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Émilie Loup-Escande, Guillaume Loup

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Designing acceptable emerging technologies: what contribution from ergonomics?

E. Loup-Escande^a  and G. Loup^b

^aUR UPJV 7273 CRP-CPO, Université de Picardie Jules Verne, Amiens, France

^bBISC, Université Paris-Saclay, Univ. Evry, Evry-Courcouronnes, France

Ergonomics has several theoretical frameworks at its disposal for assessing the acceptability of technologies, and it uses numerous methodologies that exist within the discipline. Authors generally base their studies on one or other of these theoretical and methodological approaches, which are sometimes seen as mutually incompatible. The present article, however, seeks to demonstrate the interest of combining three methodological approaches (i.e., experimental, ecological, and prospective methodologies) in designing emerging technologies that will be accepted. Our first focus is conceptual, and the arguments we present for taking a holistic view of the acceptability of emerging technologies are based on the foundations, the contributions and the limitations of three theoretical frameworks of acceptance (i.e., social acceptance, practical acceptance, and situated acceptance). Our second focus is methodological: using our own work as evidence we argue that an experimental methodology can further both the practical acceptance and the social acceptance of Virtual Reality, that an ecological methodology can further its situated acceptance, and that a prospective methodology has relevance to all three facets. We discuss and suggest some recommendations regarding the use of these methodologies according to the type of design project.

Highlights

- A holistic view of the acceptability of emerging technologies based on social, practical and situated acceptance is proposed.
- The experimental approach informs the practical and social acceptance of virtual reality.
- The ecological approach promotes situated acceptance of emerging technologies.
- The prospective approach is relevant to social, practical and situated acceptance.

Relevance to human factors/Relevance to ergonomics theory

Several emerging technologies are being introduced in various contexts and ergonomics has its place in their design. This article seeks to identify how each of the three approaches to ergonomics - herited from Human Factors, work ergonomics and prospective ergonomics - are relevant to contribute to the design of acceptable emerging technologies. Our definition of acceptability is based on three theoretical frameworks referenced in ergonomic literature: social, practical and situated acceptability.

Introduction

Designing “acceptable” emerging technologies remains a challenge in ergonomics for at least two reasons. First, the well-known paradox of design ergonomics is that much greater, given that the technologies and usages are themselves emerging (Anastassova 2006). Second, these technologies have novel features that call their usefulness into question (Loup-Escande, Burkhardt, and Richir 2013), together with what are often very innovative interfaces with issues relating to usability (Chaniaud, Loup-Escande, and Megalakaki 2018) and user experience (Tcha-Tokey et al. 2018) that affect users’ readiness to accept them (Sagnier et al. 2020).

To overcome these difficulties, ergonomics has at least three theoretical frameworks relating to the acceptability of technologies. *Social acceptance* focuses on the fact that readiness to use a technology depends on users’ perceptions regarding its usefulness and ease of use (Davis 1989). *Practical acceptance* seeks an optimal compatibility between the user, the user’s tasks, and the emerging technology (Brangier, Hammes-Adelé, and Bastien 2010). *Situated acceptance* investigates the advantages and limits of a given technology within the context of its actual use and relative to its potential (Bobillier-Chaumon and Dubois 2009). For us, it is not enough for a technology to be deemed acceptable from just one or other of these contrasting perspectives. Instead, for the design of emerging technologies we advocate a holistic approach to acceptability that incorporates all three facets.

Ergonomics “uses a holistic approach, centred on the user, which considers within its range of action physical, cognitive, social, organisational, environmental and other relevant factors, using appropriate methodologies, to improve design” (Soares and Rebelo 2012, p. 1). So, the ergonomic literature references several methods related to experimental, ecological and prospective approaches seen as complementary¹. Experimental methodology is centered on those characteristics of humans that the design of systems – and especially human-machine systems (Laville 2004) – needs to reflect. Ecological methodology uses an analysis of actual activity as a foundation for the design of situations and systems (Falzon 2004). Finally, prospective methodology seeks to design systems based on anticipated future needs, uses and behaviours (Brangier and Robert 2014). Although most authors tend to favour one of these methodologies at the expense of the others, we believe that they complement each other in the contribution they can make to the design of “acceptable” technologies.

Our aim in the present article is to demonstrate that these three methodological trends have a part to play in assessing social, practical and situated acceptance when designing emerging technologies. While there are many emerging technologies such as Augmented Reality and Artificial Intelligence (Loup-Escande, in press), we have chosen to illustrate through one particular type of new technologies (Virtual Reality) for three reasons. Firstly,

virtual reality is an emerging technology insofar as it is associated with an innovative character, unclear uses, limitations that slow down its application and a promise of transformation of the economic and social context in which it is introduced (Loup-Escande, Burkhardt, et al. 2014). Secondly, it is an appropriate illustrative case since there are many successful design projects mobilizing this technology, thus allowing for empirical feedback on situated acceptance and not only social and practical acceptability (Sagnier, Loup-Escande, and Vallery 2019). Thirdly, Loup-Escande (*in press*) demonstrated that other technologies could be considered as emerging such as Augmented Reality and Artificial Intelligence. Augmented Reality corresponds to interactive systems that present virtual entities and elements of the real environment to the user in real time. Artificial Intelligence covers the sciences and technologies that make it possible to reproduce or even increase human cognitive faculties with the help of a computer, thanks to technological progress (e.g. Big Data) and the growth of automatic learning. In this sense, the crossing of experimental, ecological and prospective approaches for the design of acceptable emerging technologies that we defend and illustrate with Virtual Reality, can be quite generalized to Augmented Reality and Artificial Intelligence.

The first section looks at how virtual reality is considered to be an emerging technology. The second section argues for a holistic approach to the acceptability of emerging technologies, given the theoretical foundations, the potential contribution and the individual limitations of the three methodologies listed above. The third section shows how an experimental methodology can prove useful in identifying the social and practical acceptance of virtual reality. We then describe how an ecological methodology is particularly well suited in relation to situated acceptance, and how a prospective methodology has pertinence for practical, situated and social acceptance. Finally, we put forward some recommendations concerning the use of these methodologies according to the type of design project envisaged.

Emerging technologies

The term *emerging technologies* – together with its synonyms *new technologies*, *advanced technologies*, and *innovative technologies* – is often to be seen in scientific articles and communications published over the last decade, but without being clearly defined (Burkhardt 2003). In the present article we attempt to explain, using four characteristics identified by Kjeldskov (2003), in what ways Virtual Reality can be considered an emerging technology.

First, emerging technologies are linked to major technological innovations. In the case of Virtual Reality, the technological innovations in question correspond to better physical models (with respect to light, movement, impacts, etc.) that have allowed a far more convincing simulation of real environments, as well as to more realistic virtual agents whose movements rest on the implementation of complex mathematical algorithms, and to devices and software that provide users with multi-sensorial feedback (Argelaguet Sanz et al. 2018).

Second, emerging technologies tend to be used in ways that are not clearly defined, for two reasons. On the one hand, the motivation behind their development is sometimes technocentric in nature: they are developed in order to test what is technologically feasible and to overcome technical obstacles, rather than to meet the needs of real applications. This is precisely what has happened in some public or private research labs in relation to virtual reality headsets (for example, Guillermo et al. 2016). On the other hand, where technologies are developed with a particular application in mind, their actual use can start

to diverge from their intended use to the extent that the the activity in which they operate changes and users acquire new skills (Loup-Escande, Burkhardt, et al. 2014).

Third, emerging technologies are subject to constraints that limit the speed at which they can be rolled out. Wilson, Eastgate, and D’Cruz (2014), and Wilson and D’Cruz (2006), identified five categories of constraints: technical constraints (due, for example, to incompatibilities between technologies); usability constraints (relating, for example, to the physical and software interfaces used in Virtual Reality); constraints of applicability (emerging technologies are often not sufficiently perfected to for them to be usable in real work situations and situations of everyday life – this is why certain suppliers of virtual reality headsets have chosen to sell their products only to research laboratories during an initial period); constraints due to a lack of feedback, where there are insufficient empirical data on these technologies’ added value in different application contexts; and finally methodological constraints (methods for identifying latent needs that might be satisfied by technological innovations exist, but they are a relatively recent phenomenon).

Fourth, emerging technologies hold the promise of being able to transform the social and economic context in which they operate. Industry 4.0, which denotes the trend towards new methods of production based on virtual technologies and/or artificial intelligence, is set to produce economic gains and to alter the relation between workers and their work (Moulières-Seban, Bitonneau, and Thibault 2016). Another example is the use of Virtual Reality in vocational training and in education generally with the aim of making complex content more accessible and generating a greater engagement on the part of learners via teaching methods that incorporate simulation (Sattar et al. 2020).

Acceptability of emerging technologies: complementarity of conceptual frameworks

Social acceptance

Theoretical basis

In models of the social acceptance of technologies, acceptability is determined by users’ perceptions (Davis 1989). Three theoretical approaches exist side by side (Bobillier-Chaumon 2013). The first approach looks at predictive variables – organizational, technological and personal – that help or hinder the acceptance of technologies. The characteristics of the organization in which a technology is to be implanted (for example, the degree to which it is centralized) may influence behaviour with respect to its adoption (Damanpour 1991; Lapointe and Rivard 2005). Bobillier-Chaumon (2013) describes how the predictive technological variables that have been researched, for example, in social presence theory (Short, Williams, and Christie 1976) and in relation to media richness (Daft and Lengel 1986) have a marked impact on users’ attitudes and behaviours. With regard to personal predictive variables, a number of works have shown that users’ profiles (including age, level of educational attainment, and personal innovativeness) are determinants of acceptability (Mathieu and Zajac 1990; Rasimah, Ahmad, and Zaman 2011).

The second theoretical approach is interested in users’ preconceptions about a future/potential technology. This approach rests to a large extent on psychosocial theories in its analysis of the acceptability of technologies. More widely used models include the TAM or Technology Acceptance Model (Davis 1989), which seeks to explain, based on the theory

of reasoned action (Fishbein and Ajzen 1975), how users' perceptions of a technology's usefulness and ease of use determine their behavioural intention to use it.

In the third approach social cognitions, seen as disparities between, on the one hand, users' expectations about a technology before it is introduced, and on the other hand, their experience of actually using it, are examined through the lens of expectation disconfirmation theory (Oliver 1981). Users are able to compare their expectations with their experience, and this gives rise to a level of satisfaction that influences their subsequent behaviour in relation to the technology.

Contributions of social acceptance in the design of emerging technologies

These theoretical models make three important contributions. First, using indicators (such as perceived usefulness and organizational conditions) these models can predict, before a technology is deployed, to what extent users will be ready to adopt it (Bobillier-Chaumon and Dubois 2009). Second, these theoretical models are often linked to measurement tools (questionnaires) that are able to record intended use rapidly and fairly comprehensively over a large sample of potential users. The third contribution, highlighted by Bobillier-Chaumon (2013), comes from the fact that these models propose precise indicators that can be reused and enhanced for different situations of use (professional, domestic, leisure, etc.) and for different types of users (employees, men, women, young people, the elderly, and so on). Results obtained can yield recommendations relating to the design of technologies (for example, features that need to be included) and to how these technologies should be introduced (such as concerning the type of training that may be appropriate).

Obstacles to the use of social acceptance in the design of emerging technologies

Independently of the theoretical model, bringing social acceptance to bear on questions of design faces three obstacles (Sagnier, Loup-Escande, and Vallery 2019). The first obstacle is the small number of studies that have looked at the organizational aspect (the few studies that have been done include Orlikowski 2000; and Čudanov and Jaško 2012), which helps to explain why little or no consideration tends to be given to a technology's context of use and to the type of activity that the technology is being incorporated into. The second obstacle is that users' perceptions of a technology's usefulness and usability are measured at a particular point in time, and so changes over time in these perceptions are not taken into account as uses evolve. The third obstacle is that studies conflate intentions to use with actual use, while it is clear that intentions to use are not an accurate predictor of how a technology will be used in practice (Turner et al. 2010).

Practical acceptance

Theoretical basis

Models of practical acceptance seek to optimize the ergonomic quality of technologies so as to favour their adoption, looking in particular at the relations between the user, the user's tasks, and the technology (Brangier, Hammes-Adelé, and Bastien 2010).

This ergonomic quality encompasses not only the instrumental aspects of a technology (that is to say, its usefulness and usability), but also non-instrumental aspects linked to a

user's emotions – these non-instrumental aspects include *fun*, or enjoyment (Blythe et al. 2004), and *pleasure* (Jordan 1998), and have given rise to models of user experience (Hassenzahl, Burmester, and Koller 2003; Hassenzahl and Tractinsky 2006).

Ergonomics has many tools and design models to promote the practical acceptance of technologies, such as for example the Cognitive Task Analysis and the User-Centered Design. Cognitive Task Analysis attempts to identify and explain the mental processes implemented in performing a task (Klein and Militello 2001) with the aim of defining the functionalities and optimizing the ease of use of the technologies by the users. User-centered design (Norman and Draper 1986; ISO 9241-210: 2019), which seeks to make technologies more useful, usable and acceptable to users, is of particular interest in relation to practical acceptance, insofar as it takes account of the dynamic nature of both instrumental and non-instrumental aspects, meaning that users can be involved at various stages of the design process.

Contributions of practical acceptance in the design of emerging technologies

Models of practical acceptance have two strengths. First, their objective is fundamentally *ergonomic* in nature, since right from the start of the design process they seek an optimal compatibility between users, technologies and situations of use (Norman and Draper 1986). We have seen that aligning technologies with people in this way relates first and foremost to the capabilities of the technology and to its other instrumental aspects (Nielsen 1994), but that it also relates to the emotional dimension of user experience when interacting with the technology (Barcenilla and Bastien 2009; Cahour and Lancry 2011). Secondly, models used in ergonomic (for example, user-centered) design, by formalizing the involvement of users, take into consideration the dynamic, changing nature of instrumental and non-instrumental qualities.

Obstacles to the use of practical acceptance in the design of emerging technologies

Practical acceptance is restrictive to the extent that it neglects the subjective nature of the relationship between humans and technology (Brangier, Hammes-Adelé, and Bastien 2010; Terrade et al. 2009), and rests on the idea that usability is simply one predictor, among others, of how far technologies will be adopted (Bobillier Chaumon 2016).

Situated acceptance

Theoretical basis

Situated acceptance holds that adoption of technology is accomplished *within and through activity* (Bobillier Chaumon 2016). From this perspective, acceptability is to be determined in the actual use of a technology and in the concrete experience of users. Situated acceptance is interested in the ways that users adopt and use technology as they go about their activity (Benedetto-Meyer and Chevallet 2008).

Situated acceptance is supported by two theoretical paradigms: namely theories of technological appropriation and theories of activity. Appropriation rests on the idea that technology is not something fixed and final, but that it is transformed by the user (Dourish 2003) according to circumstances at any given time, such as the user's needs in relation to the activity, or the capabilities and the usability of the technology. It is these circumstances that cause the user to bypass some aspects of the technology and to invent others (Orlikowski

2000). Rabardel and Bourmaud (2003) use the term “instrumental genesis” to describe this process, in which *instrumentation* refers to the emergence of new patterns of use and changes in existing patterns, while *instrumentalisation* refers to the ways in which users adapt the functions and the properties of artefacts to their own needs (Rabardel and Bourmaud 2003; Rabardel and Beguin 2005). To ensure appropriation by users, the task-artefact cycle (Carroll and Campbell 1989) associated to a participatory design is a relevant model. The task-artefact cycle is an iterative process of continuous co-development between task and artefact. More precisely, following an initial interaction between the user and the technology, the resulting artefact creates new possibilities or new constraints to the execution of the task. These possibilities and/or constraints suggest a revision of the initial task for which the artefact was created. The new task sets new requirements for the redesign of the artefact. In the participatory design, users are supposed to participate as co-designers and they are also involved in design decisions (Ehn 1993), due to some forms of democratic or multilateral participation of users together with other stakeholders involved in the design project (Von Hippel 2005).

Theories of activity, on the other hand, support the situated acceptance framework in at least four respects (Sagnier, Loup-Escande, and Vallery 2019). First, in arguing that the relation between an individual and the object of his or her activity is mediated by an artefact (Vygotski 1997), these theories see technology as a means – among other means – of accomplishing a task, which entails the need for a holistic approach. Second, these theories break activity down into a subject, an object, actions, and operations (Leontiev 1974) and allow an understanding of the specific ways in which activities differ from each other. Third, Engeström (2001) considers that as well as being mediated by artefacts and oriented towards objects, systems of activity are also collective in nature, and that the contradictions inherent in these systems are motors for change and development. For example, a new technology introduces a contradiction with an existing element in the system (such as users’ habitual practices), and this leads not only to disruptions of activity, but also to innovative attempts to change the technology, with respect both to its functional and non-functional characteristics (Loup-Escande, Burkhardt, and Richir 2013). Finally, the situated acceptance framework, originally developed by Suchman (1987), highlights the changing complexity of situations and the “opportunistic” reactivity of individuals in the face of contingencies in their environment. Individuals have to change their activity in response to contextual factors.

Contributions of situated acceptance in the design of emerging technologies

Situated acceptance has two considerable advantages in the design of emerging technologies. First, it adopts a comprehensive perspective (Bobillier-Chaumon 2013) according to which technologies are developed within the context of real activity, based on a detailed study of technological structures created by users. Second, theories of technological appropriation and of activity can help to identify conditions specific to the situation that may favour, as well as impediments (individual, collective, or organizational) that may hinder appropriation of a technology by users and its integration into working habits and practices.

Obstacles to the use of situated acceptance in the design of emerging technologies

In spite of these advantages, situated acceptance has two major limitations. The first is that it can be brought to bear only where an emerging technology is already at a fairly advanced stage in its development. And if a technology is found to be largely or wholly unacceptable

only after it has actually started to be used in practice, the cost of going back to the drawing board and starting afresh is likely to be prohibitive. The second limitation is that it can only provide contextualized data, which might be detailed and relevant to the situation in which the technology is operating, but which cannot easily be transposed and generalized to other situations. Situated acceptance is therefore unable to provide generic models of how perceptions of usefulness and usability impact acceptability, nor of how the characteristics of individuals and technologies influence the usefulness and usability actually experienced.

A holistic approach to acceptability based on all three conceptual frameworks

We believe that it is necessary to incorporate elements from all three of the frameworks described above in designing emerging technologies that are truly acceptable. In this way their different weaknesses can be offset by strengths that are to be found in the others.

First, social acceptance is able to complement practical acceptance insofar as practical acceptance does not consider the subjective relation between the human and the technology, while social acceptance considers that users' perceptions of the usefulness and ease of use of a technology will affect their attitude in using it. Conversely, practical acceptance complements social acceptance to the extent that an acceptable technology is not only one that offers a positive user experience, but it must also have "real" qualities of usefulness and usability.

Second, situated acceptance can make an important contribution to social acceptance, in that it considers the use situation and the activity, unlike social acceptance, which focuses on users' prior conceptions. Models of social acceptance, by incorporating elements from situated acceptance, could be enriched and linked to end users in well-defined use situations.

Third, practical acceptance and social acceptance are complementary in two respects. On the one hand, studies conducted outside the actual context of use can anticipate and open the way to technologies that are sufficiently acceptable (from a "practical" point of view) and avoid a wholesale rejection by users in real operational situations. On the other hand, studies of these technologies *in situ* can improve their acceptability in the "situated" sense by linking people's ideas about specific technologies to the real usefulness of those technologies. Combining contributions from the two frameworks brings into sharper focus the use of the technology in practice and gives us a clearer view of how it is integrated into users' activity and the processes of appropriation that can appear. It also helps us to devise simulated situations for assessment that more closely resemble the real ways in which the technology is used.

The sort of merging of theories that we envisage would give rise to a holistic assessment framework for emerging technologies that would include not only users' perceptions of usefulness and usability, but also instrumental and non-instrumental qualities of the technology, taking into account specific features of the use situation, of the users, and of the technology itself.

Acceptability of emerging technologies: contribution of three methodological approaches to ergonomics

Contribution of the experimental method to social and practical acceptance

Experimentation: definitions, weaknesses and strengths

The experimentation, focused on the characteristics of humans (including anthropometric, physiological and cognitive characteristics), was the first approach to be used in relation to

emerging technologies. Burkhardt (2003) describes how, for example, the first studies looking at Virtual Reality used experiments on perception and motor control to build up a corpus of empirical data that subsequently informed the design of virtual devices and environments. Experimental approach is based on a hypothetico-deductive methodology in which questions or hypotheses to be researched emerge from a theoretical examination of problems of interest, and these questions or hypotheses are then tested based on measurements made among a sample of individuals (Valléry et al. 2016).

Experimental approach has certain weaknesses. This approach considers the “average” human, and so the process of design fails to take account of individual specificities. Wisner holds that this “average” human simply does not exist, and that it is mistaken to believe that any universally desirable or useful projects could be developed on this basis (Sznalwar and Le Doaré 2006). Another limitation is that experimentation is centered around the existing state of technology and has nothing useful to say about how uses may change in the future.

Nevertheless, experimental approach also has a number of strengths. Repeated experimentation using an identical situation each time means that enough data can be acquired to allow results to be generalized. Another advantage of this experimentation is that confounding variables can be weeded out that may otherwise have led to spurious results (in our case, results relating to acceptability). Emerging technologies are often tested in controlled environments before being used in real situations, to check that their instrumental and non-instrumental qualities are unlikely to seriously impair their use and appropriation by users.

Experimentation with a view to improving social acceptance of technologies

Social acceptance of emerging technologies has been the object of experimentation in a number of studies (for example, Chow et al. 2012; Fetscherin and Lattemann 2008; Tokel and Ísler 2015). Recently, Sagnier et al. (2020) did an experimental study with a view to putting forward an extended version of the TAM. The model that they proposed includes, in addition to the TAM’s original variables (Davis 1989), other variables relating to user experience (Hassenzahl, Burmester, and Koller 2003), variables specific to Virtual Reality such as immersion (Witmer and Singer 1998) and cybersickness (Kennedy et al. 1993), and variables relating to the user such as personal innovativeness (Agarwal and Prasad 1998). They tested the model using 89 human subjects (53 engineering students and 36 psychology students) performing an assembly task in a virtual environment representing an aircraft production plant via an HTC Vive head-mounted display or a CAVE. Their results suggest that intention to use Virtual Reality is influenced positively by perceived usefulness and negatively by cybersickness. Hedonic quality and personal innovativeness are predictors of perceived usefulness. Perceived ease of use does not significantly affect intention to use and is influenced solely by pragmatic attributes. In short, non-instrumental dimensions (user experience measured in terms of hedonic quality and pragmatic quality) affect the perception of instrumental qualities (usefulness and usability, respectively); intention to use seen as an indicator of social acceptance would appear to be directly influenced by perceived usefulness and cybersickness.

Experimentation with a view to improving practical acceptance of technologies

Practical acceptance has been examined in several studies looking at emerging technologies, mainly in relation to usefulness and usability (for example, Herrero et al. 2015). Other works have included non-instrumental qualities among the factors relevant to practical acceptance. For example, following on from works on user experience (Hassenzahl 2001; Lin and Parker

2007; Mahlke 2008; Wu et al. 2009) and related aspects including usability, flow (Cheng, Chieng, and Chieng 2014), presence, and immersion (Witmer and Singer 1998), Tcha-Tokey et al. (2018) developed a model of user experience specifically adapted to Virtual Reality. This model was tested using 152 subjects, who filled out an identity questionnaire, performed a task using the *Think and Shoot* application, then completed a user experience questionnaire. *Think and Shoot* is an edutainment virtual environment for teaching people about functions and parameters, which involves amassing bullets and firing them at evil creatures. Subjects were given instructions in a pseudo programming language in which a function is an instruction to shoot and its three parameters correspond respectively to the evil creature to aim at (two possibilities), the type of bullet to use (three possibilities), and the number of available bullets remaining. An instruction could be, for example, “Shoot (fire creature, ice bullet, 0)”, which told subjects that there were no ice bullets left for shooting the fire creature and that they needed to collect some more. Objective measures, such as the time taken, the overall score obtained and the level reached, were recorded and analysed statistically using SEM (Structural Equation Modelling). The results confirmed certain relations (green arrows) between various components of Virtual Reality user experience that had been posited in the hypothetical model, while invalidating others (grey arrows), and revealing new relations (red arrows). The authors were thus able to propose a validated holistic model of user experience (Figure 1) in which acceptability is affected by usability and other components of user experience (namely flow and user engagement resulting from perceived presence).

Contribution of the ecological approach to situated acceptance

The ecological approach: definitions, weaknesses and strengths

In the area of ergonomics that is especially popular in the French-speaking world, studies real activity with a view to transforming and/or designing situations and systems of work or

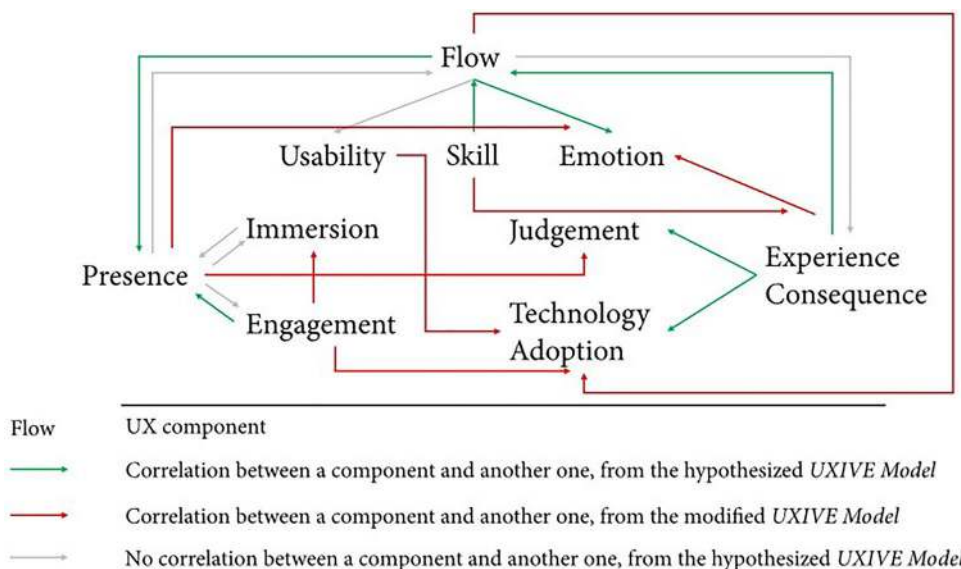


Figure 1. UXIVE model - user experience in immersive virtual environment, from (Tcha-Tokey et al. 2018).

other types of activity (Laville 2004). In relation to emerging technologies, this ecological approach seeks to integrate the different components of “situated” human activity in order to improve the ergonomics of artefacts used. Burkhardt (2003) describes how methodologies of design and assessment centered on users and training, along with methodologies based on feedback from actual use, have contributed, for example, to the design and improvement of virtual environments used in training. This approach in practice is often based on an inductive or comprehensive procedure that, in response to people’s expressed wishes or questions of a practical nature relating to a given situation, enables all those concerned to cooperate in devising and implementing solutions that benefit as many of them as possible, and that seeks to optimize systems, in particular systems where technology has a role (Valléry et al. 2016).

Ecological approach has a significant weakness, namely that it depends on the analysis of a situation at a given time and in a given context. Because of the paradox of design ergonomics in relation to emerging technologies, this approach cannot anticipate how users’ perceptions will change over time, or how new habits and practices will arise as the technology continues to be used. Therefore, when an emerging technology is deemed acceptable from an ecological perspective, this acceptability applies only to the time that the analysis of activity was done, and only to the specific context analysed.

However, ecological approach also has strengths. It can give rise to technologies that are almost perfectly adapted to the specific characteristics of users and use situations at a given time. The analysis of the activity prior to the introduction of the technology provides a detailed picture of users and potential practices, while the analysis of the activity once the technology is operational helps ensure its smooth integration. Where an ecological approach is used, data acquired from observation (both anecdotal and systematic) will often complement the verbal data acquired from interviews and/or from users viewing videos of themselves, which gives rise to a rich body of objective and subjective data that can be of great value in designing or improving the technology.

Identifying determinants of situated acceptance of technologies via an analysis of existing situations

The data that are acquired, mainly from interviews, from observation, and from users viewing videos of themselves and of others, are formalized in models of the activity or models of tasks. These models encapsulate a detailed delineation of users’ tasks (scheduling of tasks, frequency, difficulty, etc.), of the environment in which they are performed, and of the constraints that they are subject to. They are useful tools for determining the organization of components in the application, that is to say the non-functional characteristics of the technology. They also are a means of moving progressively from an analysis of activity to a specification of functional requirements (Haradji and Faveaux 2006).

This is the procedure that was used in the *Apticap* projet, whose objective was the development of a Virtual Reality training tool for workers with learning disabilities (Loup-Escande, Christmann, et al. 2014). Field observations and interviews with supervisors and workers were done with the aim of modelling two virtual tasks to be implemented in a virtual tool. The tasks were washing dishes and placing prepared meals in trays. The task-description formalism used was MAD (*Méthode Analytique de Description*, Sebillotte and Scapin (1994), which has a two-fold advantage: it is a formalism that provides a tool not only for describing tasks based on operators’ perceptions, but also for collecting data

portraying the logic of tasks from the operator's point of view. The use of MAD formalism made it possible to design virtual tasks that were accurate and realistic in terms of functions and usability, in that they replicated operators' actual gestures and practices.

Optimizing situated acceptance of emerging technology via an analysis of artefact use

There have been few studies of situated acceptance of emerging technologies (Sagnier, Loup-Escande, and Vallery 2019). Loup-Escande and Burkhardt (2019) did a study into how far the assessment of an emerging technology in its ecological context (that is to say, in real work situations) could optimize its situated acceptance (by generating expectations or latent needs). The emerging technology in their study was a Virtual Reality software application called *Appli-Viz'3D* that placed product prototypes and 3D dummies in two realistic virtual environments: a child's bedroom and a car. The study involved one of the software designers and seven users.

The results show that use situations can contribute to an analysis of situated acceptance in four different ways. First, exchanges and interactions between a designer and users with different profiles in an ecological context can suggest new features and capabilities that might be used to "tweak" an emerging technology so as to make it more acceptable, given the specifics of the situation in which it is used. In this way, users generate new needs in these situations, and are able to obtain information from the designer about the objectives behind the technology, its characteristics, its use, and technical information about how it works. Second, the range of knowledge and skills of participants means that as a group they can create an atmosphere that favours creativity, as has been suggested by earlier studies (for example, Bruseberg and McDonagh-Philp 2002). Third, the study in question confirms that through the creation of situations of real use of a technology, designers and users can learn from each other. Users were introduced to desktop-VR technology, learned to use the application, contextualized its use, and experienced the direct contribution that it could make to their activity. The designer gets to see the activity of different users, becomes aware of their sources of difficulty and of needs that have not yet been thoroughly addressed in the application. Fourth, the study showed that a designer can have a role to play in implementation, insofar as in this particular study the designer taught the users how to use the tool and via the use situation created could check that they were able to integrate the tool into their work.

Contribution of the prospective approach to social, practical, and situated acceptance

The prospective approach: a promising trend in the ergonomics of emerging technologies

Prospective Ergonomics tries to anticipate or create future needs and practices with a view to designing products, in particular products of a technological nature, that are as well-adapted as possible to their users (Robert and Brangier 2009). In Prospective Ergonomics the product is not yet clearly identified but it must satisfy a requirement of novelty. The

inherent novelty of emerging technologies means that they are of interest in Prospective Ergonomics.

As Brangier and Robert (2014) point out, the specific characteristic of Prospective Ergonomics is that it is based on an anticipation and creation of needs, practices and types of activity that do not yet exist. For them, this implies a need for creative methods in addition to other more traditional methods of ergonomics.

Although Prospective Ergonomics appears to promise a way of identifying characteristics and needs of end users with a view to improving the acceptability of future technology, at present very few methods exist for Prospective Ergonomics to utilize (Nelson et al. 2014). This helps to explain why this comparatively recent trend (in contrast to experimental and ecological approaches) has so far generated only a small number of works.

However, the Prospective Ergonomics literature suggests that it has two major strengths. First, the ergonomist is the initiator, and therefore has a significant role to play in the process of innovation, unlike in the other trends, where the role of the ergonomist more closely resembles that of an advisor providing information about existing activity and the probable use of future technology. In Prospective Ergonomics the ergonomist has more room for manoeuvre in implementing methods likely to favour acceptability *in fine* by identifying, anticipating, or creating future needs (Robert and Brangier 2009). Second, results proposing novel methodological frameworks seem promising insofar as they have given rise to original ideas (Nelson et al. 2014), revealed pertinent needs in the design of innovative products (Buisine, Boisadan, and Richir 2018), and posited previously unimagined future practices (Loup-Escande et al. 2015).

Brainstorming and user testing in advance of the design phase to improve social, practical and situated acceptance

Brainstorming and Focus Groups are among the best known and most widely used methods in ergonomics, and help to engender a creative atmosphere (Bruseberg and McDonagh-Philp 2002). These methods encourage participants to invent new uses for tools, as well as uses that are “unrestrained” or not directly derivable from the needs that users identify individually. Brainstorming and Focus Groups can be even more productive when participants have know-how in a variety of different areas (Resnick et al. 2005).

In these collective creative situations, individuals who at the outset – because of their different skills backgrounds – might have differing opinions, exchange and argue their points of view, and in some cases the end result is that the group arrives at a shared perception regarding the functions, characteristics and possible future uses of a technology. This was demonstrated by Loup-Escande et al. (2015) in the context of the *VirtualiTeach* project for the design of a Virtual Reality teaching platform. The requirements in relation to teaching were established via several brainstorming sessions with the participation of 65 teaching personnel, all prospective users of the platform.

It emerged from these sessions that a number of different subject areas could potentially be taught using Virtual Reality, thus establishing the perceived usefulness of *VirtualiTeach*. Six of these were selected as being representative in terms of their content and their suitability for being taught using Virtual Reality (Table 1), and from these six representative subject areas, proofs-of-concept were established.

Table 1. Concepts to be addressed (middle column) in learning tasks (left-hand column) via proofs-of-concept (right-hand column).

Learning Task	Concepts to be Addressed	Proof-of-Concept
Understanding the Venturi effect	Conservation of flow, conservation of energy, reversibility of dynamic pressure	Fluid flow
Understanding acoustic comfort	Perception of sound according to the type of wall covering, occlusions, reverberation	Acoustic comfort
Understanding the idea of energy chains	Composition of a motor, roles of the different components, 4-stroke sequencing, transforming linear motion into rotary motion	Heat engine
Building and understanding a kinematic model	Creation of a kinematic diagram, kinematic linkage, kinematic simulation	Kinematic diagram
Creating and validating an assembly process plan	Creation of a manufacturing task list, understanding the key steps	Manufacturing task list
Spraying a coating onto the outside of a building	Technique of spraying	Spraying a coating

These proofs-of-concept were then subjected to a Prospective Ergonomics assessment by users in the initial design stages, with a view to creating needs that had so far not been imagined either by users or by designers (Anastassova et al. 2005). Twenty-two prospective users – teachers and learners – assessed six proofs-of-concept via questionnaires. In addition to the average Likert scale scores obtained for acceptability (Venkatesh et al. 2003), presence (Witmer and Singer 1998), immersion (Fu, Su, and Yu 2009), and user experience (Hassenzahl and Tractinsky 2006), the authors recorded positive aspects, aspects to improve, and suggestions for improvement in terms of features and usability that might improve practical acceptance. Because the sample of users contained only genuine future users of the platform, the authors also recorded data on users’ habits and behaviour, with a view to using them in a future Situated Acceptance study of the *VirtualiTeach* platform, once operational.

Discussion

In this article we advocate the joint use of three methodological frameworks in an emerging technology development project. Nevertheless, according to the type of project, one of the frameworks will be dominant. The two categories of emerging technology project in which ergonomics has a role to play are on the one hand technocentric projects, and on the other hand anthropocentric projects. These two categories differ in their contexts and in their requirements/expectations, which will impact the ergonomics researcher’s perception of and approach to acceptability in each case.

Technocentric projects will often adopt a “Technology Driver” strategy with an objective of radical technological innovations via an intensive Research & Development effort (Jaruzelski, Staack, and Goehle 2014). In these projects, work on acceptability generally seeks to assess the technologies that are introduced to overcome technological obstacles and for which there are not necessarily any predetermined users. Here, experimentation will be the dominant methodology, for two reasons. First, because in these cases ergonomics is attempting to assess a technology independently of a context, which implies situations that are artificial and restricted in scope, focusing on direct interactions between a user and

the technology. Second, because the aim is to collect data (for example, on errors or on opinions) from a large sample of subjects with a view to improving the product, usually with respect to usability. Here, since it is not a question of taking individuals' specificities into account, the subject of interest is the "average human" (a concept sometimes criticized in ecological approach precisely because it neglects individual variability).

Anthropocentric projects, in which innovations are developed with a particular context and a particular type of user in mind, can be divided into three separate groups. The first two groups adopt a "Market Reader" strategy which, based on knowledge of users wishes and stated needs, introduces innovations incrementally and personalizes products, in particular technological products (Jaruzelski, Staack, and Goehle 2014). The first group corresponds to projects targeting a wide variety of users and a small number of clearly delimited use situations. For this type of project an experimental methodology will be preponderant.

The second group of anthropocentric projects are projects targeting precise situations of use and a clearly defined type of user. Here, an ecological methodology will be preponderant, since a large volume of data is not required in such cases, but rather it is a question of identifying the individual characteristics of real users, together with their functional and non-functional needs and their patterns of use of the technology in context. To improve acceptability this approach needs to be linked to an inductive procedure and a participative design phase. The ergonomics researcher needs to be able to answer questions relating to the situations of use (that in this case are known), and to include users from the initial stages of design where decisions are made right through to the introduction of the technology into the organization, where they can provide insights into the process of integration and the appropriation of the technology by operators. Sometimes, even though the use situations and the users are known, the ergonomics researcher will encounter problems of access. It may not be possible for users to have access to non-transportable equipment, possibly in a restricted zone, or it may not be possible for the researcher to access the technology in its real use situation (such as in a hospital), or the real users may not be available, for example if they cannot leave an assembly line, or if circumstances prevent their participation (such as in the case of patients who have just had surgery). In these cases, even though an analysis of real activity involving the technology would appear to be the best way of assessing acceptability in relation to individual situations and individual users, the researcher will resort instead to a simulation. A simulation is sometimes able to recreate environments closely resembling situations of final use and involving a representative sample of end users. However, a simulation cannot provide data on the process of integration into the real work situation and the appropriation of a technology by operators (in the presence of all the confounding variables that can be controlled in an artificial context), nor on the operators' perceptions of actually working with this new technology. Although simulation presents a number of advantages at the design stage, it needs to be complemented by a situated methodology in order for overall acceptability to be assessed.

The third group of anthropocentric projects are projects in which both use situations and prospective users are poorly defined. These will usually adopt a "Need Seeker" strategy, which involves anticipating future needs in order to propose a product that meets these needs as yet unexpressed, and to generate innovations centered on the functions,

characteristics and uses of products (Jaruzelski, Staack, and Goehle 2014). For this type of project, a prospective methodology will be the most appropriate, in that it can encourage creativity and conjectures regarding future use. The challenge for ergonomics is to ensure that the different aspects (functions and other characteristics) that are anticipated by and acceptable to those who imagine them are also acceptable in real use, and this can be done using the traditional tools of ecological approach.

The Table 2 summarises the differences between technocentric and anthropocentric projects in terms of innovation strategies, objectives and methodological approaches.

Conclusion

This article allows us to make two observations on the role and place of ergonomics in acceptable emerging technology design projects. First, the main objective of this paper was to demonstrate that the experimentation, the ecological approach and the prospective ergonomics are complementary and relevant in assessing social, practical and situated acceptance when designing emerging technologies. We argue that an experimental methodology can further both the practical acceptance and the social acceptance, that an ecological methodology can further its situated acceptance, and that a prospective methodology has relevance to all three facets.

Second, we make recommendations on the methodological tendencies to be mobilized according to the types of projects depending on whether they are anchored in a “Technology Driver” (or “Technology Push”) strategy, a “Market Reader” (or “Market Pull”) strategy or a “Need Seeker” strategy.

In the “Technology Push” strategy, ergonomics seeks to assess the usability of emerging technologies and experimentation is the most relevant approach.

The “Market Pull” strategy concerns two kinds of projects: projects targeting a wide variety of users and a small number of clearly delimited use situations; and projects targeting precise situations of use and a clearly defined type of user. In the first case, experimentation can be mobilized. In the second case, analysis of the activity is also recommended to identify the characteristics of the reference situation and investigate the processes of integration into the activity and appropriation by users.

Table 2. Main differences between technocentric and anthropocentric projects in terms of innovation strategies, objectives and methodological approaches.

	Technocentric projects		Anthropocentric projects	
Innovation strategies	Technology Driver	Market Reader	Market Reader	Need Seeker
Objectives	Projects assessing the technologies that are introduced to overcome technological obstacles and for which there are not necessarily any predetermined users	Projects targeting a wide variety of users and a small number of clearly delimited use situations	Projects targeting precise situations of use and a clearly defined type of user	Projects in which both use situations and prospective users are poorly defined
Methodological approaches	Experimentation	Experimentation	Ecological approach Simulation	Prospective ergonomics

In the “Need Seeker” strategy, ergonomics seeks to anticipate future needs that will enable scenarios to be drawn up for the development of an emerging technology. The prospective approach is the most suitable thanks to methods that encourage creativity and projection in use.

A main limitation of the article is that we only focus on projects related to a specific emerging technology that is Virtual Reality. We would, however, argue that these observations are applicable to other emerging technologies such as Artificial Intelligence and Augmented Reality. Indeed, they are - like the Virtual Reality - characterized by an innovative character, unclear uses, limitations that slow down their application and a promise of transformation of the economic and social context in which they are introduced. The many areas in which technologies continue to be deployed (e.g. Industry 4.0, education, energy and sustainable development, health) are relevant grounds for further work in ergonomics on the acceptability of emerging technologies.

Note

1. For a complete state of the art on design and assessment methods used in ergonomics and HCI, the reader can see Diaper and Stanton (2004), Stanton et al. (2005) as well as the special issue of *Theoretical Issue in Ergonomics Science* coordinated by Salmon (2016).

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ORCID

E. Loup-Escande <https://orcid.org/0000-0001-7664-6279>

G. Loup <https://orcid.org/0000-0003-3476-583X>

Notes on contributors

Dr. Emilie Loup-Escande is an Associate Professor at the CRP-CPO UR 7273 research center at Picardy Jules Verne University in France. She is interested in the ergonomic design of emerging technologies. She has been involved in the design and assessment of virtual reality applications (product design, training and learning, and entertainment).

Dr. Guillaume Loup is an Associate Professor at the IBISC UR 4526 research center at Paris-Saclay University in France. He is interested in the implementation of 2D/3D interactions in real-time, multiplatform implementation and the integration of devices for interacting with virtual environments.

References

- Agarwal, R., and J. Prasad. 1998. "A Conceptual and Operational Definition of Personal Innovativeness in the Domain of Information Technology." *Information Systems Research* 9 (2): 204–215. doi:10.1287/isre.9.2.204.
- Anastassova, M., J.-M. Burkhardt, C. Mégard, and A. Leservot. 2005. *User-Centred Design of Mixed Reality for Vehicle Maintenance Training: An Empirical Comparison of Two Techniques for User Needs Analysis*. Las Vegas, USA: Actes de HCI International (CDROM).
- Anastassova, M. 2006. "L'analyse Ergonomique Des Besoins en Amont de la Conception de Technologies Émergente: Le Cas de la Réalité Augmentée Pour la Formation à la Maintenance Automobile." Doctoral Dissertation., Université Paris Descartes, France.
- Argelaguet Sanz, F., B. Arnaldi, J.-M. Burkhardt, G. Casiez, S. Donikian, F. Gosselin, X. Granier, et al. 2018. "Complexity and Scientific Challenges." In *Virtual Reality and Augmented Reality: Myths and Realities*. Wiley-ISTE, London: ISTE Editions.
- Barcenilla, J., and J. M. C. Bastien. 2009. "Acceptability of Innovative Technologies: Relationship Between Ergonomics, Usability, and User Experience (in French)." *Le travail humain* 72 (4): 311–331. <https://doi.org/10.3917/th.724.0311>.
- Benedetto-Meyer, M., and R. Chevallet. 2008. *Analyser Les Usages Des Systèmes D'information et Des TIC: Quelles Démarches, Quelles Méthodes?* Lyon, France: ANACT.
- Blythe, M.A., K. Overbeeke, A.F. Monk, and P.C. Wright, eds. 2004. *Funology: From Usability to Enjoyment*. Berlin/Heidelberg, Germany: Springer Netherlands. <https://www.springer.com/gp/book/9781402012525>.
- Bobillier Chaumon, M.-E. 2016. "The Situated Acceptance of ICT in/for the Activity: Towards a Clinical Use (in French)." *Psychologie du Travail et Des Organisations* 22 (1): 4–21. doi:10.1016/j.pto.2016.01.001.
- Bobillier-Chaumon, M.-E. 2013. *Conditions D'usage et Facteurs D'acceptation Des Technologies Dans L'activité: questions et Perspectives Pour la Psychologie du Travail*. Mémoire d'habilitation à diriger des recherches, Université Grenoble 2, France.
- Bobillier-Chaumon, M.-É., and M. Dubois. 2009. "Technology Acceptance and Acceptability in Organizations (in French)." *Le Travail Humain* 72 (4): 355–382. doi:10.3917/th.724.0355.
- Brangier, É., S. Hammes-Adelé, and J.-M C. Bastien. 2010. "Critical Analysis of Technology Acceptance Approaches: From Usability to Human-Technology-Organization Symbiosis (in French)." *European Review of Applied Psychology* 60 (2): 129–146. doi:10.1016/j.erap.2009.11.002.
- Brangier, E., and J.-M. Robert. 2014. "Prospective Ergonomics: The Foundations and Issues (in French)." *Le Travail Humain* 77 (1): 1–20. doi:10.3917/th.771.0001.
- Bruseberg, A., and D. McDonagh-Philp. 2002. "Focus Groups to Support the Industrial/Product Designer: A Review Based on Current Literature and Designers' Feedback." *Applied Ergonomics* 33 (1): 27–38. doi:10.1016/S0003-6870(01)00053-9.
- Buisine, S., A. Boisadan, and S. Richir. 2018. "Radical Innovation through the Extraordinary User Method (in French)." *Psychologie du Travail et Des Organisations* 24 (4): 374–386. doi:10.1016/j.pto.2017.11.001.
- Burkhardt, J.-M. 2003. "Some Relationships between Virtual Reality and Ergonomics (in French)." *Le Travail Humain* 66 (1): 65–91. doi:10.3917/th.661.0065.
- Cahour, B., and A. Lancry. 2011. "Émotions et Activités Professionnelles et Quotidiennes." *Le Travail Humain* 74 (2): 97–106. doi:10.3917/th.742.0097.
- Carroll, J.M., and R.L. Campbell. 1989. "Artifacts as Psychological Theories: The Case of Human-Computer Interaction." *Behaviour & Information Technology* 8 (4): 247–256. doi:10.1080/01449298908914556.
- Chaniaud, N., E. Loup-Escande, and O. Megalakaki. 2018. "Design, Understanding and Usability Evaluation of Connected Devices in the Field of Health: Contribution of Cognitive Psychology and Ergonomics." Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018),582–591. doi:10.1007/978-3-319-96098-2_72.

- Cheng, L.-K., M.-H. Chieng, and W.-H. Chieng. 2014. "Measuring Virtual Experience in a Three-Dimensional Virtual Reality Interactive Simulator Environment: A Structural Equation Modeling Approach." *Virtual Reality* 18 (3): 173–188. doi:10.1007/s10055-014-0244-2.
- Chow, M., D.K. Herold, T.-M. Choo, and K. Chan. 2012. "Extending the Technology Acceptance Model to Explore the Intention to Use Second Life for Enhancing Healthcare Education." *Computers & Education* 59 (4): 1136–1144. doi:10.1016/j.compedu.2012.05.011.
- Čudanov, M., and O. Jaško. 2012. "Adoption of Information and Communication Technologies and Dominant Management Orientation in Organisations." *Behaviour & Information Technology* 31 (5): 509–523. doi:10.1080/0144929X.2010.499520.
- Daft, R. L., and R. H. Lengel. 1986. "Organizational Information Requirements, Media Richness and Structural Design." *Management Science* 32 (5): 554–571.
- Damanpour, F. 1991. "Organizational Innovation: A Meta-Analysis of Effects of Determinants and Moderators." *Academy of Management Journal* 34 (3): 555–590. doi:10.2307/256406.
- Davis, F.D. 1989. "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology." *MIS Quarterly* 13 (3): 319–340. doi:10.2307/249008.
- Diaper, D., and N.A. Stanton. 2004. *The Handbook of Task Analysis for Human-Computer Interaction*. New Jersey, USA: Lawrence Erlbaum Associates.
- Dourish, P. 2003. "The Appropriation of Interactive Technologies: Some Lessons from Placeless Documents." *Computer Supported Cooperative Work (CSCW)* 12 (4): 465–490. doi:10.1023/A:1026149119426.
- Ehn, P. 1993. "Scandinavian Design: On Participation and Skill." In *Participatory Design: Principles and Practices*, edited by Douglas Schuler and Aki Namioka. Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Engeström, Y. 2001. "Expansive Learning at Work: Toward an Activity Theoretical Reconceptualization." *Journal of Education and Work* 14 (1): 133–156. doi:10.1080/13639080020028747.
- Falzon, P. 2004. "1. Nature, Objectifs et Connaissances de l'Ergonomie. Éléments D'une Analyse Cognitive de la Pratique." In *Ergonomie*, 15–35. Paris, France: Presses Universitaires de France; Cairn.info. doi:10.3917/puf.falzo.2004.01.0015.
- Fetscherin, M., and C. Lattemann. 2008. "User Acceptance of Virtual Worlds." *Journal of Electronic Commerce Research* 9: 231–242.
- Fishbein, M., and I. Ajzen. 1975. *Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research*. Reading, MA: Addison-Wesley.
- Fu, F.-L., R.-C. Su, and S.-C. Yu. 2009. "EGameFlow: A Scale to Measure Learners' Enjoyment of e-Learning Games." *Computers & Education* 52 (1): 101–112. doi:10.1016/j.compedu.2008.07.004.
- Guillermo, A.B., F. Nouviale, J. Ardouin, E. Marchand, M. Marchal, and A. Lécuyer. 2016. Enjoy 360° vision with the FlyVIZ. ACM SIGGRAPH 2016 Emerging Technologies. doi:10.1145/2929464.2929471.
- Haradji, Y., L. Faveaux. 2006. "Evolution in Our Design Practice (1985 -2005): Modelling to Improve Cooperation with Utility and Usability as Starting Criteria... (in French)." *Activites* 03 (1): 67–98. doi:10.4000/activites.1852.
- Hassenzahl, M. 2001. "The Effect of Perceived Hedonic Quality on Product Appealingness." *International Journal of Human-Computer Interaction* 13 (4): 481–499. doi:10.1207/S15327590IJHC1304_07.
- Hassenzahl, M., M. Burmester, and F. Koller. 2003. "AttrakDiff: Ein Fragebogen Zur Messung Wahrgenommener Hedonischer Und Pragmatischer Qualität." In *Mensch & Computer 2003: Interaktion in Bewegung*, edited by G. Szwillus and J. Ziegler, 187–196. Berlin, Germany: Vieweg+Teubner Verlag. doi:10.1007/978-3-322-80058-9_19.
- Hassenzahl, M., and N. Tractinsky. 2006. "User Experience—a Research Agenda." *Behaviour & Information Technology* 25 (2): 91–97. doi:10.1080/01449290500330331.
- Herrero, R., J. Bretón-López, L. Farfallini, S. Quero, I. Miralles, R. Baños, and C. Botella. 2015. "Acceptability and Satisfaction of an ICT-Based Training for University Teachers." *Educational Technology & Society* 18 (4): 498–510.

- Jaruzelski, B., V. Staack, and B. Goehle. 2014. "Proven Paths to Innovation Success." *Strategy + Business* 77: 1–16.
- Jordan, P.W. 1998. "Human Factors for Pleasure in Product Use." *Applied Ergonomics* 29 (1): 25–33. doi:10.1016/S0003-6870(97)00022-7.
- Kennedy, R.S., N.E. Lane, K.S. Berbaum, and M.G. Lilienthal. 1993. "Simulator Sickness Questionnaire: An Enhanced Method for Quantifying Simulator Sickness." *The International Journal of Aviation Psychology* 3 (3): 203–220. doi:10.1207/s15327108ijap0303_3.
- Kjeldskov, J. 2003. "Human-Computer Interaction Design for Emerging Technologies Virtual Reality, Augmented Reality and Mobile Computer Systems." Doctoral Dissertation., Aalborg University, Denmark.
- Klein, G., and L. Militello. 2001. "Some Guidelines for Conducting a Cognitive Task Analysis." In *Advances in Human Performance and Cognitive Engineering Research, Vol. 1. Advances in Human Performance and Cognitive Engineering Research*, edited by E. Salas, 163–199. Stamford, CT: Elsevier Science/JAI Press. doi:10.1016/S1479-3601(01)01006-2.
- Lapointe, L., and S. Rivard. 2005. "A Multilevel Model of Resistance to Information Technology Implementation." *MIS Quarterly* 29 (3): 461–491. doi:10.2307/25148692.
- Laville, A. 2004. "Repères Pour Une Histoire de l'Ergonomie Francophone." In *Ergonomie*, edited by P. Falzon, 37–50. Paris: PUF. doi:10.3917/puf.falzo.2004.01.0037.
- Leontiev, A.N. 1974. "The Problem of Activity in Psychology." *Soviet Psychology* 13 (2): 4–33. doi:10.2753/RPO1061-040513024.
- Lin, J. J. W., and D.E. Parker. 2007. "User Experience Modeling and Enhancement for Virtual Environments That Employ Wide-Field Displays." In *Digital Human Modeling*, edited by V.G. Duffy, 423–433. Berlin, Allemagne: Springer Heidelberg.
- Loup-Escande, E., J.-M. Burkhardt, O. Christmann, and S. Richir. 2014. "Needs' Elaboration between Users, Designers and Project Leaders: Analysis of a Design Process of a Virtual Reality-Based Software." *Information and Software Technology* 56 (8): 1049–1061. doi:10.1016/j.inf-sof.2014.04.008.
- Loup-Escande, É., J.-M. Burkhardt, and S. Richir. 2013. "Anticipating and Evaluating the Usefulness of Emerging Technologies in Ergonomic Design: A Review of Usefulness in Design (in French)." *Le Travail Humain* 76 (1): 27. doi:10.3917/th.761.0027.
- Loup-Escande, E., O. Christmann, R. Damiano, F. Hernoux, and S. Richir. 2014. "Virtual Reality Learning Software for Individuals with Intellectual Disabilities: Comparison between Touchscreen and Mouse Interactions." *International Journal on Child Health and Human Development* 7 (4): 415–424.
- Loup-Escande, É., É. Jamet, M. Ragot, S. Erhel, N. Michinov, C. Peltier, and T. Lopez. 2015. "Designing Virtual Environments with End Users: The Case of the VirtualiTeach Project." *Terminal. Technologie de l'information, Culture & Société* 117: 1–19. <http://journals.openedition.org/terminal/1093>.
- Loup-Escande, E., and J.-M. Burkhardt. 2019. "Evaluating Usefulness in the Context of Emerging Technologies to Identify Latent Needs: elements from an Analysis of the Interactions in in-Use." *Activités* 16 (2): 1–26. doi:10.4000/activites.4554.
- Loup-Escande, E. in press. "Technologies Émergentes." In *Dictionnaire Encyclopédique de l'Ergonomie*, edited by G. Valléry and E. Brangier. Malakoff (France).
- Mahlke, S. 2008. *User Experience of Interaction with Technical Systems: Theories, Methods, Empirical Results and Their Application to the Development of Interactive Systems*. Saarbrücken: VDM Verlag.
- Mathieu, J.E., and D.M. Zajac. 1990. "A Review and Meta-Analysis of the Antecedents, Correlates, and Consequences of Organizational Commitment." *Psychological Bulletin* 108 (2): 171–194. doi:10.1037/0033-2909.108.2.171.
- Moulières-Seban, T., D. Bitonneau, and J.-F. Thibault. 2016. La Cobotique: Un Domaine Pluridisciplinaire Émergent Utile à l'Ergonome. *51ème Congrès International de la SELF*, Marseille, France, Septembre 21–23.
- Nelson, J., S. Buisine, A. Aoussat, and C. Gazo. 2014. "Generating Prospective Scenarios of Use in Innovation Projects." *Le Travail Humain* 77 (1): 21. doi:10.3917/th.771.0021.

- Nielsen, J. 1994. *Usability Engineering*. San Diego: Academic Press.
- Norman, D.A., and S.W. Draper. 1986. *User Centered System Design: New Perspectives on Human-Computer Interaction*. Hillsdale: Lawrence Earlbaum Assoc.
- Oliver, R.L. 1981. "Measurement and Evaluation of Satisfaction Processes in Retail Settings." *Journal of Retailing* 57 (3): 25–48.
- Orlikowski, W.J. 2000. "Using Technology and Constituting Structures: A Practice Lens for Studying Technology in Organizations." *Organization Science* 11 (4): 404–428. doi:10.1287/orsc.11.4.404.14600.
- Rabardel, P., and P. Beguin. 2005. "Instrument Mediated Activity: From Subject Development to Anthropocentric Design." *Theoretical Issues in Ergonomics Science* 6 (5): 429–461. doi:10.1080/14639220500078179.
- Rabardel, P., and G. Bourmaud. 2003. "From Computer to Instrument System: A Developmental Perspective." *Interacting with Computers* 15 (5): 665–691. doi:10.1016/S0953-5438(03)00058-4.
- Rabardel, P., N. Carlin, M. Chesnais, N. Lang, and M. Pascal. 1998. *Ergonomie Concepts et Méthodes (2010)*. Toulouse, France: Octarès Editions.
- Rasimah, C. M. Y., A. Ahmad, and H.B. Zaman. 2011. "Evaluation of User Acceptance of Mixed Reality Technology." *Australasian Journal of Educational Technology* 27 (8): 1369–1387. doi:10.14742/ajet.899.
- Resnick, M., B.A. Myers, K. Nakakoji, B. Shneiderman, R.F. Pausch, T. Selker, and M. Eisenberg. 2005. *Design Principles for Tools to Support Creative Thinking*. Washington DC: National Science Foundation workshop on Creativity Support Tools.
- Robert, J.-M., and E. Brangier. 2009. "What is Prospective Ergonomics? A Reflection and a Position on the Future of Ergonomics." In *Ergonomics and Health Aspects of Work with Computers*, edited by B.-T. Karsh, 162–169. Berlin, Allemagne: Springer Heidelberg.
- Sagnier, C., E. Loup-Escande, D. Lourdeaux, I. Thouvenin, and G. Vallery. 2020. "User Acceptance of Virtual Reality: An Extended Technology Acceptance Model." *International Journal of Human-Computer Interaction*. 36 (11): 993–1007. doi:10.1080/10447318.2019.1708612.
- Sagnier, C., E. Loup-Escande, and G. Vallery. 2019. "Technology Acceptance of Virtual Reality: A Review (in French)." *Le Travail Humain* 82 (3): 183–212. doi:10.3917/th.823.0183.
- Salmon, P.M. 2016. "Bigger, Bolder, Better: methodological Issues in Ergonomics Science." *Theoretical Issues in Ergonomics Science* 17 (4) : 337–344. doi:10.1080/1463922X.2016.1156783.
- Sattar, M.U., S. Palaniappan, A. Lokman, N. Shah, U. Khalid, and R. Hasan. 2020. "Motivating Medical Students Using Virtual Reality Based Education." *International Journal of Emerging Technologies in Learning (iJET)* 15 (02): 160–174. doi:10.3991/ijet.v15i02.11394.
- Sebillotte, S., and D.L. Scapin. 1994. "From Users' Task Knowledge to High-Level Interface Specification." *International Journal of Human-Computer Interaction* 6 (1): 1–15. doi:10.1080/10447319409526080.
- Short, J., E. Williams, and B. Christie. 1976. *The Social Psychology of Telecommunications*. London: John Wiley.
- Soares, M.M., and F. Rebelo. 2012. "Ergonomics in Design: solutions and Proposals for a Better Interface with the User." *Theoretical Issues in Ergonomics Science* 13 (1): 1–3. doi:10.1080/1463922X.2011.649841.
- Stanton, N., A. Hedge, K. Brookhuis, E. Salas, and H. Hendrick. 2005. *Handbook of Human Factors and Ergonomics Methods*. Boca Raton, Florida, USA: CRC Press.
- Suchman, L.A. 1987. *Plans and Situated Actions: The Problem of Human-Machine Communication*. New York, USA: Cambridge University Press.
- Szelwar, L.I., and H. Le Doaré. 2006. "Alain Wisner: Le Développement de l'ergonomie et de la Pensée Sur le « Travailler »." *Travailler* 15 (1): 39–54. doi:10.3917/trav.015.0039.
- Tcha-Tokey, K., O. Christmann, E. Loup-Escande, G. Loup, and S. Richir. 2018. "Towards a Model of User Experience in Immersive Virtual Environments." *Advances in Human-Computer Interaction* 2018: 1–10. doi:10.1155/2018/7827286.
- Terrade, F., H. Pasquier, J. Reerincq-Boulanger, G. Guingouain, and A. Somat. 2009. "Social Acceptability: Effect of Social Determinants in Analyzing the Acceptability of Technological Systems (in French)." *Le Travail Humain* 72 (4): 383–395. doi:10.3917/th.724.0383.

- Tokel, S.T., and V. İslar. 2015. "Acceptance of Virtual Worlds as Learning Space." *Innovations in Education and Teaching International* 52 (3): 254–264. doi:10.1080/14703297.2013.820139.
- Turner, M., B. Kitchenham, P. Brereton, S. Charters, and D. Budgen. 2010. "Does the Technology Acceptance Model Predict Actual Use? a Systematic Literature Review." *Information and Software Technology* 52 (5): 463–479. doi:10.1016/j.infsof.2009.11.005.
- Valléry, G., M.-E. Bobillier-Chaumon, E. Brangier, and M. Dubois. 2016. *Psychologie du Travail et Des Organisations: 110 Notions Clés*. Paris, France: Dunod.
- Venkatesh, V., M.G. Morris, G.B. Davis, and F.D. Davis. 2003. "User Acceptance of Information Technology: Toward a Unified View." *MIS Quarterly* 27 (3): 425–478. doi:10.2307/30036540.
- Von Hippel, E. 2005. *Democratizing Innovation*. Cambridge, Massachusetts, USA: MIT Press.
- Vygotski, L.S. 1997. *Pensée et Langage*. Paris, Paris: La Dispute.
- Wilson, J.R., R.M. Eastgate, and M. D'Cruz. 2014. "Structured Development of Virtual Environments. In Taylor & Francis Group." In *Handbook of Virtual Environments: Design, Implementation, and Applications*, edited by K.S. Hale and K.M. Stanney, 353–378. Boca Raton: CRC Press.
- Wilson, John R., and M. D'Cruz. 2006. "Virtual and Interactive Environments for Work of the Future." *International Journal of Human-Computer Studies* 64 (3): 158–169. doi:10.1016/j.ijhcs.2005.08.007.
- Witmer, B.G., and M.J. Singer. 1998. "Measuring Presence in Virtual Environments: A Presence Questionnaire." *Presence: Teleoperators and Virtual Environments* 7 (3): 225–240. doi:10.1162/105474698565686.
- Wu, W., A. Arefin, R. Rivas, K. Nahrstedt, R. Sheppard, and Z. Yang. 2009. "Quality of Experience in Distributed Interactive Multimedia Environments: Toward a Theoretical Framework." *Proceedings of the 17th ACM International Conference on Multimedia*, 481–490. doi:10.1145/1631272.1631338.