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Proposal of a Conceptual Framework for Collaborative Design of Immersive Professional Training: Application to the Textile Industry

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Abstract

Immersive technologies have an increasing use in professional training. However, the usability of applications has limits due to a lack of consideration of end users in the design of these new supports. This paper reviews the literature and discovers that few approaches offer to include different collaborators' work, or the end user, in the design process. This study proposes a conceptual framework design for immersive professional training (IPT) and its application in the textile industry.

Keywords: collaborative design, virtual reality (VR), user-centred design, professional training

1. Introduction

In the context of industry 4.0, new production technologies use constantly evolving industrial resources and processes. Faced with such development, manufacturers must think about the most up to date physical—and virtual—training methods that will allow their employees to improve their skills and adapt to new modes of production.

To reach this objective, some companies choose to take advantage of Immersive Technology (IT), including Virtual Reality (VR), Augmented Reality (AR), or other Mixed Reality (MR) technologies. In the field of training and ergonomics, it has been accepted for many years that IT offers real benefits (Arnaldi et al., 2018; Burkhardt et al., 2003). Despite the maturity of this technology and its visible industrial applications (Gartner, 2018), there are still obstacles to its full integration in the industrial field, particularly in general and professional training (PT).

The most prominent IT application hindrance is the lack of usability, utility, and good user experience (UX) (Akçayır and Akçayır, 2017; Arnaldi et al., 2018; Burkhardt et al., 2003; Pettey, 2018). UX covers all aspects of how people use an interactive product—the way it feels in their hands, how well they understand how it works, how they feel about it while they're using it, how well it serves their purposes and how well it fits into the entire context in which they are using it (Alben, 1996).

Different stakeholders and experts from different disciplines contribute during the design process of IPT: the VR/AR designer as an expert in 3D application design and immersive technologies, ergonomist as an expert in understanding the work and activity with the aim to make compatible product design with the needs and limitations of human beings, and the didactician as an expert in learning methods to improve the pedagogy and learning performance of learners. They participate in the integration of users during the design process which represents all the activities carried out in IPT design. However, these stakeholders often do not collaborate sufficiently with their work, and their methods tend to be too compartmentalized (Richir et al., 2015).

In addition, when transferring to companies the knowledge acquired through academic research, laboratories are often limited by their lack of knowledge of industrial scale integration processes (Richir et al., 2015). Manufacturers need to take a multidisciplinary approach, 'unifying' the methods of various disciplines concerned, while ensuring an application protocol in an industrial environment.
The aim of this paper is therefore to offer an initial conceptual framework that would enable improved collaboration between different stakeholders in the IPT design process. We hypothesize that better integration and collaboration of VR/AR designers, ergonomists, and didacticians during the design process could provide an immersive training system that is better tailored to the industrial requirements and needs of future users. We will first present a state of the art on collaborative and user-centred IPT design. In the second part, we expose our conceptual framework, and finally we discuss the application of this model in the broad context of the textile industry, and specifically at Stäubli.

2. Collaborative and user-centred IPT design

2.1. Collaborative design

The complexity, the breadth of knowledge required, and the diversity of tasks in the immersive training design process are evident (Cross, 2008). As a result, the design process requires collaboration between different stakeholders focused on different areas. The design of a training system involving IT is perfectly suited to this requirement because it involves many areas (ergonomics, IT, didactics, UX design, etc.).
Collaborative design can be defined as the process of designing a product through collaboration among multidisciplinary product developers associated with the entire product lifecycle (Shen et al., 2008). However, in their analysis of the nature of collaborative design, (Gero and Mc Neill, 1998) indicate that collaboration in the design process is episodic and cyclical. This is because the nature of design activities alternates between collaborative and cooperative phase. Cooperation is defined as a collective organization of work in which the task to be accomplished is fragmented into sub-tasks, each of these sub-tasks is then assigned to an stakeholder, either according to a perfectly horizontal skill allocation logic in which tasks and stakeholders are equivalent, or according to a logic of attribution based on the particular skills of each one (Boutigny, 2004). Collaboration means a collective work situation in which tasks and goals are common. All the actors work on the same points (Zaïbet, 2006).
The design, which takes into account the notions of cooperation and collaboration, must be improved because it is not sufficient for IPT design. There are issues related to the lack of usability of applications and this involves taking users into account.

2.2. Lack of user considerations during IPT design

Faced with UX problems that affect virtual environments (hardware and software) (Burkhardt et al., 2003), it is often reported that there is a lack of user-centred design (UCD) approaches (Frejus et al., 1997) or a lack usage of existing procedures. UCD is a fundamental tenet of UX (Lallemand et al., 2018). It consists in integrating users early into the design process in order to design both for them and with them (International Organization for Standardization, 2019, 1999, p. 13407; Norman and Draper, 1986). Moreover, works suggesting the use of UCD in virtual reality do not necessarily involve end-users but rather random subjects unrepresentative of real end-users (Ganier et al., 2013; Loup-Escande, Jamet, Ragot, Erhel, Michinov, et al., 2015). Finally, in our experience, instructors often have difficulty explaining their needs to application developers. This may be related to a lack of experience with IT in both parties, or a poor understanding of roles between instructors and developers. Taking into account a user-centred collaborative methodology would overcome this problem of understanding. The fact that end-user consideration is lacking doesn't mean it is inexistant. The existing proposals have limits that we will present in the next paragraph.

2.3. Limits of current approaches

Various literature show that the existing methods for developing IPT have improved in past years. These methodologies have emphasized the participation of different stakeholders to make the design

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process of training more effective. Furthermore, UCD has proposed as additional step in training development by the use of the ergonomist's tools to better consider the user's need.

Fuchs et al (2006) proposed the 3I2 methodology which is quite generic (Bennes et al., 2011) and not directly adapted to the context of IPT. In addition, it gives little information regarding collaboration or cooperation between stakeholders involved in the design process of training .

Richir and Fuchs (Richir et al., 2015; Richir and Fuchs, 2006), in a series of studies, suggested the I2I method to tackle the problem of the interdisciplinarity design of training in VR systems. It emphasizes the integration of ergonomists into design process through different stages. In addition, it suggests the integration of methodological tools of industrial engineering, such as functional specifications and the TRIZ method, in order to carry out 'knowledge transfers' between the different disciplines. Although this method provides a backbone for the design of training in VR systems, it cannot be qualified as a 'user-centred' method (Bennes et al., 2011). In addition, the method does not explain the details of the coordination with the different stakeholders involved in the design process.

Loup-Escande et al., (2011) have further developed the I2I method by integrating users and providing the notion of 'utility'. It turns out that despite the demonstration of its application to an actual industrial case, the addition of seven steps of definition and prioritization of needs, upstream of the eleven steps proposed by Richir and Fuchs in I2I leads to a certain heaviness and a strong sequential aspect.

Lourdeaux et al., (2002), dealing with the design of a virtual environment (VE) for training, states that each step must be carried out in collaboration with different experts: experts in the field (the professional activity to be reproduced in the VE), human and social science experts (ergonomists, psychologists, cognitivists, etc.), and technical experts (VE designers). This method seems to highlight a 'concurrency' which approaches the characteristics of collaborative design and the user-centred character. However, this approach is not yet user-centred enough and remains a design method FOR users—and not WITH. It is for example limited in the collection of expertise during the phase of specifications of educational objectives (EO). In the proposed steps, no tools are given to the users to involve them in the design process. In addition, this methodology is still quite limited with the notion of coordination of the different professions that must take part in the process of designing training using IT. It does not provide information on the role of each profession involved in such a project.

The work of Loup-Escande (Loup-Escande, Dominjon, et al., 2013; Loup-Escande, Jamet, Ragot, Erhel and Michinov, 2015; Loup-Escande, Jamet, Ragot, Erhel, Michinov, et al., 2015) on the VirtualiTeach Project shows that it is possible to apply a user-centred approach in this educational context. However, authors also highlight limitations such as the implementation time which is increased by the successive 'design-evaluation' iterations necessary for these new emerging technologies. This increases the cost of such projects. In addition, the authors take precautions regarding the establishment of a favourable climate of communication between designers and end-users. They also take precautions concerning the articulation to be found in the design and in the involvement of users.

Boccara and Delgoulet (Boccara and Delgoulet, 2015; Delgoulet et al., 2015;Boccara, 2018) in a series of studies proposed to position the methods of ergonomics and didactics at the same 'crossroads' level. The aim here is to identify relevant reference situations [1](Samurçay and Rogalski, 1998) in the anticipation of probable future situations in order to guide the design process (Boccara and Delgoulet, 2015). These reference situations therefore work in production and work in training. They can help to guide the design choices of a training VE demonstrator. The approach proposed here is very interesting because it provides the ergonomist with reference frames of situation (Boccara and Delgoulet, 2015). However, the method stops at a first definition of scenarios and does not show how these scenarios can be co-constructed with all these actors (ergonomist, didactician, instructors, learner), or even the involvement of these stakeholders in the design stages which follow the definition of the scenarios.

[1] The reference situations refer to the most critical scenario in terms of required skills, or difficulty in performing the activity, or even the most challenging ergonomic risk factors such as an awkward posture at a workstation.

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These methodologies are limited by the fact that they keep a high sequential character and that few works clearly specify the modalities and the stage of collaboration and collective work in the design phase of the training development.
One improvement that could be made to existing methodologies would be to propose a paralleling in time of the stages for each profession to formalize cooperation and coordination. This would allow for less sequential processes and potentially reduce project time. Finally, adapting these works to the industrial sector and to training in occupational risks and diseases, such as musculoskeletal disorders (MSDs) would improve accessibility for manufacturers.
It seems that a multidimensional approach "unifying" the methods of the different disciplines may need to meet the industrial requirements for the development of PT. In addition, it is necessary to clarify the modalities of collaboration and collective work between all the stakeholders involved in the design process of IPT. The next part will present our proposal for a conceptual framework for the design of IPT.

3. Conceptual framework

Based on our knowledge of the relevant state of the art, we propose a conceptual framework represented using the IDEF3 modelling language. The objective of the IDEF3 (Bersier, 1995) method is to provide a structured system for expressing in a graphic form the knowledge of one or more experts in a particular system, organization, or activity. This responds to our need to model the coordination, the phases of cooperation, and collaboration between the different stakeholders involved. IDEF3 is based on entering descriptions and events in two forms: a diagram showing the ordering of processes (process diagram) and a diagram showing the successive state of an object (transition diagram). In this paper, we do not show the transition diagram. The goal is to allow synchronization of the methods proposed today to create an effectively concurrent and coordinated approach. This synchronization of methods should also allow to specify the role of each stakeholders during the design process. It is presented in a very sequential manner, but the proposal that is made is iterative in nature, each step is iterative.
The first diagram (Figure. 1) represents the process diagram of our conceptual framework at a macroscopic level. This diagram shows the main stages that make up the product design process. This goes through classic steps; starting with the analysis of needs and ending with feedback. Our proposal is based on the first two steps: 'Analyse the need' (Figure. 2) and 'Design the conceptual artefact' (Figure. 3).

Figure 1. Process diagram of the conceptual framework at the macroscopic level

For the conceptual framework, we recommend a process integrating different collaborators, that is to say, the ergonomist, the didactician, the VR/AR designer, and the project manager. The project manager is in charge of the overall planning and execution of a particular project. The process diagram of the first step, 'Analyse the need' (Figure. 2) was built from the I²I 'for utility' method (Loup-Escande, Dominjon, et al., 2013) aiming to take into better account the characteristics and needs of users in order to design an artefact that is really 'useful', that is to say, meeting the needs of end-users. We extracted the following steps from the proposition of Loup-Escande et al. (2013) :

- Collect the requirements of the sponsors: phase during which the sponsors discuss their goals, expectations, wishes, and constraints.
- Analyse user needs: it concerns the evocation of conscious needs by users and the identification of non-conscious needs among users by analysing reference situations, that is to say, situations that do not include the future artefact

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- Consultation of sponsors, users, and designers: it aims to bring together the various actors in the project so that they build a common representation of what the future artefact could be.

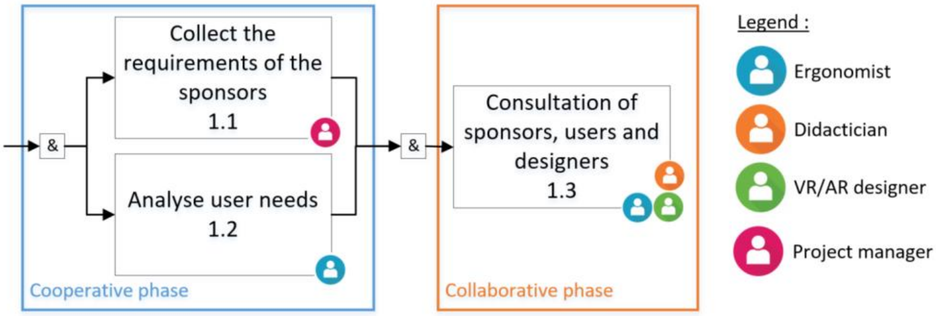

Figure 2. The first stage of framework: 'Analyse the need'

These steps will allow carrying out a complete analysis of the need on the part of the applicants as well as the future end-users (who will be the instructors and the learners). The step 'collect the requirements of the sponsors' will be done by a project manager and the 'analyse the needs' one, by an ergonomist in a cooperative way. It is, from the consultation of the needs of these two groups in a collaborative way by the ergonomist, the didactician and the VR designer that a first common representation on the future artefact will be made.

The diagram process of the step 'Design of conceptual artefact' (Figure. 3) highlights the design steps of the ergonomist, the didactician, and the VR/AR designer to be carried out in collaboration. The tasks they will perform will be firstly be carried out in cooperation, to allow them to work individually. They will then work together to build the new training program from the collected data in the cooperative phase.

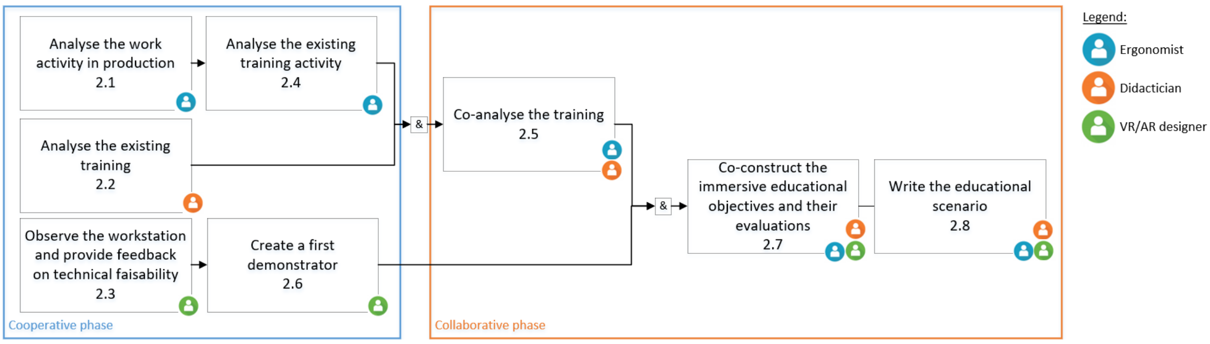

Figure 3. The second stage of framework 'design of conceptual artefact'

The step 'Design the conceptual artefact' aims to make an in-depth analysis of the work activity according to the different points of view of the collaborators. This step will also make it possible for the different stakeholders to become aware of each other's constraints. From the ergonomist's point of view, Boccara and Delgoulet suggest that the reference situations to be analysed are: work in production and work in training (Steps 2.1 and 2.4, Figure. 3). These two steps must be carried out by the ergonomist. The didactician must also analyse the training. For their part, they will analyse the training especially from the pedagogical point of view, by collecting the EO and the evaluation methods of existing training if such a methods are available (Step 2.2, Figure. 3). The ergonomist and the didactician are both interested in the existing training but from a different point of view, one is interested in content and the other one in activity. These two actors can then start working together by carrying out a co-analysis of the training in order to have a common representation of it as recommended by Boccara and Delgoulet (Boccara, 2018; Boccara and Delgoulet, 2015; Delgoulet et al., 2015). Concerning the VR/AR designer, they can discover and observe the workstation and associated activity to define the technical constraints related to their profession (Step 2.3, Figure. 3) and will be able to create a first demonstrator (Step 2.6, Figure. 3) to have artefacts that can be used for the next steps. We then propose a step from the work of

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Lourdeaux which consists of co-constructing the Immersive Educational Objectives (IEO), that are transmitted via the immersive application, and how they will be evaluated (Step 2.7, Figure. 3). Once the IEOs have been defined, they can be used to write the educational scenario of the future training program (Step 2.8, Figure. 3). This scenario will be the starting point for the VR designers to develop the solution further.

4. Framework application in the textile industry

4.1. Context

This new conceptual framework was implemented in a design project for IPT within the company, Stäubli. It's about training in the manufacturing of a part of the weaving machines which is called the dobby (Figure. 4). Its function is to drive the frames to form the shed (opening) and allow the interweaving of the threads as defined by the weave (weaving weft). The dobby blades are connected to the frames by a transmission system and the diagram is dictated to the machine by an electrical box. The dobby is a machine with very specific and sensitive assembly in order to ensure the quality of its functions. These machines run 7 days a week, 24 hours a day and can go up to 1100 strokes/min in weaving. The assembly of the dobby was therefore chosen in order to test our proposed conceptual framework.

Figure 4. Dobby

4.2. Framework application

4.2.1. Analyse the need

The project started with the need analysis phase. The collection of sponsors requirements (Step 1.1, Figure. 2) was carried out by the project manager within the process department. This collection has enabled us to discover certain limits of the current training concerning the assembly of the machine:

- Training is carried out in companionship with an expert operator on a workstation
- Long training period
- Request for hiring, and therefore training, is cyclical for the textile sector

The requirements are therefore to be able to develop a training aid tool that will free up the trainer and the workstation, improving the quality of the training, and reducing training time.
The Step 1.2 'Analyse user needs' (Figure. 2) was carried out by an ergonomist with a representative of the sponsor/operator to better understand their needs. After a presentation of the work environment, the assembly and training process, the ergonomist was able to record several concerns regarding the difficulties encountered by the expert operator during a training session:

- No accessible training plan and little consistency in the way of training operators
- Little confrontation of certain assembly hazards or type of machine
- Little awareness of occupational disease, because it is not part of the operators' field of expertise

This analysis made it possible to target certain user difficulties that were not known to the sponsors. These difficulties support the challenges of this project.

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The last step of the analysis of need is 'to consult the sponsors, users and designers' (Step 1.3, Figure. 2). This step made it possible to cross the requirements of the sponsors and the need of the users to determine the main objectives of this project. The solution lead to a virtual reality assistance tool which will complete the companionship part of the training. That is to say, the learner will have several virtual reality exercises during his/her training. This application will simulate part of the assembly, providing them more exposure to the job and to encounter hazards which are infrequent during the companionship training. This tool will also help the operators by standardizing the knowledge transmitted. While the learner is in training, the instructor will be released. By improving the quality of the training program, the training time can be reduced.

4.2.2. Design of conceptual artefact

The step 'design the conceptual artefact' as explained above, aims to deepen the analysis of the activity according to the different points of view of the stakeholders (ergonomist, didactician, and VR designer). Each stakeholders will first work in a cooperative manner, (individually), then in collaboration.

Let us start with the ergonomist's point of view. To analyse the work activity (Step 2.1, Figure. 3), much information was collected including: video captures of the operator at work and data on the working environment (noise, temperature, light, layout). To analyse the training activity (Step 2.4, Figure. 3) interviews were conducted with seven operators/instructors in order to find out their approach to the training plan (flexibility, opinions, and difficulties encountered). The responses to the interviews made it possible to consolidate and complete the needs analysis (Step 1.2, Figure. 2). Step 2.2, 'Analysis of the existing training' (Figure. 3) was carried out by the project manager instead of the didactician. The training data was collected from the assembly line-up. This serves as a framework for the instructor, as there is no accessible training plan. At the same time, the VR designer must 'observe the workstation and provide feedback on the technical feasibility' (Step 2.2, Figure. 3). This step was carried out during a consultation with subcontractors. They were invited to observe the work environment and the operation to be reproduced in virtual reality. For the next step, 'Create a demonstrator' (Step 2.6, Figure. 3), they could not create it, but we could test their own apps with similar characteristics and context—which help to get an idea of the final artefact.

This cooperative phase finished; now the collaborative phase can begin. The step, 'Co-analyse the existing training' (Step 2.5, Figure. 3) was carried out with the ergonomist and the project manager. From the information collected during Step 2.2 and 2.4 (Figure. 3), the project manager was able to cross data with the ergonomist in order to make a common representation of the training (profile of trainer and learner, course of training, EO to transmit, and difficulties related to training). From the discussions with the subcontractors, they were able to discuss the IEO to be transmitted and the method to evaluate them (Step 2.7, Figure. 3). In order to go further in the project, a first educational scenario (Step 2.8, Figure. 3) was written in order to request cost and development time from the subcontractors, to choose who will develop the solution. This educational scenario was written by the project manager from the activity analysis data and the co-analysis of the training. The scenario (Figure. 5) is composed of a series of tasks translated into interaction with the same vocabulary used by the VR designer. The scenario also provides information on where to find the task in the videos, the tools used, and the results following the interaction.

Nb	Timing	Tasks	Interaction	Details	Tool 1	Tool 2	Results	Comments
				Reglage de la table.mp4				
1	00:00	Adjust the height of the station	Trigger controllé (WIP)	Press the up-down pad to lower or raise the table and right-left to turn it			Movement of the support	
Q1				Why is it important to adjust your workstation?				
				Modulator adjustment.mp4				
2	00:00	Put the hammer down	Trigger	Position the hammer to self-centre the bevel gear	Hammer	None		
3	00:03	Set up the tool to turn the modulator	Put	Take the tool gear and position it on the dobby	Tool gear	None	1/4 turn handwheel rotation + bevel gear + blades	
Q3				Why should the tool gear be used?				
4	00:11	Remove the tool to turn the modulator	Put	Take the tool gear and hold it in your hand or put it down	Tool gear	None		

Figure 5. Extract of scenario sent to VR designers

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The Steps 2.7 and 2.8 (Figure. 3) were further developed once the subcontractor was chosen for the rest of the project. The selection criteria were cost and time to develop. Following this, the project reached prototype stage (Figure. 6). The VR prototype was developed on Unity software and the application run by Steam VR. For the VR headset, we use the HTC Vive pro with two controllers.

Figure 6. Workstation on the left, VR prototype in the middle and VR user on the right

5. Discussion

In this study, we carried out a state-of-the-art about collaborative and user-centred IPT design. We have described the limitations of work that deals with methodological proposals drawn from computer science, ergonomics, and didactics disciplines. A synthesis of this state of the art has shown that few proposals, to our knowledge, offer a methodological framework unifying the different disciplines required for the design of immersive training systems. This study proposed a conceptual framework to develop IPT by integrating and collaborating between different stakeholders of the design process. We showed that by applying this conceptual framework to an industrial project, we have been able to highlight some limitations that need to be addressed to improve our framework. One of the first limitations is that the framework is very theoretical, and within a company it is not always possible to have access to specific stakeholders. In our case the didactician was represented by the project manager and the work of the VR designer was performed by a subcontractor. It is therefore necessary to improve the methodology at this level in order to provide guidelines to non-experts.

To adapt the framework to an industrial environment, we have identified milestones to add some additional steps. One of the steps is to define a training plan (if it does not exist); and another step is the search for a subcontractor, since it influences the defining of the need. However, we must also find a way to involve the VR designer—without having to define the scenario before the project defining is carried out—to keep flexibility in the project, or replace the VR designer by a non-expert with guidelines. In the training analysis, we could also include guidelines to explain what the didactician should do such as filming the interaction between a trainer and learner during a training course, and conducting interviews with learners in training. The analysis of the activity made it possible to observe only operators and the trainers, but for a complete study it is necessary to further analyse the learner, who is also one of the users.

To enable the meeting points between the different actors to be successfully completed, we could propose the use of Intermediary Objects (IO) (Vinck and Jeantet, 1995) in the process. They are known for their characteristics of mediation, transformation and representation (Boujut and Blanco, 2003) which are perfect instruments for coordination or cooperation of the actors of the design. They facilitate the convergence between different disciplines or professions in order to guide and act during the design process. For example, the scenario which was written by detailing the interactions of the application was appreciated by the subcontractor, to facilitate the cost of the solution and its development. It could be improved by taking into account the needs and tools of the ergonomist, and the didactician, and also those of the VR designer, so that they have a common document to work on together. We could also imagine an IO to facilitate interactions with sponsors, and have a representation of the future product in order to ensure their adherence to the project.

The framework presented in this study is basically similar to other UCD models already developed. However, we analyse two work situations (the one in production and in training) based on this framework and we converge this analysis with VR technical specificities. We tested our approach on the relevance of the steps that are suggested and the sequence of steps in relation to the compilation of

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the different works between them. We have verified that there is no inconsistency in what we have suggested.

Our perspectives are to continue the development of the framework. The results of the application of modified framework with existing practices at Stäubli will serve to recommend avenues for the improvement of our proposal regarding the differences between theory and the industrial environment. An evaluation phase of the application will be conducted in the future and will serve as feedback to improve and complete the framework.

6. Conclusion

This study has shown that there is little or no description of the collaboration between the different stakeholders in IPT design process. Without this, other stakeholders in the field cannot gain from the contributions of each of the experts' points of view.

A conceptual framework for the design of IPT was proposed based on literature which includes six macro-milestone ranging from 'needs analysis' to 'experience feedback'. This study focuses on the first two milestone which are 'needs analysis' and 'designing the conceptual approach'. Using the IDEF3 modelling language, we have given the description of the tasks to be performed for the ergonomist, the VR / AR designer, and the didactician, and the recommended phases of collaborative and cooperative work. Finally, we presented an industrial project that was tested against our conceptual framework. We already notice that our framework must still improve to consider industrial requirements/limitations.

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