a medical prototype interface, when more ergonomic factors are included in defining the user background, more design flaws might be detectable and a wide range of error detection could be achieved [31].

If studies of user integration are limited to studies of rather inexpert users, then it is obvious that the contribution of user to the design process will be limited. By studying the design process in which the expert user is integrated, the new insight of collaboration would be acquired and better models and tools could be created to help the designers.

In this study, the surgeon role is considered as the expert user, in the design of a new surgical instrument. A design experimentation is investigated to understand the contribution of the expert user on the collaborative design process. Our methodology of the collaborative design and the user integration is explained in the following session.

3 Research methodology

For this research, we decided to use the existing UCD models (ISO 13407 and ISO 18529) to guide the project. In the UCD model, each process is defined with a purpose statement and a set of base practice. Although the UCD processes are more descriptive than "what to do", they provide a good basic structure for the design development. Moreover, user is not considered as a design collaborator, which seems inappropriate for our research context. Collaborative design implies the collaboration of distinct individuals with different areas of expertise or knowledge to work towards the accomplishment of common goals, simultaneously or chronologically, and co-locationally or remotely [32]. Accepting this insight of collaboration, we have considered the expert user as a collaborator in the whole or some main steps of the design process.

As a design approach, we chose a coevolutive approach for describing the development process [33]. In this thought, new instrument development and new application maturation coevolve. In other words, the design artefact is not only the instrument but a couple, consisting of a physical product and an operational procedure. Figure 2 shows a schematic view of this approach.

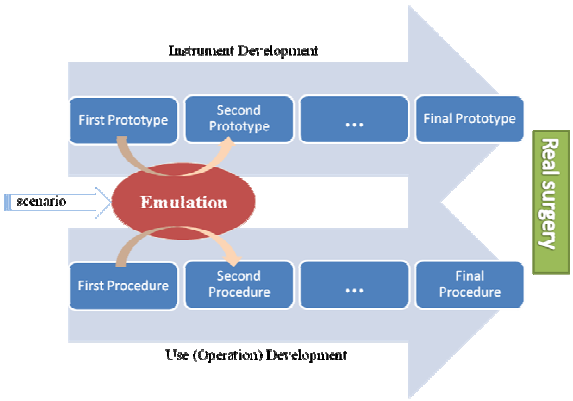

Figure 2: Coevolution of the Prototype and Procedure in the design process of new surgical instruments

The concept of ascertaining of fixing the value or worth of under design artifact with the user is essential to design process, and discussed in almost all design models in different titles like evaluate designs against requirements and usability evaluation [34]. The emulation introduced by the authors as a step in which the evaluation of designed instrument and designed usage takes place [33]. Emulation helps the designer to understand what the expert user think and know about the prototype. This understanding gives the designer the ability to emphasis with him. Moreover, the emulation is a practical environment for the expert user to make the designer understand what he desires, by saying, doing, and making objects, even simultaneously.

Our research project called Destin (DEsign for Surgical-Technological Innovation) has started with an actual problem in open surgery, and new ideas of a surgeon, explained in the next section. The project has been set up by the agreement between the Grenoble University and the Hospital of Grenoble, in order to provide a team in which technical designers and expert users (surgeons) could collaborate. Laboratory of Informatics of Grenoble (LIG) offered tools and facilities for observation of participatory design. The design process of an innovative surgical instrument was investigated, and the project was directed by researchers of Grenoble University.

The project followed the main idea of UCD, in these steps (see Figure 1): 1) Understand and specify the usage, 2) Specify the user requirements 3) Product design solutions 4) Evaluate designs against requirements. However, during the project we experienced some necessary changes, according to the collaborative notion, and the expert user integration. What we faced and what can be proposed as a modified model are explained in detail in the following sections.

The importance of surgeon observation for understand the real needs of surgeon is reported [35]. A data collection format has been prepared in order to bring together all the possible information from observation in the operating bloc. There are four steps of data collecting: First, before the operation: asking the surgeon to explain successive objectives of the operation. Second: during the operation with the prototype, we asked him to describe what he does and his complement about the prototype. Both of his act and voice were recorded with two different cameras, one established on his head for recording what he is watching. Third: just after the operation, we asked him to summarize his operation and point-out advantages and disadvantages. The forth step: some days after, he watched the film of operation and rexplained what he did. This precision was necessary particularly for the beginning in order to clear understanding of the usage.

Conform to the explained methodology, the project has started in 2006. The experimentations took place at Orthopedic service of Grenoble Hospital. The details of the experiment are explained in the next section.

4 Application case

In the design of medical appliance, health care and robo-surgical device, particularly for new operations, there is a communication and co-operation between designer and customer (often end user), and there has been an increased interest in participatory design and in designing aided by scenario. The interest in participatory design can be seen as both an effort to develop a new technical solution for a conventional use (e.g. new mechanically developed instrument for a common surgery), as well as an innovative idea of user for improve the use which need some new tools (e.g. a surgeon who proposes a new operation). As such, this represents an important development in many ways and by introducing new aspect of user integration, it can support affording a rich design process.

To better understand the present discourse it is often useful to consider its background. This story begins with the innovative idea of a surgeon for amelioration of an open surgery to turn it to a Minimally Invasive Surgery (MIS) operation. MIS is a new kind of surgery in which the operation perform trough a small incision and surgeon avoids cutting the muscles, even rarely separates them. So the patient has less pain, less bleeding and will recover quicker. In comparison to the usual, open surgery, MIS operations are better for the patient, but harder for the surgeon and they need some special instruments.

In Spine surgery, MIS is a very challenging subject. More and more patients come to the surgeon's office hoping to have an "easier" surgery. Scar size, muscle dilation versus stripping, and recovery time are the three main factors that separate a traditional surgery from a minimally invasive one. In the specific surgical application studied here (spine surgery), 50% of serious sport accidents (falls of motorbike,

ski, parapet, etc.) results in lumbar fracture of the L1 vertebra. To ensure position and rigid alignment where the fracture took place, surgeons apply spinal instruments, or implants, such as screws and rods to the spine. These implants are joined together to maintain spinal stability and are rarely removed. Spinal fusion and implants are used to restore stability to the spine, correct deformity and bridge spaces created by the removal of damaged spinal elements such as discs.

4.1 *Description of the operation*

Currently, the "classical" lumbar arthrodesis operation (place screws and implants in three consecutive vertebras) is performed using tools introduced into the patient's back through a large incision of about 12-15 cm. The surgical procedure is shown in (Table 1, A). This operation is an invasive surgical operation consisting of repairing the fractured vertebra, while having the muscle stripped beforehand and repositioning the adjacent vertebrae to their original positions. Large bands of back muscles are stripped free from the spine and pulled off (retracted) to each side for visualization of the spine and easy access to the bones for instrument implantation. This stripping and retraction can cause considerable back pain, and the muscles, to some degree, are permanently scarred and damaged. The postoperative consequences are very handicapping. To transform this operation from open to MIS, the incisions should be minimized. The general idea is to implant the screws by tubular retractor (small incision) and to deliver the rods percutaneously. Therefore, a mechanical instrument and system is needed to insert the rod through the skin and muscle into the heads of the implanted screws. This system must be compatible with the screw implanting procedure, so modifying the screwing system is also required in this conceptual design. The new procedure is shown in (Table 1, B).

Table 1: Actual procedure of open surgery and proposed procedure to switch to MIS

A) procedure of open surgery (actual)	B) Procedure of minimally invasive surgery (proposition)
Identifying fractured vertebra	Identifying fractured vertebra
Incision (12-15 cm) • Muscle striping • Position the retractor	
Positioning screws (3 pairs of screws in 3 vertebras)	Positioning screws (3 pairs of screws in 3 vertebras) • Incision (1-2 cm) • Insertion tubular retractor • Position screws
Inserting (putting) and fixing rod (2 times) • Vertical placing of rod • Fix the rod in screws head (with bolt)	Inserting and fixing rod (2 times) • Incision (0.5 cm) • Insertion rod by rod holder • Fix the rod in screws head (with bolt) • Release the rod holder • Release tubular retractors
Suturing (12-15 cm)	Suturing (8 small sites)

The idea is to avoid the grand incision by passing rods through a needlepoint incision and manipulate it to enter three tulips (screw's head) on a straight line. The difficulty rises on the fact that without the large incision, there is no visibility inside during this new established operative procedure. The precise placement of the holes (located compared to the vertebrae) depends of the knowledge and the experience of the surgeon. The delicate insertion of the screws through the skin, muscles and grease, without damages caused to the patient, requires the design of complementary surgical tools.

4.2 *Surgeon and the design process*

The design progression produced a rich, varied but complex set of data which was somehow relevant to our methodology and did lighten new insights about the user integration. As mentioned before, the idea of the transformation of the actual surgery to a MIS form became from the surgeon. To understand the problem details and the requirements, designers went to observe an open surgery. After some observation, discussion on the usage specification and agreement on requirements, the conceptual design started. Design in this step was iterative. An idea of solution has been realized in a prototype and has been tested on a phantom (mannequin) following a procedure. The design artifact (prototype and procedure) evaluation happens in the emulation. Once the result is satisfying, it exits the loop and considered pertinence enough to start the detail design. Detail design is also a parallel task, the designer and the surgeon work together to finalize each the details of the prototype and the procedure. In order to start the clinical evaluation, the prototype should be functional and should be realized under certain standards. Then, the clinical evaluation will start and

will take between some months to a couple of years to reach the clinical validation.

The surgeon's role was not limited to the preliminary ideas for design solution, but extended to help on scenario preparation, prototype evaluation, further elaboration on the new problem-solution discussion, help in detail design concerning the usage (operation) constrains, and finally preparing standard protocol for clinical evaluation. Contribution of the surgeons to the design progression can be classified to requirement specification, preparing prototype-protocol, emulation and observation.

Requirement specification

After understanding the context, the second phase of the design process, understanding the specified requirements needed more or less an intense knowledge exchange between the surgeon and the designer. Our study showed the surgeon had an active role in problem definition and even in proposing new concepts. The translation of clinical problems into the design specification could be happened only in the close cooperation of designers and surgeons.

However, according to the observation, it was not quiet easy for the surgeon to explain the exact usage. Although the idea was simple, the minimally invasive nature of the operation made it difficult to imagine what would exactly happen during the new operation. The lack of a communicative tool could be considered. Thus, he made the effort to explain the usage requirements, by using a phantom. We used the scenario as a tool to describe the usage and the usage situation. In the scenario we explained the new operation in detailed tasks, the interaction of under design artefact with other instruments, and the usage situation constrain like the x-ray imaging. Obviously this part of scenario is written under the surgeon's guide.

Preparing prototype-protocol

The first scenario was prepared based on the surgeon description of new surgical operation. In this phase a new instrument should be designed for the new surgical protocol. Thus, the technical solution proposition should be in face with the expected protocol by the surgeon. In order to prepare this collaborative design, we organised the design session in which the surgeon and the designer could work together. The designer used the CAD model to show his proposition. The project showed that surgeons can implicate themselves as much as possible in the concept design, and provide practical idea for the instrument, concerning the usage. By the way, they had the maximum knowledge about the real usage constrains and situation.

Once the concept of prototype-protocol achieved the first agreement, the realisation starts. We outsourced the fabrication to a trade company, in order to have a professional prototype. At the same time, we prepared the operation protocol in the standard way. In fact, the first evaluation could be on a phantom or a cadaver, but the reliable validation should be on the patient, which necessities the certificated prototype and authorized protocol.

Emulation

As mentioned, the evaluation of solution could not be reliable by evaluating the concept. In the emulation the surgeon manipulate the prototype on a phantom in the operating room. The surgeon verified functions and usability of the prototype doing the operational tasks. Mechanical forces, movements, ergonomic factor and so on were discussed with him during the emulation stage. The surgical gesture is a good example of professional knowledge of the surgeon. Moreover, the prototype should have been checked not to have any incompatibilities with the other operation tools. In the case of some mismatching, like we happened in this experience, proposing new alternatives dependent on surgeon's knowledge and opinion.

In all of emulations, the surgeon was asked to describe what he does and some how to explain why. More over, he was asked to criticize the prototype and to give his solution propositions for problems. The fact of recording the operation helped us to review the verbalization many times in order to understand what exactly he meant. Beside of strange technical words and expression, many obvious points in surgeon's comment were explored to find the reason. Better understanding of surgeons actions and desires cause to clear need list, and to make more preferment of the design.

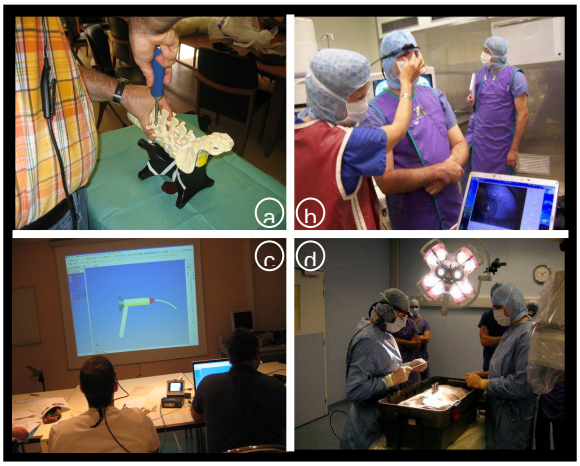

Figure 3 – a) Demonstration of new procedure on phantom, b) Observation in the OR, Eye-tracker set up, c) Surgeon and engineer working on the detail design, using a CAD model, d) Emulation in the OR, using the prototype on cadaver

Observation

Despite of theoretical discussion and practical problems of user observation, it is essential to collect a rich set of information during the collaboration [36]. In this project, the observation was participative. The surgeon was asked to explain what he does during the manipulation. Nevertheless, it was very important and difficult to observe what the surgeon does during the operation. Because of his unique situation just beside the patient, we can not exactly see his hands' movements. The operation is MIS and he guides himself by taking radio images. These images are hard to recognize for a non expert, and are too rapid to follow. Moreover, the danger of radiation forces everyone to step aside from the operation site. After two emulations, we established the best combination: a general camera that records the whole scene and a frontal camera placed on surgeons head for more focused view on operation location and on x-ray machine. The final set-up consist of two high quality digital cameras focused on the operation site, a frontal camera to track what the surgeon looks at, an eye-tracker to have the maximum information on the coordination among the operation site, the instrument box and the x-ray images. We also captured the x-ray images during the operation. An integrated sound recorder was used to capture the surgeon's description and the dialogue between him and the designer.

From this experience we figured out that surgeons are more familiar and comfort with the observation than what we expected from the literatures. The complexity and high pressure activities in the operation room necessitate a well defined, non disturbing observation set-up. For example we used the hard disk integrated cameras, because it is not possible to have the wire around the operation table. The eye tracker was in form a pair of glasses, easy to wear and easy to remove in case it was disturbing. Table 2 shows the successive emulations and the improvement in the instrument prototype, operating procedure and emulation situation and observation set-up.

Table 2: Evolution during development of the design; some examples of critters

	1st emulation	2nd emulation	3rd emulation	4th emulation
Procedure	Task : rod insertion Rod insertion bottom-up Pre-cut rod type1	two screws + rod insertion Rod insertion bottom-up Pre-cut rod type 2	six screws + rod charge-insertion-release Rod insertion top-down General rod	Three screws + rod charge-insertion-release Rod insertion top-down General rod
Situation	Simple spine model	Spine model + filler + simple cover	Spine model + better filler + better cover	Cadaver
Observation	General camera (G)	G + Frontal	G + Eye tracker	G + Eye tracker

Due to this observation, we found out that the new contributions of the expert user could influence the design organisation. A modified UCD model would be useful to demonstrate the general approach of the design organisation, to provide design steps and processes. In the next section, our proposition for such a modified model is explained.

5 New process model for expert user-centered design

Through such experience, knowledge of design is interchange between designer and expert user. Designer is the responsible for the progression, and will need a process model to manage the design activities and outcomes of design. Here the nature of the design is user integrated, participative, and collaborative in some steps. After the experiments described above, we will have a UCD process model, accompanied with the support tools. In the following we give the practical definition of each of the process. The model is shown in Figure 4.

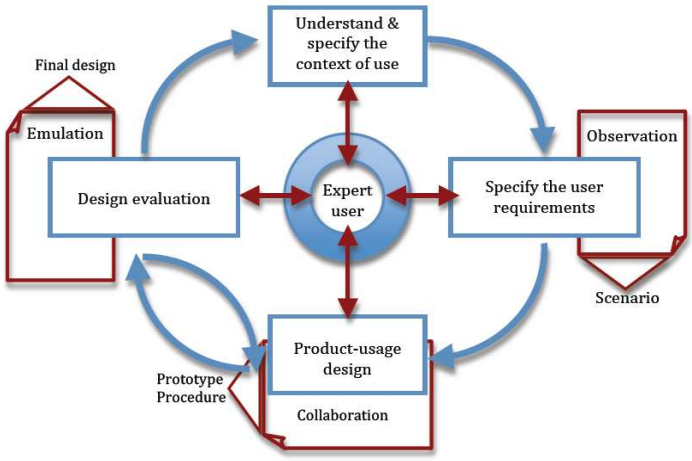

Figure 4: Expert user-centred design model

Specify the user requirements

The purpose of this process is to define the usage and the usage environment. Usage is defined in form of task description, how the user should use the design artefact to achieve the goals determined from the previous step. This design phase is where the usage of user is defined. The scenario of use is created here to make the proper relation between user and the design artefact. Scenario not only explains the usage procedure, but also provides the adequate information about the usage situation and environment.

This design phase realized generally by the discussion between designer and user, but in specific context it needs using the intermediates of explanation, like a simulator (physical or virtual). For instance, in case of surgical instruments design, a phantom is always needed in order to clarify the discussion between user and designer.

The outcome of this process is a written report, scenario, which explains the usage, the environment, and the interaction of the design artefact with other instrument.

Product-usage design

The purpose of this process is to produce the couple design artefact; product and usage. Here, usage is basically the scenario from the previous process, but the modification and details concerning the product proposition should be added. These details include user interface, user documentation, user support, and user training.

This process is the main design activity of the team, while the other processes are more preparation and support. Although many knowledge exchange took place in other processes, in parallel development of product-usage the engineering and technical solutions confront the usage constrains.

The organisation of this process includes the collaborative session, the separate solution development in technical and usage aspects, and the prototype development.

Supportive tools are needed to facilitate the collaboration, like CAD software, element of usage situation, etc. The outcome of this process is the prototype of the solution, and the usage procedure which should be produced in parallel. This step and the next step are iterative. The designed artefact would be evaluated and the result would come back for necessary modifications.

Design evaluation

The main purpose of this process is to evaluate the designed product-usage in a real situation. This process addresses on evaluation of usability by the performance of the expert user. The term emulation here is to put emphasis on the physical real element of the situation.

The emulation needs a set up. Usually recording the emulation is very useful, in order to remind the discussion, critics, new solution and what so ever happened during the session. The outcomes of this process are the evaluation results, in form of notes, documents and mainly the recordings.

As the figure 4 shows the results of evaluation would return the design activities to the previous process to redesign or modify the solutions. This model makes clear the integration challenge of expert user integration. Product design needs the usage design, which is not the entry of the procedure. The challenge of design specialist in this case is to provide an organisation to understand, clarify and evaluate the usage of expert user parallel to the product design progression. As widely recognised, this is a true challenge in many cases. One should understand that the model has been created from one experience, conceptually tested by similar cases, and is still object to refinements.

6 Conclusions

The user integration in the design process has been introduced to the design studies by different approaches. The user-centred design models and methodologies led us to infer that design activities should understand the user's needs and evaluate the design solutions against user requirements. This study, however, proposes a more essential and collaborative role for a group of users, called expert users. The investigation of surgeons as a role model of an expert showed that the presence and integration of these users in the design progression is not inconsiderable. The proposed model is fundamental to the development of such a design practice.

The proposed model is based on the multi actor participation process, which presents a basic design process in user integration. In this way, one possible conclusion is the need of a new methodology which can help the designers to pursue the expert user needs

and their usage specifications. The concept of main design phases like evaluation as we suggest, may need some additional supports for emulation and observation in order to provide the better reliability of the evaluation.

Many studies showed the expert's point of view is very limited and banded in his carrier ([37] [38] [39]). Our study would suggest that this notice is not completely valid in problem-solving situation. During the collaboration expert user showed interests to modify the usage tasks vis-a-vis the design solutions.

This study has taken a step in the direction of proposing a design model for expert user integration in design process, by studying a particular user group. It is possible of course that all expert users do not behave like surgeons. In addition, this study investigated only one design progression. It is important to emphasize that experimental problems in the research design limit our interpretation.

The approach outlined in this study should be enriched with practical tools and procedures for the designers and users, as well as the project leader. It would be beneficial to replicate the proposed model on larger number of project, and from different subject of design. Moreover, presence of social scientists/researchers would serve to have a better collaborative activity analysis. In our near perspective, we will start such a design organisation to investigate the expert user integration in different design cases.

Finally, the most important limit of the proposed model is its design coming from a unique experiment of a new surgical instrument design. However, research methodology used (literature review, case study, observation and analysis of each meeting and emulation between actors) allows authors to validate complementary tools to the existing UCD model.

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