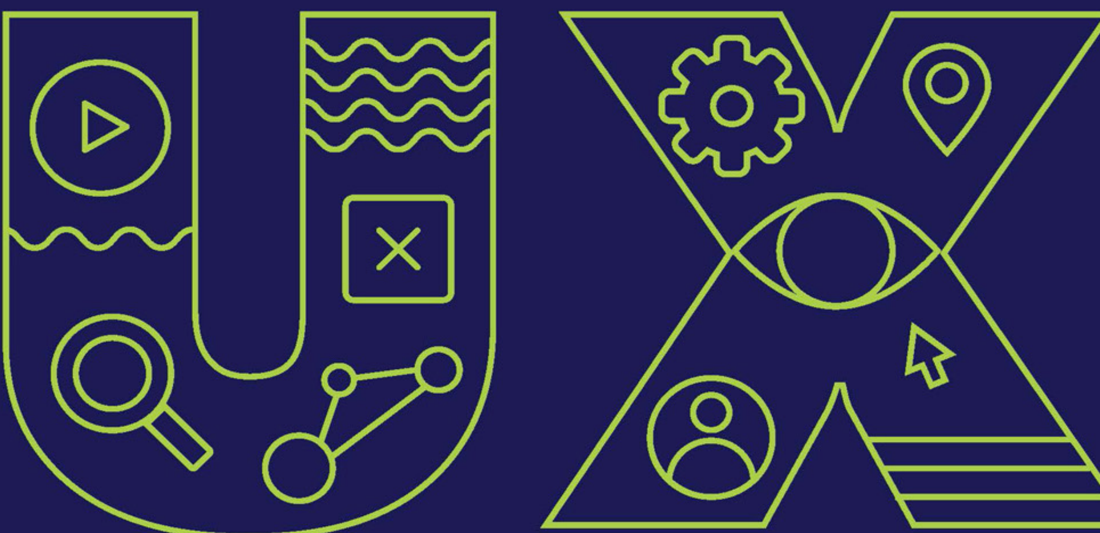
# Handbook of Usability and User Experience

## Methods and Techniques




**Edited by**
Marcelo M. Soares
Francisco Rebelo
Tareq Z. Ahram



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# Contents

# Preface

Each day we interact with dozens of products and systems. From the simplest to the most complex, each with its particular forms and interaction requirements, those forms and requirements must meet user needs. To meet the user needs, products, systems and environments must have specific usability characteristics for this purpose. The result of a good interaction is the by-product of a good design which provokes a positive user experience.

Global challenges altered social and working relationships, and ways of interaction with products and systems. In order to attend to these new requirements, new methods of interactions must be rethought to promote a better user experience.

This volume of the *Handbook of Usability and User Experience* will present methods and techniques to be used to design products, systems and environments with good usability and accessibility and user satisfaction.

This first volume, *Handbook of Usability and User Experience: Methods and Techniques*, contains 18 chapters. It is divided into five parts. Part I includes seven chapters, discussing methods and models for usability and UX. These chapters introduce the concepts of usability and its association with user experience, the methods and models for usability and user experience; relevant cognitive, cultural, social and experiential individual differences, which are important for understanding, measuring and utilizing individual differences in the study of usability and interaction design; a human-centered, participatory framework for the development and implementation of technology in a work environment is also introduced. Additionally, new methods and approaches for collecting usability and UX, using full-size mock-up,and understanding the mechanics of focus groups to be applied by designers are presented and discussed.

Part II, which contains three chapters, is related to usability and UX in the health sector. The use of usability assessment to improve healthcare is presented. Three case studies are reported in which digital applications connected patients to healthcare services are described. A study focusing on the effectiveness of and satisfaction with animations representing four types of medicines usage conducted with user-patients and health professionals is introduced. Finally, case studies are reported in which digital applications connected patients for healthcare services.

Part III presents two chapters on the relationship between usability and user experience in the built environment. The first one introduces concepts, methods and techniques of usability and user experience related to the built environment. The second chapter discusses people's interactions with built environments, and how the new technologies are changing this interaction and architecture.

Part IV summarizes the state-of-the-art review of usability and UX in the digital world. Digital human modeling in usability is discussed and the application of DHM in three different setups is shown. The remaining chapters introduce sensitive aspects of the users' interaction with machine learning (ML) algorithms, and how users perceive the relationship with voice interfaces and personified virtual assistants.

Part V presents the usability and UX in the current context and emerging technologies. In the first chapter, the authors discuss the changes, transformation of life and adaptation in face of the new scenario presented by the global pandemic crisis in the year 2020 and the consequences regarding the adoption of new behaviors and user experience. In the next chapters, a new technology based on infrared computerized thermography is presented for the evaluation of product usability, and an integrated model to evaluate the user experience (UX), based on the user emotional reactions and behavioral decisions, using virtual reality and biosensors technologies is discussed and analyzed.

We hope that this first of two volumes will be useful to a large number of professionals, students and practitioners who strive to incorporate usability and user experience principles and knowledge in a variety of applications. We trust that the knowledge presented in this volume will ultimately lead to an increased appreciation of the benefits of usability and incorporate the principles of usability and user experience to improve the quality, effectiveness and efficiency of consumer products, systems and environments in which we live.

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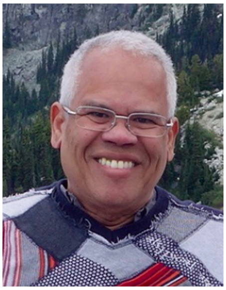

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# Section 1

## Methods and Models for Usability and UX

# 1 Usability and User Experience

## *Methods and Models*

*Marcelo M. Soares, Tareq Ahram and Christianne Falcão*

## CONTENTS



## 1.1 INTRODUCTION

In the home, office and leisure environments, we deal with a wide variety of consumer products on a daily basis. To gain a cutting edge in an increasingly competitive market space, manufacturers are constantly looking for ways to improve the quality of their products. On the other hand, users are increasingly demanding of better quality products and have less tolerance for difficulties in the use of products, giving greater emphasis to designs and products that are easy to use and allow for ease of learning and better aesthetics (Han et al., 2001). If a product or system is difficult to use, it wastes user time and causes frustration and discomfort, thereby discouraging its use.

The market for consumer products is characterized by constant change. It is expected to add new features and functionality to products, making them increasingly complex over the years. Manufacturing companies are expected to keep up with this rapid technological evolution, designing and manufacturing products not only with better performance but also lower costs at an accelerated pace. According to Acosta et al. (2011), companies identify usability as a strategic factor in product competitiveness, efficiency, differentiation and best practice, which can be integrated into the different phases of the product development lifecycle. Product development,

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according to Krishnan and Ulrich (2001), is the transformation of the market opportunity into a product available for sale to consumers and users.

Based on the belief that the design of the product must meet the user's needs, usability focuses on creating an excellent user experience, which is in the process that underlies the real goal of usability. The user experience and usability evaluation process starts by looking at who uses the product, understanding their goals and needs and selecting the right techniques to answer the question: does this product meet the user's needs and requirements?

Usability evaluation focuses on understanding how people use the product, with regard to the interaction between the user, the task and the product. Some authors (Jordan, 1998; Norman, 2006; Preece et al., 2002; Göbel, 2011) report that in the past, many products were designed with little emphasis on the user, and this caused frustration and wasted time as they did not offer adequate usability. With the saturation of the market and consistent technological advancements, aspects such as aesthetics and features that can be associated with usability have become ever more important for determining product value and brand success. In parallel, this issue was emphasized by the growing complexity of products, requiring greater attention to user needs, and in order to allow technical benefits to be explored. During this phase of identifying user needs and requirements, which started in the 1990s, usability parameters received greater attention, initially with a focus on market studies, engaging the user more and more in the design process.

Although usability is well known as a key element in product design, the concepts used are derived from the field of human–computer interaction (HCI), highlighting the need to formalize the concept when it comes to consumer products. This chapter introduces various usability concepts, presenting the evolution of their application in consumer products over the past three decades.

## 1.2 WHAT IS USABILITY

The concept of usability was first discussed by Shackel (1984), who defines usability of a system or equipment as its ability to be used easily and effectively, in human functional terms, by a specific range of users, when receiving adequate training and support for fulfilling a specific task, within a certain expected time interval and environmental factors. That is, usability corresponds to the capacity of product, system or service to be used easily and effectively by humans (Shackel, 1991, p. 24).

Usability is better known and better defined in terms of the approach to HCI. These concepts are used to improve the user–software interface side of the product (Nielsen, 1993). The importance of this dimension in the design of consumer products was first considered in the early 1990s by companies such as Thomson Consumer Electronics, Apple Computers and Northern Telecom (March, 1994). Later, Jordan (1998, 2000) noted a theme of growth with the increase of publications in the field, more usability professionals being employed, more research conferences on the subject and greater public awareness of the field of usability and user experience. Since the last decade, usability has been applied on a large scale to design products that are easy to use, easy to learn, accessible and comfortable, making our daily life less stressful and more productive.

Nielsen (1993) considers usability as an aspect, among others, that influences the acceptance of a product, whose objective is to develop transparent interfaces capable of offering easy, pleasant, effective and efficient interaction, allowing the user full control of the environment without becoming an obstacle during the interaction.

Nielsen also suggests that usability and ease of use can together form a usable system. The usefulness of the product can be defined as its ability to perform its intended functions and necessary operations, and that usability corresponds to how well the product works so the user can use its functionality. This view is supported by Eason (1984), stating that usability can limit the degree to which a user can perform a potential objective of a computer system.

Steve Krug, in his famous book *Don't Make Me Think!* (Krug, 2000), features usability from a simple perspective, with the certainty that something works well when a person with skill and average experience (or even minimal experience) can use a product for which it is intended and designed, without getting confused or frustrated. According to Bevan (1995), usability is often defined as the ease of use and acceptability of features in a system for a particular class of users who perform specific tasks in a determined environment. This will facilitate user performance and overall product satisfaction, while acceptability influences the system when used. However, the expression "easy to use" offers little guidance on the product interface.

The International Organization for Standardization issued the ISO 9241-11 (ISO, 2018) which brings the most classical and recognized usability concept together in a unified standard: "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use."

*Effectiveness* refers to "the extent to which an objective or task is achieved. Effectiveness measures the relationship between the results obtained and the intended objectives; that is, to be effective is to achieve a given objective." *Efficiency* refers to "the amount of effort required to achieve an objective." The less the effort, the greater the efficiency. *Satisfaction* refers to the level of comfort the user feels when using a product and how acceptable the product is to the user in relation to the desire to achieve their goals.

Comparing the definition of ISO as proposed by Shackel (1991), it is evident that importance is given by the researcher to the fact that usability is dependent on the context of use. Jordan (2006) corroborates by highlighting that the definition given by ISO makes it clear that usability is not simply a product property in isolation, but that it also depends on who is using the product, the objective that it intends to achieve and in what environment the product is being used.

Thus, the usability of the product must be assessed from three aspects: the user, the product and the context of use.

## 1.3 FOCUSING ON THE USER

Nielsen (1993) highlights that the two most important considerations for usability are the user's task and users' individual characteristics and differences. For Norman

(1999), product development is focused on the human being and the process must be initiated with users and their needs in mind instead of technology. The technology's purpose is to serve the user through its suitability to the task. If there is any complexity, it must be inherent in the task and not the tool.

The user, according to Ward (2011), refers mainly to the category of population inserted between the owner of the technology and the end-user of a particular type of consumer product. Some designers use the term "*target market*" to describe a population of users for which a product is being developed. It is also important to consider that, in certain types of products, people involved in installation and maintenance can also be considered users if their needs are identified as having an impact on the design process and on the final results.

Dejean and Wagstaff (2012) propose the following question to identify all users and divide them between the direct and indirect users: does the "user" choose the product with which it is interacting or not? Therefore, if the answer is yes, then it's a direct user; if the answer is no, then it is an indirect user.

On many occasions people may contact involuntarily products being classified as indirect users. Considering the behavior of users and the consequence of use, it is important to identify the indirect users to preview the role in the evaluation of usability. On the other hand, direct users correspond to people who have a voluntary choice to use the product (Dejean; Wagstaff, 2012). An example is a wheelchair user (the direct user) and their carer (the indirect user).

Therefore, the defining of the user must include all those whose work is affected by the product in some way. Before starting design, it is important to consider the characteristics of those who will use the final product (both the direct and the indirect user), for whom the product is intended. According to Jordan (1998), this can be, for example, the general public, a private session of a consumer population, a small group of specialists or even an individual user. The important aspect here is to understand the characteristics of people who will use the product and information about the various features of the product, and what are the implications caused by their use; for example, some products are safety-critical systems, while others are for entertainment; therefore, for example, reliability and redundancy factors can affect various features to prevent or reduce the chance of human error and mistakes. Consider, for example, power plants or control security systems. From there (where accuracy and error-free are essential), requirements are generated so that users' needs are addressed in the project.

The population of users with special needs is of particular importance to usability evaluation and product design. Some products must meet specific requirements and be used by various user types, whether senior citizens, the elderly or those with visual, auditory, cognitive-mental or movement impairments. Kumin et al. (2012) carried out a study to assess how users with Down syndrome could use *touch screens* in their tasks. The research sought solutions so that usability tests could be conducted using what is termed in the field of usability evaluation as a "participant profile," as well as to identify potential challenges encountered in the use of *tablets*.

Jordan (1998) draws attention to the need to know the user's physical and cognitive characteristics while designing consumer products. The user's physical characteristics refer to people's individual measurements for the purpose of understanding human physical variation, for example, height, reach or strength. Cognitive characteristics include specific knowledge that users may have, such as attention, knowledge, information processing, attitudes expected by users or any expectations that users may have about a product. Such factors are susceptible to variation according to the target audience for which the product is intended.

Jordan (1998) states that to determine the target audience, some user characteristics must be considered:

- **Experience**: Previous experience with the product, or similar products, is one of the factors that affects the user's ease of use or difficulty in performing a certain task.
- **Domain of knowledge**: This refers to the user's knowledge of the task and/or if it is necessarily linked to the product used to perform it.
- **Cultural background**: The culture of users is also a factor that influences their interaction with products. Information tools must be in accordance with local culture-population stereotypes.
- **Limitations**: It must be taken into account that not all users are in full physical functionality. Many have physical and/or mental limitations that must be considered.
- **Age and gender**: Seniors, adults, youth, teens and children, male or female, should be treated specifically. The strength, the intellectual capacity and the performance of the tasks can be extremely affected by these factors, thus degrading or even damaging perception of the product's usability.

When observing the first three characteristics described by Jordan, these represent a focus on the importance of observing the user's previous experience; that is, the knowledge acquired from interaction with the use of the product, and personal characteristics and experiences, also called "repertoire of knowledge." In this direction, Chamorro-Koc et al. (2009) emphasize the importance for the designer to consider the user's cultural knowledge and previous experience instead of following their own personal interpretations to describe the user's needs and the prediction of their behavior.

There are many different types and characteristics of users. Because of this, understanding its nature implies great difficulties, requiring efforts that go beyond market research. Given the difficulty of classifying users, Meister and Enderwick (2002) suggested addressing them from the following perspective:

- **The user as a subject in usability and prototyping tests**, where the focus is on knowing how and how good or bad their performance is in relation to a particular equipment or to a characteristic of this equipment.
- **The user as someone who has preferences**, particularly for consumer products.
- **The user as a specialist in specific subjects**, as an information provider.

## 1.4 UNDERSTANDING CONSUMER PRODUCTS

The human race has survived for hundreds of thousands of years, if not 2 million years, in diverse contexts, often hostile. Human beings have always been trying to build utensils that strengthen or complement their natural characteristics and aptitudes, for example inventing the wheel to help move heavy weights, or sewing animal cloths to survive harsh winters and ice ages. This has made it possible for human beings to survive in challenging times, thus allowing human dominance in the environment in which they live. In this way, some human needs are met by the use of objects, which means products being used. Such products reflect the environmental, social and cultural conditions of a society, and can be produced in an artisanal or industrial way. In the industrial form, products are produced by means of industrial processes for mass consumption, and the product becomes a particular offer that a company provides to customers (Kahn, 2001).

Products, to give a broad definition, are physical and tangible elements, whereas services are intangible. Among these, it is important to characterize consumer products. According to several authors (Cushman; Rosenberg, 1991; Schulze, 2011), there is a difference between consumer products and commercial or industrial products. The latter refers to machinery and equipment for use in industry in general, and more specifically in production, to produce goods and provide services. Consumer products are those for personal, family or domestic use in a residential or social environment and not in a work environment, such as appliances, furniture and toys. The ISO 20282-1 standard (ISO, 2006) describes consumer products as intended to be purchased and used by an individual for personal use instead of professional use, such as electric kettles, smartphones and electric drills.

The major differences between product consumption and product trades are the number of characteristics, the capacity of production and operation speed. Consumer products are distributed through a long channel with many steps between the factory and the final consumer and are usually purchased in small quantities by a single individual (user) from the retail trade. In contrast, commercial products are usually purchased by a wholesale buyer of a company or by the manager (Cushman; Rosenberg, 1991; Schulze, 2011).

As for users of consumer products, they are usually not trained, not specialized and not supervised by agents experienced in purchasing. They are also subject to irregular, less systematic use and even to uses not foreseen by the manufacturer. The user of a commercial product is usually trained, highly specialized and supervised.

Besides, these users have at their back several people who support the operation of the product, such as toolmakers, job analysts and maintenance technicians. These products are rarely used differently from what was programmed by the company and envisaged by the manufacturer (Cushman; Rosenberg, 1991; Schulze, 2011). However, users can be of any age, gender or physical condition, as well as of great educational, cultural or economic variation (Hunter, 1992).

Both consumer products and commercial products depend on intense marketing and need to be continually improved in order to become competitive (Cushman; Rosenberg, 1991). To this end, the focus has a dual function, one being the quality of the interaction with the product and the other being the power of attractiveness of the product for purchase by appeal (Bauersfeld; Bennet; Lynch, 1992).

Nowadays, new design principles are being introduced to meet a new product concept called "*smart or intelligent product*." Based on theories developed in Germany for intelligent environments, this concept has been affecting economic and industrial growth in many nations. According to Ahram et al. (2011) and Das and Cook (2006), an intelligent environment is able to acquire and apply knowledge about an environment and adapt it to its inhabitants, promoting a better experience.

The Ambient Intelligence (AMI) group identifies two motivating objectives for the design of intelligent products (Sabou et al., 2009):

1. The growing need to simplify the use of daily products when their functionalities have become increasingly complex. Simplicity is timely throughout the product's life cycle from support to manufacture, repair and use.
2. Increase in the number, sophistication and diversity of product components, as well as the tendency for suppliers and manufacturers to become increasingly independent of each other, which requires a considerable degree of openness in the characteristics of the product.

The key issue that characterizes smart products is the knowledge aspect, representing products that facilitate daily tasks and expand everyday objects (Ahram, Karwowski, Soares, 2011). The Smart Products Consortium (SPC) defines a smart product as an autonomous object designed to self-incorporate into different environments throughout its life cycle and which allows natural human–product interaction. These products are able to proactively approach the user using sensors, input and output data, and have the ability to adjust to the environment, being sensitive to the situation and the context of use. The related knowledge and functionality can be shared and distributed among several smart products, evolving over time (Sabou et al., 2009; Ahram; Karwowski; Amaba, 2011; Ahram; Karwowski; Soares, 2011). Intelligent products are already part of our daily life and have instigated great transformations. In many airports, for example, a system has been adapted: self-check-in is an automated process, replacing long waiting lines for airlines' kiosk representatives, creating a self-service environment for travelers globally. Nowadays, those *check-ins* are done from the ease of your smartphone while riding to the airport in a soon-to-be autonomous self-driving car.

## 1.5 CONTEXT OF USE FOR CONSUMER PRODUCTS

When a product (or system) is developed, it will be used within a particular context and by a population of users with certain characteristics (Maguire, 2001). In this sense, the usability of the product is not an independent activity and is related to the context. Changing any aspect relevant to the context of use may change the ability to use the product (Bevan; Macleod, 1994).

Therefore, the characteristics of the context to determine usability must be as important as the characteristics of the product itself (Trivedi; Khanum, 2012).

Context of use, according to ISO 9241-11 (ISO, 2018), comprises users, tasks, equipment (*hardware*, *software* and materials) and the physical and social environment in which a product is used.

The physical context comprises the location where the user is performing the task. The natural environment is the real place of the product, and when tests are carried out in this environment, they are called field studies. An artificial environment is a simulation of the natural environment, sometimes called a controlled environment, and the studies performed in this environment are called laboratory studies or tests.

Field tests take place in a more natural environment. According to Markopoulos et al. (2008), in an artificial scenario, there is greater control of the data. Still, it lacks realism, while a natural scenario has realism but difficulties in control are encountered. These laboratory tests are performed in a controlled environment, providing greater control for the treatment and manipulation of variables. It is possible to employ facilities to collect data with high-quality streams, such as video recording. Laboratory tests have received both recognition and criticism. Razak et al. (2010) describe some advantages: the control of conditions for the accomplishment of the research, the possibility of all participants to experience the same configuration and to concentrate on the specific phenomena of interest of the research, facilitating data collection. Park and Lim (1999) point out that the simulation of usage settings is difficult, time-consuming and expensive and does not have contextual factors. Bruno and Muzzupappa (2010) point out that evaluation carried out in laboratories does not provide the discovery of usability problems that occur in the real world since laboratory tests are only simulations of product use.

The social context corresponds to the people involved and plays an important role in usability. The people involved can be the evaluators and monitors of the tests, as well as the users. There is also a substantial effect from other people who may not be directly involved with the assessment, such as family members and curious users. Stoica et al. (2005) found that, while laboratory evaluations provide excellent data, the social context as well as the presence of other people around them also play an important role. Although the social context is considered to be important, little research has been carried out to identify its influence on usability assessments (Triverdi; Khanum, 2012).

## 1.6 USABILITY MEASUREMENT

Usability measurements allow the term usability to become more concrete and easier to evaluate (Hornbaek, 2006). These measures are summarized in two aspects, efficiency and effectiveness, and are subsequently decomposed into various dimensions by several researchers. The basic idea is that usability can be measured and the aim is to know in practice how much the task with the product can be accomplished and successfully completed.

According to Tullis and Albert (2008), measuring user experience offers much more than just a simple observation. Metrics add structure to the design and solid evaluation process, give explanations to results and provide information for decision-makers. Without the information provided by usability metrics, important business decisions can be made with inadequate or even incorrect assumptions.

Tullis and Albert (2008) also added that usability metrics could help reveal patterns that are difficult or impossible to notice. When evaluating a product with a small sample, without collecting any metrics, the most obvious usability problems are usually revealed. However, there are other, more subtle problems that require the help of metrics.

Nielsen (1993) points out that usability is not a single property of an interface but has multiple components. In this sense, it considers five dimensions to define such a concept in a clear and objective way: *ease of learning*, *efficiency*, *easy to memorize*, *few errors* and *satisfaction*.

Nielsen's (1993) approach, among others outlined in Table 1.1, unifies three different aspects of usability (Nielsen, 1993; Han et al., 2001; Raita; Oulasvirta, 2011):

- **Operational measures**: The operational measures correspond to the quantitative variables corresponding to the performance, the task time and the number or error rate of the user.
- **Objective measures of usability related to the user's knowledge levels**: These measures correspond to the performance of the experienced user, the learning ability or learnability of the novice user and the ability to relearn by a casual user of a given product.
- **Subjective measures**: Subjective measures reflect opinions and experiences based on the user's perception.

**TABLE 1.1**
**Usability Dimensions from Different Authors and ISO Standard**

| Shackel (1991) | Nielsen (1993) | Abran et al. (2003) | Quesenbery (2003) | ISO 9241-11 (2018) | Rubin and Chisnell (2008) |
|---|---|---|---|---|---|
| **Objective dimensions** | | | | | |
| *Efficiency* | | *Efficiency* | *Effective* | *Efficiency* | *Effective* |
| | *Efficiency* | *Efficiency* | *Efficient* | *Efficiency* | *Efficient* |
| *Ease of learning* | *Ease of learning* | *Ease of learning* | *Easy to learn* | | |
| | *Easy to memorize* | | | | |
| | | | | | *Usable* |
| *Flexibility* | | | | | |
| | *Few errors* | | *Fault tolerance* | | |
| | | | | | *Accessibility* |
| | | *Safety* | | | |
| **Subjective dimensions** | | | | | |
| | *Satisfaction* | *Satisfaction* | *Engaged* | *Satisfaction* | *Satisfaction* |
| *Attitude* | | | | | |

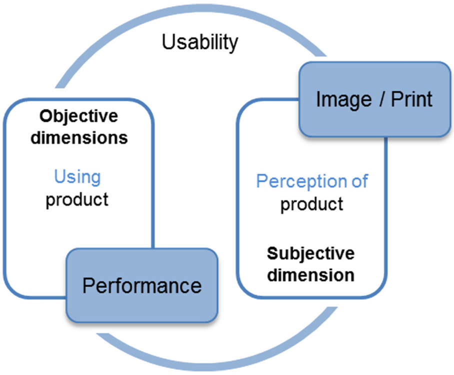


**FIGURE 1.1** Product usability approach. *Source:* Adapted from Han et al. (2001).

Based on Han et al. (2001), Figure 1.1 shows the product's usability approach considering the objective and subjective dimensions.

The usability dimensions presented by various researchers and the ISO standard are summarized in Table 1.1. Each line in the table has a dimension, grouped according to the definitions given by the authors and divided into objective and subjective. When looking at the table, it is noticed that many authors have dimensions with the same meaning but with different nomenclatures. The proposed dimensions combine usability with other attributes and concepts of systems or products, offering measurable usability criteria, which are necessary for their understanding.

However, the dimensions presented were developed to evaluate the *software* user interface and may leave gaps in the evaluation of consumer products. To meet this need, Kim and Han (2008), based on an in-depth literature review, propose 18 dimensions of usability for electronic consumer products, as shown in Table 1.2. It should be noted that not all the dimensions listed are relevant to all types of evaluation, and additional dimensions may be required for testing with products that have a particular type of system or specific performance.

## 1.7 USABILITY MODELS

The definitions of usability characterized by the dimensions presented previously need to be adapted in order to effectively facilitate the evaluation and testing of usability. To this end, some authors propose "usability models." According to Leventhal and Barnes (2008), a model not only sets out the characteristics of a usable interface but also indicates how the characteristics will fit, what they mean and how they contribute to usability. Without a model and its implications for the causal effect of different user interfaces and situational characteristics, the usability engineer/designer might have to guess the factors that potentially influence the usability of a product or system.

Different approaches for assessing usability are proposed in different contexts, such as *software* (Leventhal; Barnes, 2008) and electronic consumer products

**TABLE 1.2**
**Usability Dimensions for Electronic Consumer Products**

| Usability dimensions | Description |
|---|---|
| **Simplicity** | A product's interfaces and methods of interaction must be simple, clear and intuitively recognized. |
| **Consistency** | Interfaces and methods of interaction must be consistent within the product and between products in the same family. |
| **Modeling** | Each interface and method of interaction must have only one meaning and one behavior. |
| **Control locus** | The user must be given authority to control all functions and the appearance of the user interface. |
| **Direction** | All operations must be designed to give the user the feeling of direct manipulation. |
| **Feedback** | The status of the product and the consequences of any user operation must be provided clearly and immediately. |
| **Helpfulness** | Any useful information must be provided to the user whenever necessary. |
| **Pardon** | When an error is recognized, the user must be offered the possibility to take corrective actions. |
| **Error prevention** | Interaction interfaces and methods must be designed to prevent errors. |
| **Adaptability** | Interface changes should allow adaptation to different users and conditions in accordance with the experience, knowledge and preferences. |
| **Accessibility** | Any functions and interfaces must be easily accessible. |
| **Learning ability** | The effort required to learn interfaces and methods of interaction should be small. |
| **Memorization** | Interfaces and methods of interaction should be easy to remember. |
| **Familiarity** | Familiar interfaces and interaction methods must be adopted so the user can apply their previous experience. |
| **Predictability** | The interaction method and the meanings of the interfaces must be in accordance with the user's expectations. |
| **Informational** | The interfaces presented to the user must be clear and easy to understand. |
| **Efficiency** | All usage functions must be implemented in a product. |
| **Efficiency** | A product must be designed to allow a user to perform functions quickly, easily and economically. |

*Source:* Adapted from Kim and Han (2008, p. 336).

(Kwahk; Han, 2002; Kim; Han, 2008). Table 1.3 presents a summary of the usability models used, as well as their definitions.

The three models developed by Eason (1984), Shackel (1991) and Nielsen (1993), and presented in Table 1.3, suggest that certain properties of the interface have a causal influence on usability. In the Shackel and Nielsen models, a number of dimensions that contribute to usability are identified, whereas in the Eason model we find a different approach. According to Eason, the characteristics of the three

**TABLE 1.3**
**Taxonomy of Usability Models**

| Model | Dimensions | | Definition |
|---|---|---|---|
| Eason model (1984) | Assignment | Frequency | Number of times a task is performed by the user. |
| | | Opening | Extent to which a task is modifiable. |
| | User | Knowledge | The knowledge that the user applies to the task. This must be appropriate or not. |
| | | Motivation | What determine the user the fulfillment of his task? |
| | | Criterion | The user's ability not to choose to use any part of the system. |
| | System | Easy to learn | The effort required to understand and operate an unfamiliar system. |
| | | Easy to use | The effort required to operate a system once it is understood and mastered by the user. |
| | | Task match | The extent to which each information and function that a system provides corresponds to the user's needs for a given task. |
| Shackel model (1991) | Efficiency | | It is described by the task interval that must be better than the required performance level, as well as a specific percentage of a target user range within a specific range of the usage environment. |
| | Ease of learning | | Corresponds to the time between training the users and supporting the installation of the system, including the time of relearning. |
| | Flexibility | | Corresponds to the permission of some percentage variation specified in the task and/or in the environment in addition to what was specified first. |
| | Attitude | | Corresponds to acceptable levels of the human cost in terms of tiredness, discomfort, frustration and personal effort. |
| Nielsen model (1993) | Ease of learning | | The system must be easy to learn so that the user, even without having experience, can quickly begin to obtain satisfactory results from the work performed. |
| | Efficiency | | It is directly related to the productivity of the system so that once the user has learned the system, high productivity is possible. |
| | Easy to memorize | | The system must be easy to remember so that the occasional user does not have to learn everything about the system again after some time without using it. |
| | Few errors | | The system must have a low error rate so that users make fewer mistakes when using the system, and as soon as errors are made, they can be corrected simply and quickly. In addition, catastrophic errors should not occur. |
| | Satisfaction | | The system should allow pleasant interaction so that users are subjectively satisfied when using it. |

dimensions—*user*, *system* and *task*—are independent variables, and the way these dimensions interact with each other will influence usability results.

An important contribution of the model proposed by Eason is that you cannot measure usability without considering the user and the target task. These two approaches provide essential contextual information and can influence usability as much as the characteristics of the user interface itself.

The models proposed above were developed mainly to analyze *software* and *websites* from the context of human–computer interaction. However, they can be adapted to study the usability of consumer products.

In search of a specific model for products, Kahmann and Henze (1999; 2002) describe a model based on three elements: *object*, *intervention* and *result* (Figure 1.2). The PESC USESCAN® model has been widely applied in several product usability tests through the P5 company formed by the authors.

The *object* is the subject of the usability study. Depending on the production phase of the development process, the quality of the object can vary considerably. This variation corresponds from the conceptual to the material; that is, elements of the idea, the concept, the model, the prototype and the product.

The *intervention* corresponds to the object of usability testing. The type of an object determines the target of the intervention. This target, for example, can be visible product requirements based on a manager's ideas, or it can be testing concepts to determine specific requirements.

*Results* correspond to the data obtained in the *intervention* in the form of information. According to the authors, the resulting concept is not intentionally used because it can only be realized when the results are incorporated and accepted in a product development process.

As shown in Figure 1.2, a line is drawn representing the model proposed by the authors. The process starts by demonstrating the movement of the object from the

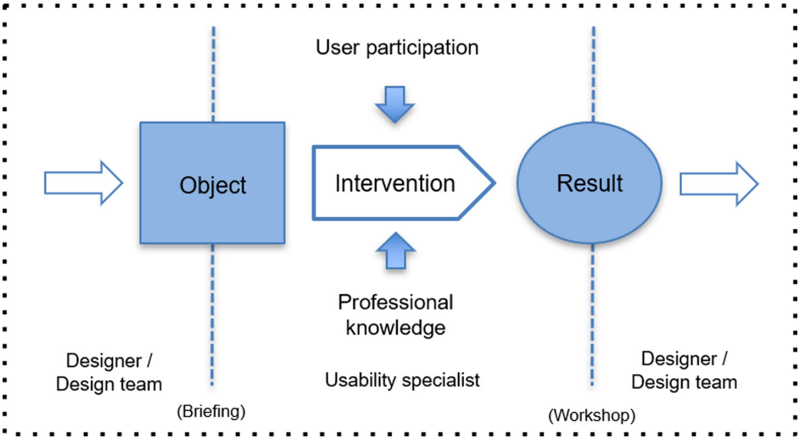


**FIGURE 1.2** P5 USESCAN model. *Source:* Adapted from Kahmann and Henze (2002, p. 300).

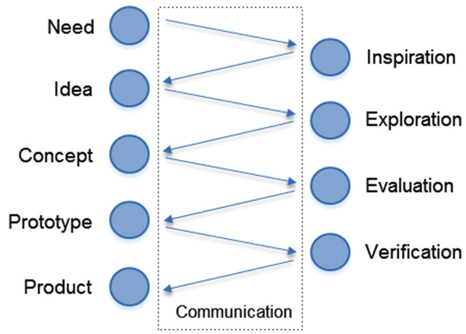


**FIGURE 1.3** *Ping-Pong* model. *Source:* Adapted from Kahmann and Henze (2002. p. 299).

designer (or team) to the usability professional who will develop the tests, from a *briefing*, represented by the line on the left. The process ends with the presentation of the data collected to the designer (or team) through a *workshop*, according to the line on the right. By doing this, the process can be repeated several times.

To better illustrate the product development phases in which usability tests are part, Kahmann and Henze (2002) propose an additional approach that consists of four phases: inspiration, exploration, evaluation and verification. Figure 1.3 represents this process as a whole. On the left are shown the different stages of materialization of the product, whereas on the right side are positioned the four phases of the study and usability.

Inspiration corresponds to the initial idea, *insight*. Exploration seeks what type of interaction can or should occur when using the product and which aspects are relevant, forming the concept of the product. The next phase corresponds to the evaluation of this concept. This corresponds to the testing of prototypes, the way in which different interactions work in a qualitative way. In the third and final phase, the verification will take place in a quantitative survey to verify that the expected interactions work in the right way. The completion of the process corresponds to the final product.

The information collected during the intervention must be divided into objective and subjective. The objective information, called professional knowledge, consists of the information of a physical and cognitive nature, corresponding to the data on dimensions, permissible forces, font sizes and color combinations. On the other hand, user input information is obtained from usability tests. In these tests, qualitative methods are generally used, and the results obtained are not absolute and can be considered as subjective data.

The model proposes several evaluations throughout the product development process. It demonstrates how usability analysis should be conducted, placing all elements in context. Although the approach is focused on the interaction between user and product based on the terms defined in ISO 9241-11, the configuration of this model allows adapting the dimensions of usability, or even one of the models previously presented, according to the objectives or scope evaluation.

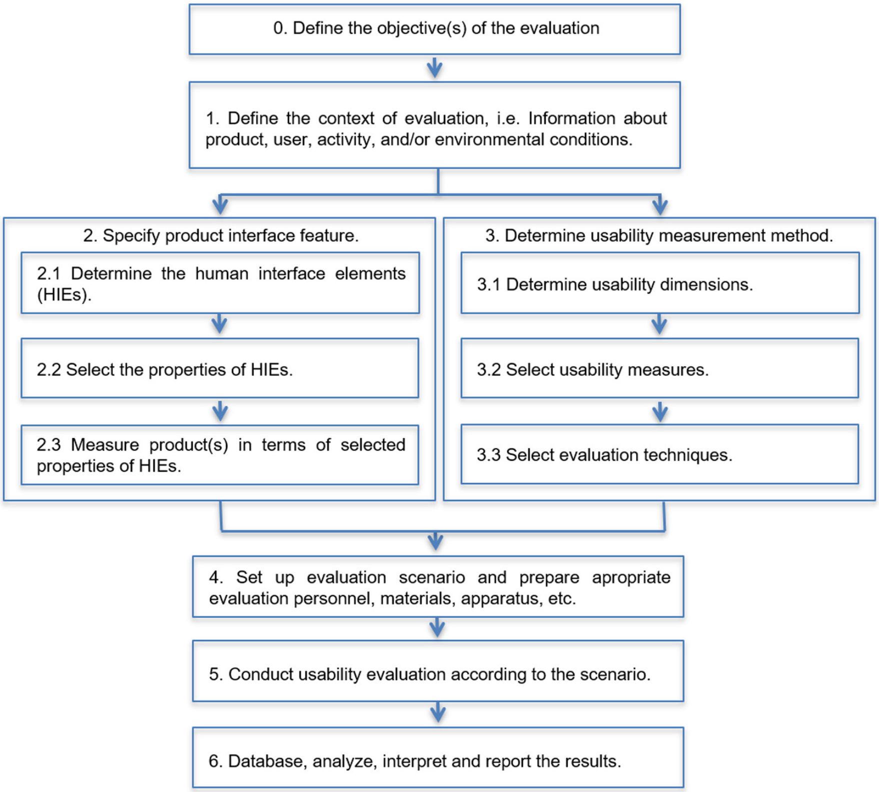


**FIGURE 1.4** Usability evaluation model. *Source*: Kwahk and Han (2002).

In the context of consumer electronic products, Kwahk and Han (2002) developed a usability evaluation model, as shown in Figure 1.4.

The usability assessment procedure begins with a preparatory phase. In phase 1, the evaluators will require the taxonomy of the context variables to define the status of the tests. From a list of context variables that are considered important, such as characteristics of users or the environment, evaluators need to configure each one as a constant, controlled or random variable.

Detailed information about the characteristics of the product interface to be evaluated is provided in phase 2. The elements of the human interface are first analyzed to subsequently measure each product in relation to these properties. In phase 3, the dimensions of usability, measures and evaluation techniques are determined. This step can be performed in parallel with step 2, if it is necessary.

Kim and Han (2008) propose a model that provides a level of usability by measures that can be used in step 3. The model consists of two phases: single integrated model and full model. The individual model is used to calculate the level of usability of each dimension proposed in Table 1.1, while the integrated model calculates the overall level of all these dimensions.

Step 4 is the place where the assessors build the scenario for the assessment and prepare all materials, devices, etc. so that the assessment is carried out in step 5. Step 6 corresponds to a very important step where the results of the evaluation are stored in a database for efficient management for further analysis, product optimization, analytics and design changes.

## 1.8 CONCLUSION

This chapter introduces the readers to the concept of usability and its association with the user experience. It also covers various aspects of usability evaluation and models. Although the concept of usability comes from the HCI area, its application in consumer products has evolved over the years, based on the various studies and a summary of several researchers presented in this chapter. Different dimensions have been proposed as indicators for a clear view of usability and its aspects, as well as models for their application, which form the basis for evaluating the usability of the product.

It is understood that the fundamental focus of usability remains the ease of use when interacting with a product. To define this concept it is necessary to develop measures for the user experience and to establish a level of success for the product. These measures can be directed toward an understanding of the user's needs and requirements of the physical, cognitive and emotional dimensions, which are understood as complementary and interdependent. Therefore, the characteristics of the interaction between a user, product and context of use determine the usability of the product.

Based on these relationships, conceptual models were built to assess the usability, but many of these models relate to the assessment of *software* usability, addressing factors that represent hypothetical constructs about usability in measurable criteria from specific metrics. However, these criteria and metrics are not consistently defined in the different models when related to consumer products. These offer little information on how to select certain metrics in the face of broader usability goals in a given context of use, making practical application difficult. In order to overcome these difficulties, models have been developed specifically for categories of products: gathering information on how to collect data according to the general objectives of the product's usability, according to the model of Kwahk and Han (2002), taking into consideration the phases development, according to the model of Kahmann and Henze (2002).

According to the model of Kahmann and Henze (1999; 2002), as well as the emphasis given throughout this chapter on the importance of user participation, it becomes evident that there is ever-increasing need for designers and software engineers to overcome their personal interpretations of a given situation and start to consider users' cultural differences, expectations and previous experiences. Design errors can arise from the differences between the concept that designers have in mind about users and the concept that users actually have about everyday product use. In this sense, user expectations are a central issue in the usability of the product.

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# 2 Implications and Methodological Issues for the Study of Individual Differences in Usability and User Experience

*E. Brunsen, W. B. Hicks and A. C. McLaughlin*

## CONTENTS



## 2.1 THE IMPORTANCE OF INDIVIDUAL DIFFERENCES IN USER EXPERIENCE

Human factors research and its subfields of usability, user experience and human-computer interaction have always been concerned with matching design to the capabilities and limitations of the human. Writ large, this has meant considering fairly universal capabilities and limitations, such as the limit of how many items can be maintained in short-term memory (Miller, 1956), the shortest reaction times (e.g., Olson & Sivak, 1986), the excellence of the human processor in noticing patterns (e.g., Mattson, 2014) and our biases in decision-making (e.g., Kahneman, 2011). There has also been a focus on designing for group differences, for example, designing in general for aging due to age-related differences in grip strength, vision or working memory capacity (Hofer & Alwin, 2008). Though such tailoring of design to these group differences has greatly improved usability (see Czaja, Boot, Charness,

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& Rogers, 2019), the issue is that there is no "average user," even within a group. Designing for a group is more beneficial than not, but with the advent of sensor technology, AI and "glass" interfaces that can be easily changed, we have the opportunity to consider individual differences in user-centered design, in user testing and in data analysis.

Using individual differences in design is not a new idea. Cronbach and Snow (1977) initiated the idea of aptitude-treatment interactions in education. They were most concerned with changing education and training according to evidence-based person-instruction interactions, but the concept of considering an individual within a situation, environment or technology generalizes to questions of design and usability. In 2009, Szalma called for inclusion of individual differences in human factors research by demonstrating how the study of individual differences was important to both application and theory development in human factors psychology. This echoed Underwood's 1975 address to the American Psychological Association, where he discussed using our knowledge of individual differences in building and testing the limits of psychological theory. For the remainder of this chapter, we will focus on applying our knowledge of individual differences in usability studies. We start by identifying categories of individual differences important to usable designs and then provide a step-by-step process for usability researchers.

### 2.1.1 Examples of Individual Differences

#### 2.1.1.1 Cognitive Abilities Important to Usability

We begin with a consideration of two individual differences in cognitive ability/cognitive resource that can have important user interface implications: spatial ability and working memory capacity. These cognitive resources, sometimes referred to as fluid abilities, are limited. This means that (1) humans do not have an infinite capacity and all show limitations under certain circumstances and (2) within the limits of human capability, these resources are assumed to have a normal distribution. For each, we provide a description of the ability, the methods by which it has been measured and an example of its application to usability and design.

##### *2.1.1.1.1 Spatial Ability*

Spatial ability has many facets, from navigation to mental rotation to visualization (Hegarty & Waller, 2005). Those with high spatial abilities tend to be able to navigate environments and interfaces better than those with poor ability. For example, in a study of using a telephone menu system, older persons with lower spatial ability had trouble with the auditory menu system. However, when provided with a visual menu that accompanied the audio, they performed similarly to higher ability users (Sharit, Czaja, Nair, & Lee, 2003).

If a designer believes spatial ability will be important for the task the user wants to accomplish (for example, a map or traffic application), the choice of measure should be based on a task analysis. In the task analysis, consider what kind of spatial ability is most needed for the task. The most common measure of spatial ability is the measurement of the ability to rotate objects mentally. The most common test used

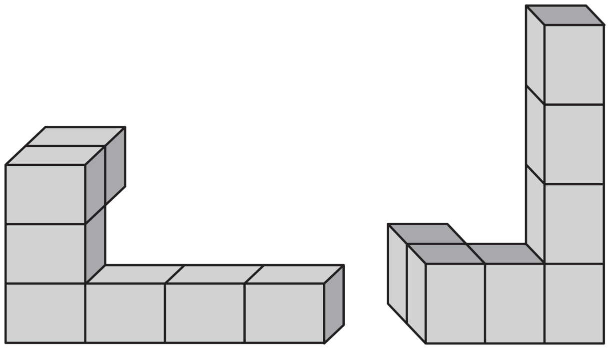

**FIGURE 2.1** Examples of spatial ability measures. The mental rotation task (Shepard & Metzler, 1971) tests a person's ability and mental representations of objects (two-dimensional and three-dimensional) as it is related to the visual representation of such rotation within the mind. It must be determined whether the object on the left is the same as the object on the right, only rotated.

is the updated Mental Rotation Test (Peters et al., 1995; based on the original test by Shepard and Metzler, 1971), which presents shapes that the participant must assess for similarity to other rotated versions of the shape (Figure 2.1). This measures the ability to mentally rotate, but not other spatial abilities, such as the ability to navigate. Navigation ability is typically measured using virtual environments. For example, a virtual world called *Virtual Silcton* has participants navigate a campus or city, with performance scores indicating their navigational ability (Blacker, Weisberg, Newcombe, & Courtney, 2017; Galati, Weisberg, Newcombe, & Avraamides, 2017; Nazareth, Weisberg, Margulis & Newcombe, 2018; Weisberg & Newcombe, 2016; Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014).

Spatial ability differences can be crucial in the usability of a design. For example, if all usability participants are under age 30, they are likely at the peak of their spatial abilities (the same is true for the other cognitive abilities we describe). This means they are likely to be able to overcome undue spatial demands made by the interface, for example, a map display that reorients during use. Testing with such participants may give a false indication of usability, as they may be able to perform regardless of the spatial demands. However, those low in spatial ability may find the same interface impossible to use. Even those with high spatial abilities could have issues when multitasking or distracted, which might only be uncovered in a usability test that included a mandatory distraction.

#### *2.1.1.1.2 Working Memory Capacity*

Working memory capacity is a measure of the ability to hold raw information in immediate awareness so that it can be manipulated and transformed (Schneider & McGrew, 2012). Smartphones provide a typical example of how a poorly designed interface can consume working memory beyond an individual's capacity. For example, security measures on phones often require a verification code (sent to the device) to be immediately entered into an application on the phone or a computer. The users' working memory must hold their current goal (e.g., access their email), an understanding of what step they are in toward that goal, the method of moving back and forth between the application requesting the code and the text message providing the code and usually the short-term memory demands of holding five to six digits in memory until they can be entered, as the user must move back from the received text to the entry screen for the code. Smartphones improved this process by automating the access to and copying of the code, so that the application does not need to be exited to view the code nor does the code need to be held in human memory to enter on another screen. This design change should particularly aid persons with permanent or task-induced lower working memory capacities. It is notable that around ten years passed between the advent of the smartphone and this simple design change for greater usability.

Measures of working memory capacity that are simple to administer individually include the Automated Operation Span test (Unsworth, Heitz, Schrock, & Engle, 2005) and Reading Span (Friedman & Miyake, 2005). Alphabet Span (Waters, & Caplan, 2003) is a test easily administered to groups of users at one time. Because working memory capacity tends to decline with age, recruiting users over age 65 is another method to attain a diverse sample. For controlled experiments and research, we recommend administering several measures of working memory capacity to best estimate the construct of working memory, as any single measure may be a poor indicator (Rabbitt, 1997).

Like spatial ability, differences in working memory can translate to large differences in the usability of a product or system. For example, when designing auditory menus, such as for phone menu systems, using a broad rather than deep menu system is especially important for users with lower working memory capacity (Commarford, Lewis, Smither, & Gentzler, 2008). In a comparison of scrolling through a website or clicking through discrete pages, those with high working memory capacities were able to remember the text they read using either method. However, those with lower working memory capacity remembered more when the pages were discrete, and scrolling was not required (Sanchez & Wiley, 2009). These are just two examples from a large and extensive literature on the connection between interface design decisions and working memory capacity.

#### 2.1.1.2 User Attributes to Consider for Usability Studies

##### *2.1.1.2.1 Expertise Level*

Expertise level refers to the amount of prior knowledge regarding the specific interface being used. Novices are assumed to have little or no prior experience or knowledge, while experts typically understand the interface and associated task on a qualitatively different level. This is due to the development of proceduralized, automatized actions (Anderson, 1996), chunking of those actions so that a series of steps become one cognitive step for the user (Gobet, 2005) and development of a mental model for how the interface works, generally allowing better troubleshooting of errors (Payne, 2003). Novices become experts by moving through stages of skill acquisition: the cognitive stage, where all actions are highly accessible, slow, conscious and error prone, to the associative stage, where procedural knowledge is being developed, and finally to the expert stage (also called the autonomous stage due to the automaticity of responses to inputs from the interface and task) (Fitts & Posner, 1967). This qualitative difference between novices and experts makes it a crucial individual difference to consider when designing for usability.

Expertise can be measured in many ways, from tests of knowledge to measurements of performance. It is likely the expertise level of the user is known or can be easily assessed with a questionnaire. For example, in the design of a medical device for persons with diabetes, the *Diabetes Knowledge Questionnaire* has been used to determine whether the potential user understands the disease and the steps that should be taken to maintain their health (Eigenmann, Skinner, & Colagiuri, 2011). This measure can be used in two ways: first, during recruitment of usability participants, to ensure a variety of knowledge levels interact with the designs, and second, if important design decisions differ for various knowledge levels, it can be used to direct new users to tailored interfaces.

It can be more difficult to assess expertise in a novel system. In these cases, it may be best to either assume a novice level for all users or to use analogous systems to assess expertise (e.g., questionnaires about experience with 3D video games may inform the interaction techniques developed for a novel augmented reality interface). It may also be possible to measure more general differences in expertise that apply beyond a specific system, as with the *Technology Experience Questionnaire* (Ham, Bunn, Meyer, Khan, & Hickson, 2014). However, the ultimate research and usability questions must be kept in mind: for a novel system, will differences in analogous expertise matter for the design? If so, what is the best tool to measure those differences?

A classic example of providing tailored interfaces depending on expertise can be found in the home computer. Expert users tend to prefer command line interfaces, for their flexibility and power. However, such interfaces demand extensive prior knowledge—they are difficult or impossible to use by novices as they depend on "knowledge in the head" (Norman, 2013) (Figure 2.2). Graphical user interfaces (GUIs), such as most websites or Windows-related operating systems, place menus, buttons and other methods of interaction on the display. Here, the user can "recognize" rather than recall, and a well-designed interface will be usable by novices. However, clicking on menus and choosing options repeatedly slows down the command line expert, which is why most Operations Support Systems (OSS) offer the flexibility of either approach. Allowing different interfaces for use by different experience levels matches Nielsen's (1994) heuristic of "Flexibility and efficiency of use: Accelerators, unseen by the novice user, may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions."

#### *2.1.1.2.2 Locus of Control and Self-Efficacy*

Locus of control (LoC) is the degree to which people believe that they have control over the outcome of events in their lives, as opposed to external forces beyond their control. Those with a strong locus of control believe that events and situations in

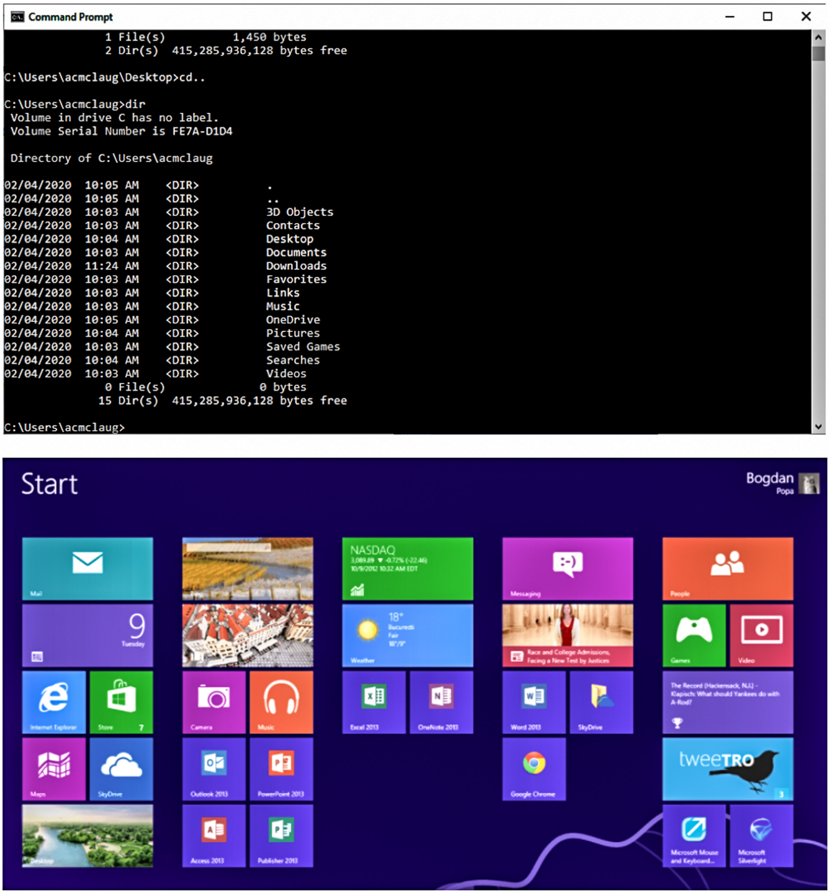


**FIGURE 2.2** Command line interface (top) for expert use compared to graphical user interface (bottom) for novice to moderately skilled users. Both contain similar functionality.

their own lives derive, for the most part, from their own actions. An example of this would be scoring high on an exam. Those with a high internal locus of control believe it was their doing for their score, while those with a high external locus would give credit to external factors such as a guide or a study sheet.

A scale used for locus of control that has been applied in the area of health research is the Multidimensional Health Locus of Control Scale (MHLC) (Wallston, Wallston, & DeVellis, 1978). The scale includes three potential loci for health belief: internal (e.g., healthy diet and exercise), powerful others (e.g., a doctor controls or contributes to the individual's health) or chance. Factors that affect LoC include age, family origins, cultural beliefs, stress and self-efficacy (Wallston, 2005). One of Shneiderman's rules for usable design includes supporting internal locus of control (Shneiderman, Plaisant, Cohen, Jacobs, & Elmqvist, 2017). We suggest another alteration to this rule might be to consider that users will have differences in locus of control, and the design should support this variety.

Dupuy, Consel and Sauzéon (2016) studied the match of LoC and self-determination in older adults with an adaptive interface using a self-determination theory (SDT) scale and found that both play a large role in technology acceptance. They promoted acceptance of new technologies by older adults in assisted living homes by offering them interfaces designed to support self-determination. For example, users could choose the assistive technologies they wanted via a catalog, and it was easy to install or uninstall any technology. This supported feelings of behavioral autonomy. All technologies were able to be paused, such as when guests came over, which supported psychological empowerment. Individual differences in initial self-determination were analyzed, finding that the higher the self-determination score, the more likely that person was to accept the new technologies. Further, they found that their designs raised the self-determination scores of the users after their interactions during the study. By figuring out these levels of LoC and SDT, they were able to design a better platform for the older users and improve the design process for other technologies specifically used with older adults. A study by Lee, Lee and Hwang (2015) found similar results for younger adults.

An application of the locus of control measurement might be to compare users in how they research a large purchase online (including others' reviews, how many websites they looked at, how many product details they care about, how many product comparisons and so on). Srinivasan and Tikoo (1992) conducted such a study, measuring locus of control and then information search when purchasing a car. Those with more internal locus of control searched more for information relating to the purchase as they believed additional information would result in enough benefit to warrant the effort of searching. We did not find design or usability studies that included locus of control measures, but it follows from Srinivasan and Tikoo that designs could be used to either encourage desired behavior (convincing those with external locus of control to gather more information) or to offer interface options that matched the locus of control level of the user (e.g., a search engine that either returns many options or takes the user directly to the first and most likely website). Some options for measuring locus of control include the MHLC, Rotter's Forced Choice Scale (1966), James' Locus of Control Scale (1957), Bailer's (1961) scale for children and the Duttweiler Internal Control Index (1984).

Self-efficacy is used to describe one's belief in their ability to achieve a defined goal (Bandura, 1986). Self-efficacy has been shown to impact motivation, mindset and task performance, as it is a measure concerned with perceived capability (Urdan & Pajares, 2006; Rhew, Piro, Goolkasian, & Cosentino, 2018). Bandura's (1986) Social Cognitive Theory highlights how personal or cognitive factors (e.g., personal knowledge, attitudes or expectations), the environment (e.g., knowledge accessibility and social norms) and human behavior (e.g., self-efficacy and personal ability) interact with one another to affect a person's outlook and self-belief in relation to goal-oriented objectives. Individuals are prone to act based on their self-efficacy judgments or how well they believe they can perform (Stajkovic & Luthans, 1998). As behaviors are often guided by attitudes, behavior change or improvement may be achieved by manipulating and crafting the environment to promote self-efficacy (Regan & Fazio, 1977). This can improve not only task performance, but persistence and resilience to difficulty as well (Bandura, 1997).

In reference to performance, self-efficacy has shown to have three separate dimensions: magnitude, strength and generality (Bandura, 1986; Stajkovic & Luthans, 1998). Magnitude refers to the threshold of task difficulty an individual believes of which they are capable. An internal judgment of whether the aforementioned magnitude is strong or weak refers to strength. Self-efficacy beliefs can also vary widely in generality. Some beliefs are task- or domain-specific, while others may promote a more generalized belief of self. For example, a user might have high self-efficacy concerning their expected performance with new interfaces but low self-efficacy concerning making healthy nutritional food choices. Thus, it must be considered whether it is important to measure self-efficacy specific to the task or domain in which the new product or interface will be used or to measure self-efficacy more generally, such as technological self-efficacy.

Measures like the Computer User Self-Efficacy Scale (CUSE) have commonly been used to assess an individual's perceived confidence and competence in computer use (Cassidy & Eachus, 2002). For example, the CUSE was used in a study on the acceptability of telemedicine. Older persons with higher scores on the CUSE had higher intentions to engage with telemedicine technologies and were willing to expend more effort to engage with those new technologies (van Houwelingen, Ettema, Antonietti & Kort, 2018). In testing the telemedicine system, it might be easy to select usability participants high in computer self-efficacy (e.g., coworkers, parents or friends of the highly educated usability testers), so an effort should be made to measure (if not screen) computer self-efficacy.

## 2.2 AN APPROACH TO INCORPORATING INDIVIDUAL DIFFERENCES IN USABILITY

In the remainder of the chapter, we present the steps of applying an individual differences lens to a design problem. We suggest an adaptation and extension of the steps suggested by Szalma (2009) (Figure 2.3).

### 2.2.1 General Steps

As with all usability improvements, we start with the two commandments of human factors psychology: know the task and know the user. The tools for understanding the task are well known, such as hierarchical task analysis and cognitive task analysis. We recommend Gillan (2012) and Crandall et al. (2006) for overviews. Knowing the users may not be as straightforward as the designer should have in mind what qualities of those users may impact their performance, enjoyment or other use of the system. For example, gender could be collected to describe users of a library search interface, but there is no reason to expect that gender would impact how the system is used. Thus, the first pass at a user analysis can be general and at the group level: are there certain age groups expected to or not expected to use the system? Are there

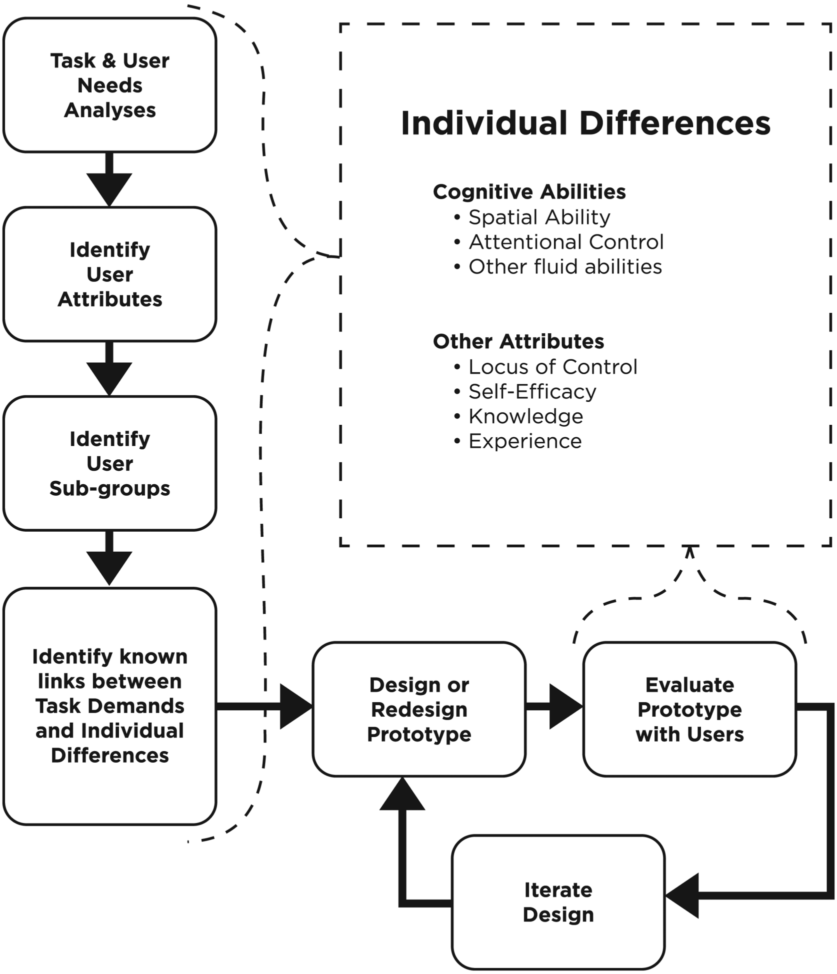


**FIGURE 2.3** Adaptation and extension of the research considerations of individual differences. Figure shows general steps of interface or system development with indications of stages where individual differences are crucial.

expected gender differences in goals, intent or use? Will the system be used by novices, experts or both? Will the system be frequently or rarely used? Answers to these questions are a start to the next step: identify relevant person characteristics.

Identifying relevant person characteristics is the crucial step in including individual differences in design. It is the step that requires the most background knowledge of psychology and anthropometry. In this step, consider the task demands, outlined in the task analysis, and whether those demands are high enough to expect individual differences to impact use of the system. For example, a system that displays a map might demand "spatial ability," but inspection of the system shows the maps in this system are so simple as to have inconsequential spatial demands. Further, the system operates serially, so there is no chance of multitasking while under spatial demand. It could be concluded that the individual difference of spatial ability would not matter and thus should not be included in any tests or analysis. However, on the other side, task analysis might reveal that the map system demands moderate amounts of spatial ability, likely while driving (another spatial task). Here, the demand may exceed what some users are able to provide, and testing users low in spatial ability would reveal the impact of the design choice.

The third step is to connect the information from Step 1 with Step 2. It is important to have a working knowledge of likely individual differences or consult with experts in the domain (e.g., human factors professionals). Designers should ask themselves, at least for the most crucial steps in the task analysis, what cognitive abilities or other attributes are needed or overloaded by the interface? For example, if an app requires a long security code, but that code only appears for a few seconds, this would be hard to remember and enter for people with lower working memory capacity. Once the environment is considered, such as navigating a noisy and crowded sidewalk to locate a ride share location, memory and entry of such a code may be impossible even for those with high working memory capacities.

In the fourth step, utilize the method suggested by Szalma (2009) to decide (1) whether subgroups of users likely exist, and whether their needs may conflict with each other, and (2) what are the overall needs for users of the interface, ignoring their potential individual differences. Following these steps will ensure that the system can fulfill the needs of users, but will also reveal whether a flexible design is needed to accommodate subgroups. For example, the preferences of many expert software developers for command line interfaces might conflict with casual computer users who need a graphical user interface to accomplish their goals.

In the fifth step, design or redesign the system or interface. This may mean large, conceptual changes or constrained element changes. During the design, revisit the task analysis and update as needed. Simply having gone through the earlier steps may have inspired different ways of thinking about the design, making it more usable for the range of individual differences important to the task.

The last steps are to perform a standard usability evaluation, where performance or experience metrics are predefined and measured as users experience the system or interface, and iterate the design based on the outcome. The added piece here is to include the important individual differences as predictors or manipulations: for example, if attentional control is important to performance, one could recruit older persons (likely to score lower on tests of spatial ability, working memory, attentional control) or one could screen to include potential users high or low on attentional control using psychometric tests.

## 2.3 CONCLUSION

We have discussed the importance of considering individual differences when conducting basic and applied research, when conducting usability and UX studies and in applying human-centered design methods. We have also discussed the literature on individual differences linked to usability and design, including the paucity of such research and the need for more. It makes sense that, when technologies were mostly physical, created in factories and fully formed upon release to the public, it would be difficult to include tailoring to individual differences. However, as technologies move toward the virtual, with software-controlled interfaces and multiple input methods, it is time to start considering how these designs could and should be tailored to different groups and *individuals.* These systems, interfaces and displays can be easily presented or updated to fit an individual—the remaining step is to understand how to do so. Because there is little explicit guidance as of yet, it falls on the researchers and designers to explore the individual differences likely to affect use of the product. We end with the following guidelines for researchers and practitioners.

For researchers:

1. Include measurement of individual differences in future studies. Many of the studies we reviewed posited that results could have been due to individual differences (such as in locus of control), but did not have the measures.
2. Include these measurements in planned and post hoc analyses.
3. Use individual differences to test general theories—if a theory suggests multitasking performance decrements are due to lack of attentional resources, compare those with low and high amounts of that resource to test the theory.

For designers and practitioners:

1. Use the literature when possible to drive the choice of individual differences to include in usability studies, designs and personas.
2. Develop a general understanding of the individual differences that are likely important to the design. Include these in recruitment of participants to avoid a sample biased against real-world differences in cognition or other attributes.
3. Include these explicit questions when designing any product:
   a. What are potential differences in cognition that might make the planned design harder to use?
   b. Will people use this product when distracted or with diminished cognitive ability due to the environment?
4. Consider individual differences explicitly at multiple points in the design process: when assessing user needs and when testing designs.
5. Include usability participants who are representative of the individual differences of interest.

Following these guidelines does not guarantee success. Usability, especially usability for individual differences, is not a recipe or an algorithm. It is an art that depends on the application of knowledge, including knowledge of the user, knowledge of individual differences and knowledge of the task. This art is blended with the science of measurement and analysis—no system should be assumed to match individual differences purely based on theory. It must also be tested. We hope that the information and suggestions in this chapter will result in individual differences being considered more often, from the initial design through the final testing of any new interface.

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# 3 Three Methods of Usability-UX Task Analysis, REM, UX System Diagrams

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## CONTENTS



## 3.1 INTRODUCTION

The usability-UX (User Experience) task analysis, REM (hierarchical Requirements Extraction Method) and UX system diagram are proposed as new methods for collecting usability and UX. Usability-UX task analysis is a variation of task analysis allowing user requirements to be obtained systematically and quantitatively. REM is a method for extracting user requirements by root cause and final purpose based on problems of products or systems. UX system

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diagrams can create UX and feelings based on the four attributes of product, story, feeling and sense by UX. As new products or systems related to service design become more complex in the 21st century, new logical methods for usability and UX to extract user requirements are required. This is because most existing methods depend on intuition and personal ability, and so they seem to not be useful or effective for complex systems such as service design, social design and so on, which are needed in the 21st century.

## 3.2 USABILITY-UX TASK ANALYSIS (YAMAOKA 2012)

### 3.2.1 Background and Purpose

Usability and UX have become very important elements in the creation of attractive products, GUIs and services. However, designers and engineers cannot get information on usability and UX efficiently and systematically. Usability-UX task analysis is used for collecting user requirements and UX etc. in an efficient and systematic manner. This method is constructed based on task analysis which can obtain problems regarding tasks for products and is a popular technique in ergonomics. The usability and UX data extracted by this method can be analyzed using qualitative and quantitative methods such as multiple regression analysis, FCA (formal concept analysis) and so on.

### 3.2.2 Proposed Method

Usability-UX task analysis was developed based on task analysis to get user requirements systematically and quantitatively from the viewpoint of the good and bad points of a task (Figure 3.1). Task analysis is a very important method to extract user requirements or problems for each task.

The procedure of collecting user requirements is as follows.

1) The test participants evaluate each task of products, GUIs and services.

Each task is evaluated from the viewpoint of the good and bad points of usability, and the UX of the task. Test participants are asked to fill out appropriate evaluation words in the blanks in a Sentence Completion Test (SCT) after operating the products, GUIs and services. SCT is aimed at collecting the causal relationship of the usability of the task (Figure 3.2).

The tasks of products are evaluated from the viewpoint of UX according to a three-grade evaluation: good, ordinary and bad. And they also are evaluated from the viewpoint of usability (good and bad points) according to the Likert scale: strongly agree (5), agree (4), neutral (3), disagree (2) and strongly disagree (1).

2) After each task is done, synthetic evaluation is finally conducted as mentioned above.
3) The good and bad points are analyzed.

| Task | Product (A), or operational screen (A) | Product (B), or operational screen (B) |
|---|---|---|
| Task (1) | UX/feeling: good, ordinary, bad<br>The reason: ____________<br>____________ | UX/feeling: good, ordinary, bad<br>The reason: ____________<br>____________ |
| | Good points:<br>As [ (a) ] is [ (b) ], it's good. | Good points:<br>As [ (a) ] is [ (b) ], it's good. |
| | Bad points:<br>As [ (a) ] is [ (b) ], it's bad. | Bad points:<br>As [ (a) ] is [ (b) ], it's bad. |
| | Evaluation: 5—4—3—2—1 | Evaluation: 5—4—3—2—1 |
| Task (n) | UX/feeling: good, ordinary, bad<br>The reason: ____________<br>____________ | UX/feeling: good, ordinary, bad<br>The reason: ____________<br>____________ |
| | Good points:<br>As [ (a) ] is [ (b) ], it's good. | Good points:<br>As [ (a) ] is [ (b) ], it's good. |
| | Bad points:<br>As [ (a) ] is [ (b) ], it's bad. | Bad points:<br>As [ (a) ] is [ (b) ], it's bad. |
| | Evaluation: 5—4—3—2—1 | Evaluation: 5—4—3—2—1 |
| Synthetic evaluation | UX/feeling: good, ordinary, bad<br>The reason: ____________<br>____________ | UX/feeling: good, ordinary, bad<br>The reason: ____________<br>____________ |
| | Good points:<br>As [ (a) ] is [ (b) ], it's good. | Good points:<br>As [ (a) ] is [ (b) ], it's good. |
| | Bad points:<br>As [ (a) ] is [ (b) ], it's bad. | Bad points:<br>As [ (a) ] is [ (b) ], it's bad. |
| | Evaluation: 5—4—3—2—1 | Evaluation: 5—4—3—2—1 |

**FIGURE 3.1** Usability-UX task analysis.

The good points become user requirements, while the bad points are changed into good user requirements. For example, a bad point of "heavy" is changed into user requirement "light," which is an antonym of "heavy." The idea of including the two words with positive and negative comments is a very important user requirement.

4) Qualitative analysis

---

SCT

As [ (a) ] is [ (b) ], it's good or bad.

---

**FIGURE 3.2** SCT (Sentence Completion Test).

User requirements including UX are collected and structured.

As user requirements are collected and structured by grouping, very important user requirements are selected.

5) Quantitative analysis

User requirements are also analyzed using statistical methods. Multiple regression analysis of usability can be done using the five-grade evaluation data of the Likert scale. UX can also be analyzed using the three-grade evaluation data by multiple regression analysis.

## 3.3 EXAMPLE OF THE APPLICATION OF USABILITY-UX TASK ANALYSIS

A web screen of six hotels and three mechanical pencils (Figure 3.3) was evaluated and analyzed using usability-UX task analysis. Six university students (female, 20–26


**FIGURE 3.3** Three mechanical pencils.

| Task | An operational screen (A) | An operational screen (B) |
|---|---|---|
| Task (1): Home page | UX/feeling: ✓good, ordinary, bad<br>The reason: imagine hotel easily from the animation. | UX/feeling: good, ✓ordinary, bad<br>The reason: The photo is good |
| | Good points:<br>As [ a photo on screen ] is [ shown by scrolling ], it's good. | Good points:<br>As [ the photo ] is [ good and I can imagine the hotel], it's good. |
| | Bad points:<br>As [ wording of recommended plans ] is [ not good ], it's bad. | Bad points:<br>As [ useful information of the hotel ] is [not understood ], it's bad. |
| | Evaluation: 5—✓4—3—2—1 | Evaluation: 5—4—3—✓2—1 |
| Task (2): Screen of guest room | UX/feeling: ✓good, ordinary, bad<br>The reason: Amenities are shown<br>on every screen | UX/feeling: good, ordinary, ✓bad<br>The reason: The Japanese-style room is not the same as its photo. |
| | Good points:<br>As [ amenities ] is [introduced by photo ], it's good. | Good points:<br>As [ (a) ] is [ (b) ], it's good. |
| | Bad points:<br>As [ the movie] is [ the same as the home page ], it's bad. | Bad points:<br>As [the hotel rates and photo ] are [ hard to see ], it's bad. |
| | Evaluation: 5—✓4—3—2—1 | Evaluation: 5—4—3—2—✓1 |
| Task (n) | | |
| Synthetic evaluation | UX/feeling: ✓good, ordinary, bad | UX/feeling: good, ordinary, ✓bad |
| | Good points:<br>As [the movie and home page ] are [easy to understand ], it's good. | Good points:<br>As [the atmosphere ] seems [ to be good ], it's good. |
| | Bad points:<br>As [the words on the screen] is [ designed closely], it's bad. | Bad points:<br>As [ concrete data of meals and rooms ] are [not shown ], it's bad. |
| | Evaluation: 5—✓4—3—2—1 | Evaluation: 5—4—3—2—✓1 |

**FIGURE 3.4** An example of usability-UX task analysis of a web screen (shown as a part of a web screen of six hotels and three tasks).

years old) answered questions on tasks for a web screen of six hotels (Figure 3.4), and eight university students (female, 20–26 years old) answered questions on tasks for three mechanical pencils (Figure 3.5).

The test participants checked all of the tasks of the products and screens as the synthetic evaluation and grade (Table 3.1).

| Task | Mechanical pen (A) | Mechanical pen (B) |
|---|---|---|
| Task (1): Picking up a mechanical pencil | UX/feeling: good, ✓ordinary, bad<br>The reason: The weight is light. | UX/feeling: good, ordinary, ✓bad<br>The reason: The pen is thick. |
| | Good points:<br>As [ the body ] is [ light ], it's good. | Good points:<br>As [ the shape ] has [ cues to use it ], it's good. |
| | Bad points:<br>As [ the body ] is [very light and cheap ], it's bad. | Bad points:<br>As [ the shape ] has [a plane surface as part of the body ], it's bad. |
| | Evaluation: 5—4—✓3—2—1 | Evaluation: 5—4—3—✓2—1 |
| Task (2): Holding a mechanical pencil | UX/feeling: ✓good, ordinary, bad<br>The reason: It fits me very well. | UX/feeling: good, ✓ordinary, bad<br>The reason: I used it. |
| | Good points:<br>As [ the part to hold ] is [rubber ], it's good. | Good points:<br>As [the part to hold ] has [knurling not to slip ], it's good. |
| | Bad points:<br>As [the part to hold ] is [sticky ], it's bad. | Bad points:<br>As [ the shape ] makes [way to use ], it's bad. |
| | Evaluation: 5—4—✓3—2—1 | Evaluation: 5—4—3—✓2—1 |
| Task (n) | | |
| Synthetic evaluation | UX/feeling: good, ✓ordinary, bad | UX/feeling: good, ordinary, ✓bad |
| | Good points:<br>As [this pen ] is [the same as pens I normally use ], it's good. | Good points:<br>As [ the lead ] is [delivered holding the pen ], it's good. |
| | Bad points:<br>As [the pen point ] is [hard to see ], it's bad. | Bad points:<br>As [a sound ] is [generated when writing ], it's bad. |
| | Evaluation: 5—4—✓3—2—1 | Evaluation: 5—4—3—✓2—1 |

**FIGURE 3.5** Usability-UX task analysis of a mechanical pencil (shown as a part of three mechanical pencils and three tasks).

1) Four screens such as the home page, guest rooms, accommodation plans and ideal plans were selected as tasks. Table 3.2 shows some of the results for the usability-UX task analysis of six hotels.
2) Four tasks for the mechanical pencils such as picking up the pencil, holding it, clicking it and writing were selected. Table 3.3 shows some of the results for the usability-UX task analysis of the three mechanical pencils.

**TABLE 3.1**
**User Requirements Collected from Synthetic Evaluation**

| The requirements collected in synthetic evaluation | | |
|---|---|---|
| **Requirements organized as good points** | **Important requirements** | **Requirements organized as bad points** |
| Light and easy to write | Writing easily important | Difficult to write |
| Light and easy to hold | Holding easily is important | Heavy and tired to hold |
| Friendly | | |
| Fit in hand | Fitting in hand is important | Doesn't fit in hand |
| High-grade image | High-grade image is important | Cheap-looking |

**TABLE 3.2**
**UX Items Collected in the Writing Task**

| UX organized as good points | Important requirements | UX organized as bad points |
|---|---|---|
| Light and easy to write | Writing is an important requirement | Difficult to write |
| Smooth and easy to write | Smooth is an important requirement | Not smooth |
| Easy to hold | Holding easily is an important requirement | Thin and difficult to hold |

**TABLE 3.3**
**Average (AV) and Standard Deviation (SD) of User Requirements of Mechanical Pencils A, B and C**

| | Average and standard deviation of user requirements | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Task 1 | | Task 2 | | Task 3 | | Task 4 | | | |
| | Picking up mechanical pencil | | Holding mechanical pencil | | Clicking mechanical pencil | | writing | | Synthetic evaluation of user requirements | |
| | AV | SD | AV | SD | AV | SD | AV | SD | AV | SD |
| A | 3.14 | 0.70 | 3.42 | 0.98 | 2.71 | 1.38 | 2.57 | 1.13 | 3.00 | 1.00 |
| B | 3.00 | 1.15 | 2.57 | 0.79 | 2.43 | 1.27 | 2.57 | 1.51 | 2.71 | 0.76 |
| C | 3.00 | 1.00 | 2.43 | 0.53 | 3.57 | 0.98 | 4.29 | 0.76 | 3.57 | 1.13 |

The collected usability and UX were structured and analyzed.

Collected data was structured and analyzed by average, standard deviation and multiple regression analysis.

### 3.3.1 Structuring of the Data

The requirements or UX collected regarding the good points and bad points from synthetic evaluation were grouped (Tables 3.1 and 3.2). When the requirements or

**TABLE 3.4**

**Average (AV) and Standard Deviation (SD) of UX of Mechanical Pencils A, B and C**

| | The average and standard deviation of UX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Task 1 | | Task 2 | | Task 3 | | Task 4 | | Synthetic evaluation of user requirements | |
| | Picking up mechanical pencil | | Holding mechanical pencil | | Clicking mechanical pencil | | Writing | | | |
| | AV | SD | AV | SD | AV | SD | AV | SD | AV | SD |
| A | 2.29 | 0.49 | 2.57 | 0.53 | 2.00 | 0.82 | 2.29 | 0.76 | 2.14 | 0.38 |
| B | 2.43 | 0.79 | 2.43 | 0.53 | 1.57 | 0.79 | 1.86 | 0.90 | 2.00 | 0.82 |
| C | 2.29 | 0.76 | 1.86 | 0.90 | 2.57 | 0.79 | 2.71 | 0.49 | 2.43 | 0.98 |

UX based on good points were opposite to the requirements based on bad points, the requirements or UX became very important. When "being easy to write" as a good point and "being difficult to write" as a bad point were selected for an example, they were opposite to each other and then "writing easily" became the important requirement.

### 3.3.2 Analysis of the Data

1) Average, Standard Deviation

The average and standard deviation of user requirements and UX of mechanical pencils A, B and C were calculated (Tables 3.3 and 3.4). When the numerical value of the average is high, the average of user requirements and UX means a good evaluation. If the numerical value of the standard deviation is high, the standard deviation of user requirements and UX shows that the opinions of participants were divided. Mechanical pencil C had generally high scores in the average and UX, but the standard deviation was also high and the opinions were divided. As mechanical pencil C is designed for drawing, it is heavy and substantial compared with the other mechanical pencils.

2) Multiple Regression Analysis

Multiple regression analysis was done to extract important user requirements and UX (Tables 3.5 and 3.6). As mechanical pencil A is light, relatively ordinary and high scoring, the important task to influence synthetic evaluation was clicking regarding use requirements and holding regarding UX. Mechanical pencil B has a special clicking button located in the middle of the body in order to push while writing. This special function made it lower in evaluation. Mechanical pencil C is heavy and substantial compared with the other mechanical pencils, and so it had a high score.

**TABLE 3.5**
**Important Tasks to Influence Synthetic Evaluation Regarding User Requirements**

| | Explanatory variable | | | | Response variable |
|---|---|---|---|---|---|
| | Task 1 | Task 2 | Task 3 | Task 4 | |
| | Picking up mechanical pencil | Holding mechanical pencil | Clicking mechanical pencil | Writing | Synthetic evaluation of user requirements |
| Mechanical pencil A | — | — | ✓ | — | |
| Mechanical pencil B | — | — | — | ✓ | |
| Mechanical pencil C | — | — | — | — | Important tasks do not influence synthetic evaluation |

3) Formal Concept Analysis

FCA is very useful in the case of a lot of parameters such as attributes or evaluation items in a matrix, because it makes them clarify the relationships between them. Although the relationship of the parameters of mechanical pencils is not complicated, FCA is useful and easy for designers, engineers and planners, and so FCA is introduced using this example in this section.

a. The questionnaire data was changed into binary data

**TABLE 3.6**
**Important Tasks to Influence Synthetic Evaluation Regarding UX**

| | Explanatory variable | | | | Response variable |
|---|---|---|---|---|---|
| | Task 1 | Task 2 | Task 3 | Task 4 | |
| | Picking up mechanical pencil | Holding mechanical pencil | Clicking mechanical pencil | Writing | Synthetic evaluation of UX |
| Mechanical pencil A | — | ✓ | — | — | |
| Mechanical pencil B | — | — | ✓ | ✓ | |
| Mechanical pencil C | ✓ | — | — | — | |

**TABLE 3.7**
**Binary Data for Usability**

| | Task 1 | Task 2 | Task 3 | Task 4 | |
|---|---|---|---|---|---|
| | Picking up mechanical pencil | Holding mechanical pencil | Clicking mechanical pencil | Writing | Synthetic evaluation of user requirements |
| A | 1 | 1 | 0 | 0 | 1 |
| B | 1 | 0 | 0 | 0 | 0 |
| C | 1 | 0 | 1 | 1 | 1 |

**TABLE 3.8**
**Binary Data of UX**

| | The average of UX | | | | |
|---|---|---|---|---|---|
| | Task 1 | Task 2 | Task 3 | Task 4 | |
| | Picking up mechanical pencil | Holding mechanical pencil | Clicking mechanical pencil | Writing | Synthetic evaluation of user requirements |
| | AV | AV | AV | AV | AV |
| A | 1 | 1 | 0 | 1 | 0 |
| B | 1 | 1 | 0 | 0 | 0 |
| C | 1 | 0 | 1 | 1 | 1 |

The average of user requirements and UX of mechanical pencils A, B and C were changed into binary data. If the usability or UX average is higher than the usability average (2.99) and UX average (2.23) for each total average, the average is 1 (Tables 3.7 and 3.8). If lower, the average is 0.

b. Making Hasse diagrams

FCA shows a Hasse diagram using the binary data of usability and UX (Figures 3.6 and 3.7).

c. Interpreting the Hasse diagram

Each mechanical pen is connected with its evaluation item through lines from the top point in the Hasse diagram. An arrow is added to understand the relationship between the mechanical pencils and the evaluation items. Users can understand the relationship according to the arrows from the top point to the mechanical pencil. The

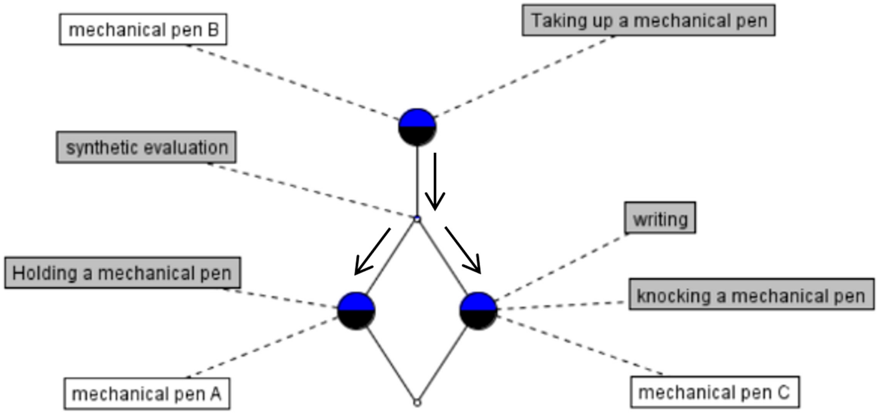


**FIGURE 3.6** The usability output of FCA.

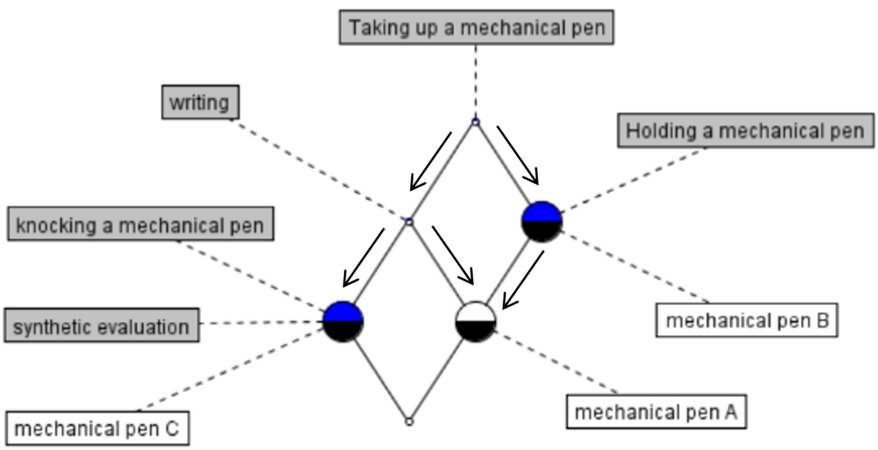


**FIGURE 3.7** The UX output of FCA.

evaluation items located in the upper position in the Hasse diagram are important and shared with many mechanical pencils.

## 3.4 REM (HIERARCHICAL REQUIREMENTS EXTRACTION METHOD) (YAMAOKA 2013)

### 3.4.1 Background and Purpose

After a usability specialist has observed products or systems, they only extract problems of usability and improve them. However, they don't usually grasp the root cause and final purpose. Grasping the root cause and final purpose of products and systems can give an ideal and essential understanding of them for the usability specialist.

REM is a method to extract user requirements by root cause and final purpose based on problems of products or systems. The relationship between results and cause may require the root cause of products and systems, while the relationship between purpose and means may require the final purpose.

### 3.4.2 Proposed Method

The procedure of REM is as follows (Figure 3.8).

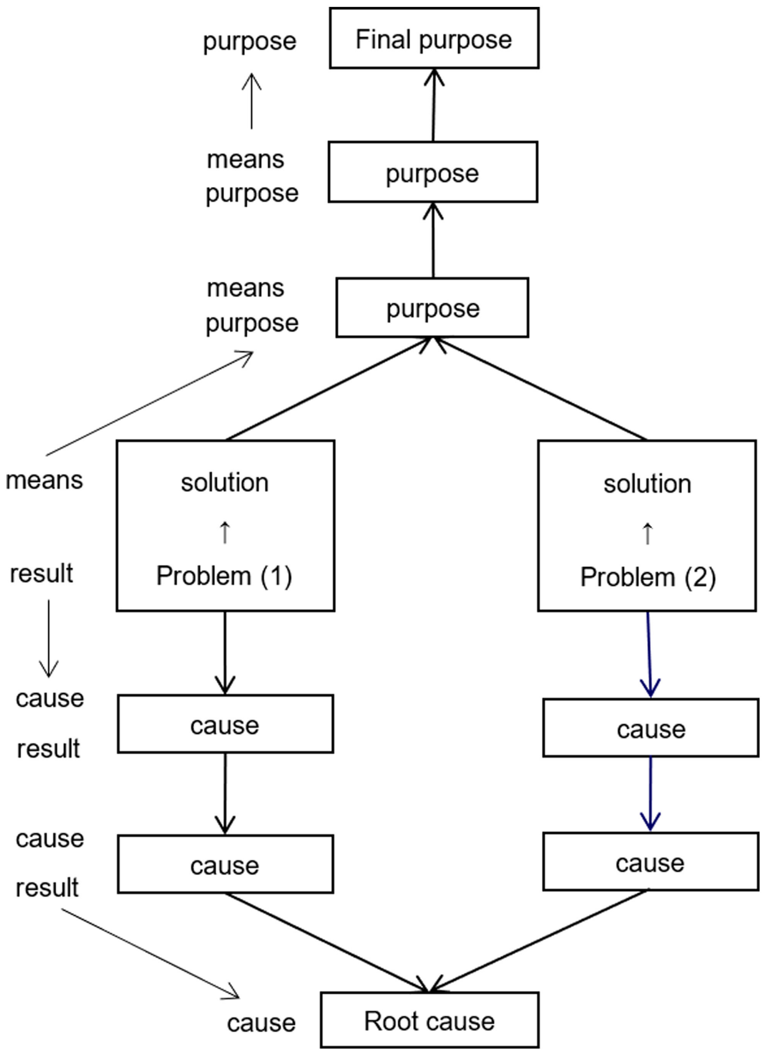


FIGURE 3.8 The structure of REM.

### How to obtain the final purpose

1) Problems are extracted based on observation, protocol analysis, check list, questionnaire and so on.
2) A problem is selected and solutions are produced based on the problem.

In the case of a heavy camera as the problem, a light camera is the solution.

3) A purpose is needed from the perspective of the relationship between purpose and means. In short, the purpose is realized using the means.

For the example above, no fatigue to use the camera is the purpose required based on the means of a light camera.

4) Each purpose is required to repeatedly raise the saturation state from the perspective of the relationship between purpose and means.
5) The final purpose is produced when the purpose cannot be abstracted.

New user requirements and UX are created based on the redefined final purpose. For the above-mentioned example, the final purpose is to realize comfortable operation. As one example, a new camera with all voice instruction is produced based on the idea of comfortable operation.

### How to obtain root cause

1) As the problem is the result, a cause is needed from the perspective of the relationship between the result and cause.

For the above example, the problem is the heavy camera and so the cause seems to be to have a lot of functions not used in the camera.

2) Each cause is required repeatedly up to the saturation state from the perspective of the relationship between the result and cause.
3) The root cause is produced when the cause cannot be abstracted.

For the example above, the root cause seems to be technicism.

The second hierarchy level of the final purpose is concrete user requirements, and the second hierarchy level of the root cause is the concrete cause of the problem. The opposite concepts of the concrete causes of the problem show the user requirements.

As REM can extract the final purpose and root cause of products, systems and so on, the user requirements and UX can be produced.

## 3.4.3 Observation

Before doing REM, observation is required to obtain the problems. Although the problems are also obtained by usability-UX task analysis, easy observation is

**TABLE 3.9**
**Five Aspects of HMI and 15 Items**

| | Five aspects of HMI (human machine interface) | Search problems using the following items |
|---|---|---|
| 1. | Physical aspect | a. Check user's posture |
| | | b. Check operational direction and strength of the controls |
| | | c. Check fit between the controls and the user's body |
| 2. | Information aspect | a. Check user's mental model |
| | | b. Check easiness to understand |
| | | c. Check easiness to see |
| 3. | Temporal aspect | a. Check working time |
| | | b. Check recess |
| | | c. Check machine response time |
| 4. | Environmental aspect | a. Check air conditioning |
| | | b. Check lighting |
| | | c. Check noise and vibration |
| 5. | Organizational aspect | a. Check organization's policy |
| | | b. Check information sharing among members |
| | | c. Check motivation of members |

introduced. The problems are extracted easily from the viewpoint of the five aspects of HMI (human–machine interface). The total 15 check items of the five aspects of HMI can easily search for problems (Table 3.9).

## 3.5 EXAMPLE OF REM APPLICATION

An example of a desk lamp in a hotel and a cafe shop using REM is shown.

1) A desk lamp in a hotel room (Figure 3.9)

As a desk lamp inside causes glare, it's very hard for customers to read books or PC screens. Although the hotel is a business hotel next to a railway station, desk lamps used in luxury hotels are usually placed on a desk. After using REM, the final purpose is defined as "Providing a comfortable environment in the room." A new idea "Barrier-free design for everybody" is created based on the final purpose and root cause.

2) Cafe shop (Figure 3.10)

A new idea "Providing a familiar user experience and healing in a cafe" is proposed as the final purpose to solve "Not having customers in a café." Finally, "Easy access to the cafe, and forming a familiar interior of healing with aroma, sound, etc." is created.

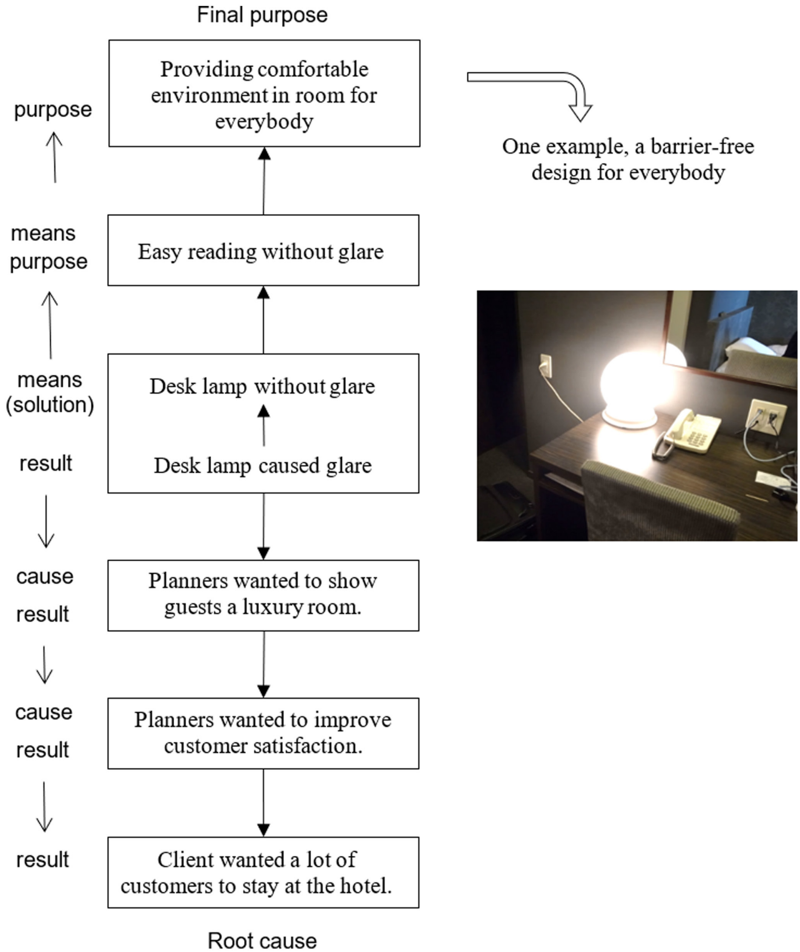


**FIGURE 3.9** A desk lamp as an example of REM.

## 3.6 UX SYSTEM DIAGRAM

### 3.6.1 Background

UX system diagrams can create UX and feelings based on the four attributes of product, story, feeling and sense by UX. UX becomes an important factor to construct various designs. It is difficult to create UX based on human intuition because of its ambiguity. If designers and engineers depend on intuition to design, they require a lot of knowledge, intelligence and experience. However, they can construct UX using the UX system diagram as a frame of thinking even if they don't have a lot of knowledge, intelligence and experience.

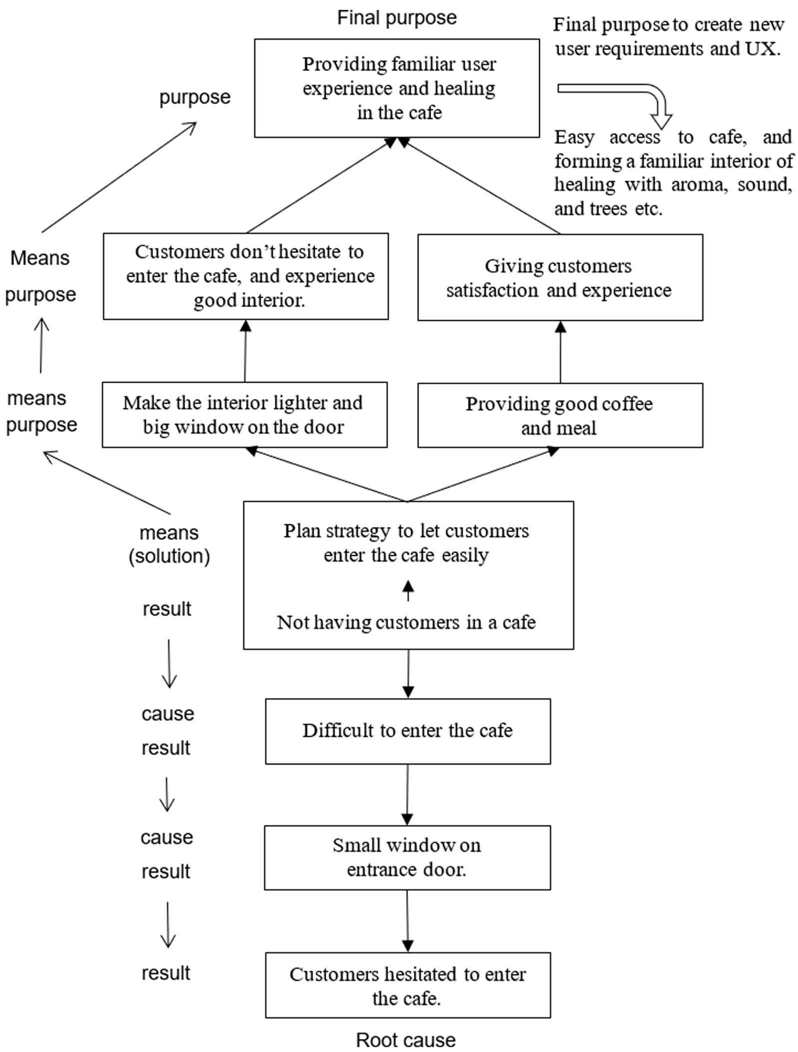


**FIGURE 3.10** A cafe as an example of REM.

### 3.6.2 Proposed Method

This method creates a new UX using a combination of the following four factors.

1) **Three attributes of the product**: useful, usable, desirable (Null and Cherry 1998)
2) **Story**: newest story, real story, historical story, fictional story
3) **Feeling**: lovely, admired, joyful, interesting, impressed, surprised, expected, comfortable, satisfied

**TABLE 3.10**
**Definition of Senses by UX**

| Senses by UX (senses produced by user experience (UX)) | |
|---|---|
| **Sense** | **Definition** |
| Extraordinary sense | Sense from travelling and going to a concert |
| Sense of usability | Sense from usability such as Web services and IC cards |
| Sense from five senses | Sense from five senses such as watching a 3D movie and smelling perfume |
| Sense from obtaining something | Sense from obtaining useful information and accepting presents |
| Sense of admiration | Sense evoked by admiration such as big-name brand products and favorite artist |
| Sense after doing a task | Sense of accomplishment, fulfillment and unity such as completing a project |
| Sense of familiarity | Sense from familiarity such as attachment to an old house or old watch |

4) **Sense from UX**: sense from UX is produced by user experience (UX). There are seven kinds of sense: extraordinary sense, sense of usability, sense from the five senses, sense from obtaining, sense of admiration, sense after doing tasks, sense of familiarity (Table 3.10).

Figures 3.11 and 3.12 show the relationship between the three attributes of product, story and feeling and sense by UX. If the relationship between the two keywords is closely related, a line is drawn between the two keywords such as newest story and surprised and so on.

## How to use the UX system diagram

1) Making a story using the UX system diagram
2) Suitable keywords are selected from the UX system diagram
3) As selected keywords are connected and lines drawn, the story and UX are decided.

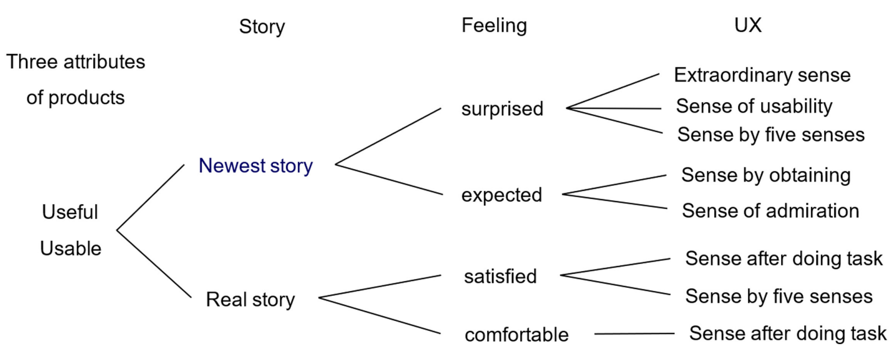


**FIGURE 3.11** UX system diagram in useful and usable aspects of product or systems.

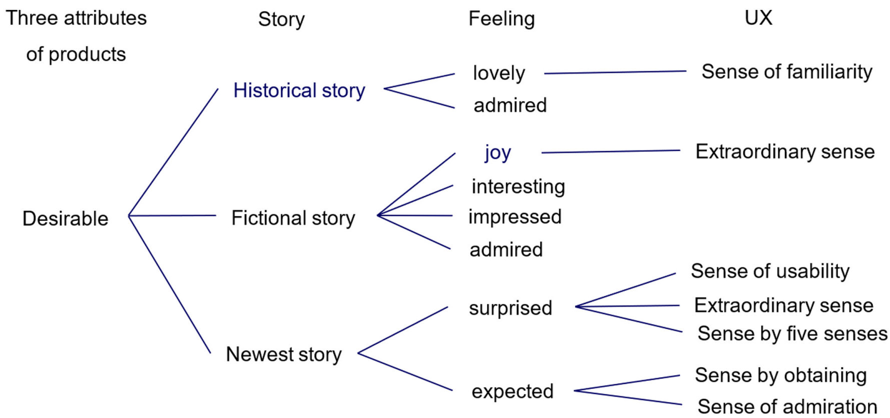


**FIGURE 3.12** UX system diagram of desirable aspects of product or systems.

## 3.7 EXAMPLE OF UX SYSTEM DIAGRAM APPLICATION

Two examples:

1) **Latest medical equipment introduced into a hospital**

When a hospital introduces latest medical equipment, the patient or people planned to be hospitalized have expectations on their sense of its administration.

The items of "Useful, Usable," "Newest story," "expected" and "Sense of admiration" are connected as one story (Figure 3.13). Each item selected shows concrete content as below:

"Useful, Usable"------ "Newest story"------ "expected"------"Sense of admiration"

"Useful, Usable": latest medical equipment

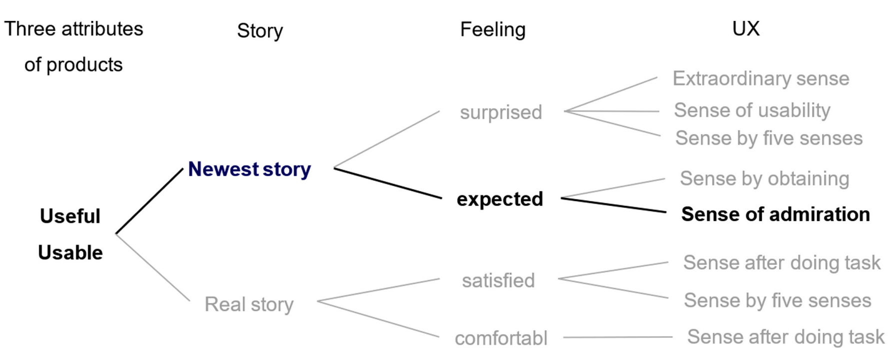


**FIGURE 3.13** Example 1: Newest medical equipment introduced in hospital.

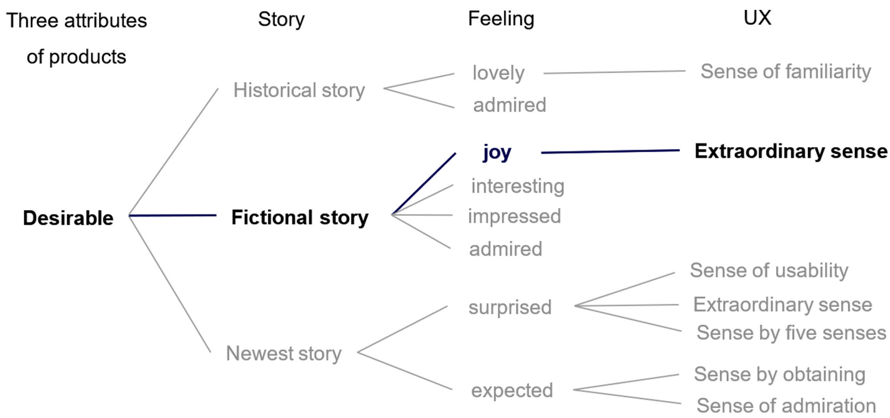


**FIGURE 3.14** Example 2: A fictional Cinderella Castle constructed.

“Newest story”: the hospital introduces the latest medical equipment
“expected”: patients or people planned to be hospitalized have expectations
“Sense of admiration”: a sense of administration

2) **A fictional Cinderella Castle constructed**

If a fictional Cinderella Castle in an amusement park is constructed, users enjoy and are moved from the perspective of having a dream and extraordinary sense (Figure 3.14).

“Desirable”------“Fictional story”------“joyful”------“Extraordinary sense”
“Desirable”: Cinderella Castle
“Fictional story”: a fictional Cinderella Castle was constructed
“joyful”: users enjoy from the perspective of having a dream
“Extraordinary sense”: users enjoy from the perspective of extraordinary sense

The UX system diagram can create a UX structure and decide a design plan using the three attributes of product, story, feeling and sense from the UX.

## 3.8 CONCLUSION

The three methods for usability and UX can show how to obtain user requirements and UX. Designers, engineers and planners as beginners of collecting user requirements especially can obtain them using the three methods without intuition.

Usability-UX task analysis can collect user requirements and UX efficiently and systematically. REM can also extract user requirements by root cause and final purpose based on the problems of products or systems. The problems can be found by usability-UX task analysis or observation. UX system diagrams can create UX and feelings based on the four attributes of product, story, feeling and sense from the UX. The relationship between the three methods is shown in Figure 3.15.

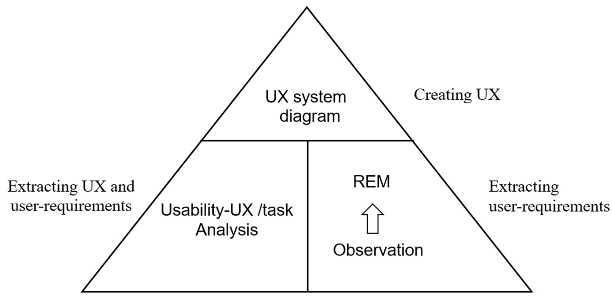


**FIGURE 3.15** The relationship of the three methods.

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# 4 Remote Usability Testing

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## CONTENTS



## 4.1 INTRODUCTION

Usability evaluation is an essential step in the user-centered design cycle (International Organization for Standardization, 2019). For usability evaluation, different approaches and methods are available: model-based evaluations (Kieras, 2012), inspection-based evaluations (Cockton, Woolrych, Hornbæk, & Frøkjær, 2012) and user testing (Dumas & Fox, 2012; Lewis, 2012). This latter method is probably the most documented one. There are countless articles and books on it (Barnum, 2020; Dumas & Redish, 1999; Rubin & Chisnell, 2008; Tullis & Albert, 2013).

With the Internet, remote usability testing has gained popularity, especially for testing Web sites. In remote user tests, researchers and participants are in different locations and participants use their own hardware and software. This is made possible by different technologies.

The aim of this chapter is to present a state of the art in remote usability testing. The differences between the two approaches in terms of methodology and tools, advantages and drawbacks of each will be addressed. Before presenting the state of the art in remote usability testing and allowing the comparison between in situ user tests and remote testing, we will describe how the user tests are prepared and conducted in the traditional lab.

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## 4.2 PREPARING AND CONDUCTING A USER TEST

To assess the usability of interactive systems, experts collect behavioral, physiological and self-reported data (Bergstrom & Schall, 2014; Sauro & Lewis, 2016; Tullis & Albert, 2013). But before capturing these data, experts have to go through the following steps for preparing the test (Bastien, 2010):

- The definition of the test objectives,
- The selection and recruitment of test participants,
- The selection of tasks that participants will be asked to perform,
- The creation and description of task scenarios,
- The choice of the measures and the way the data will be recorded,
- The preparation of the test material and test environment (the usability laboratory),
- The choice of the tester and the design of the test protocol per se (instructions, design protocol, etc.),
- The selection of satisfaction questionnaires,
- The analysis of the data,
- The presentation and communication of the test results.

Some of these steps, as they take place in a usability lab, are detailed in the following sections.

### 4.2.1 The Definition of Test Objectives

The design flaws may be identified during the development cycle of an interactive system or when the system is released. In the first case, we talk about formative evaluations which are conducted at the beginning of the design process and continue until the final system is released. In other words, evaluations are usually performed with each new version of the underdevelopment system in order to identify and fix usability problems. These evaluations end when predefined criteria are met (e.g., a planned number of iterations, a percentage of successful tasks, etc.).

In the second case, summative evaluations are intended to assess the final system in order to measure its performance, to validate that the system meets a set of requirement criteria and to benchmark the system to previous versions or to competing products.

### 4.2.2 The Selection and Recruitment of Test Participants

Tests participants should be representative of the end users in terms of characteristics, knowledge and skills. The number of users that need to be mobilized is an issue that has been addressed by several authors. Early studies concluded that five users were sufficient to identify 80–85% of usability problems (Lewis, 1994; Nielsen & Landauer, 1993; Virzi, 1990, 1992).

However, more recent studies have indicated that five users could not be sufficient. For example, Spool and Schroeder (2001) report that 35% of usability problems were found with the first five users, but that critical usability problems were found from the 13th and 15th test participants. Faulkner (2003) also conducted a study involving 60 users who were asked to complete a computerized timesheet. The author found that the risk of relying on a group of five users could cause half of the usability problems to be missed.

### 4.2.3 The Definition of Task Scenarios

During user testing, participants are usually asked to perform predefined tasks. These tasks are selected according to several criteria such as the objectives of the test or research hypotheses, the end user's goals, the frequency with which they are performed by the end users, the areas of the system where there may be potential usability problems, the system's business objectives, the results of a previous test or inspection methods or the new functionalities which have to be tested.

Following the selection and definition of the tasks, the experts have to write instructions and test their comprehensibility. When writing the instructions, experts will keep in mind that users are invited to achieve specific objectives and not to follow a succession of actions.

### 4.2.4 The Choice of Measures, Their Analyses and Their Representation

During a user test, experts collect specific information related to effectiveness and efficiency of the interaction and also satisfaction with the system, which are the characteristics of usability (International Organization for Standardization, 2018). The data can be classified into three categories:

**Behavioral data**. The most commonly used behavioral data collected during a user test are the task status (i.e., success or failure), task duration, error rate and physical or/and cognitive efforts. In the context of Web sites, clickstreams and the lostness metric (Smith, 1996) can also be collected and computed.

The task status is a way of reporting whether or not the user has completed the task and to what extent. From this task status, several analyses and representations can be produced: the ratio of successes (or failures), the average calculation of the tasks (i.e., the number of participants who succeeded or failed in completing the task) and the average calculation for each participant (i.e., the number of tasks that the participant was able to complete or fail to complete).

The time on task is the time elapsed between the start of a task and its completion. Duration of the task can be calculated and presented not only for each task (i.e., the average time the user takes to complete the task) but also for each user (i.e., the average time the user takes to complete all tasks).

Errors are the actions that can cause the task to fail. Errors can be calculated and presented as error rate per task per user or for each task per user. It is also possible to assign a severity score (low, medium, high) and then calculate the frequency for each category of errors. These errors are generally due to usability problems.

Physical efforts refer to the physical activity required to perform the task, whereas cognitive efforts are the mental resources involved in responding to a particular task.

They can be analyzed by counting the number of actions, such as clicks, performed to complete the task. Usually, experts calculate an average number of actions for each task (per participant).

Clickstreams illustrate the paths taken (by users) on a Web site. It can be used to identify the pages that participants go through in their search for information and to calculate the percentage of participants taking each route (e.g., Figure 4.1). It allows assessing the heading and links and their relation to their content.

The lostness metric (Smith, 1996) indicates whether or not users are lost on a Web site. The coefficient is calculated from three elements: (1) $N$: the number of unique Web pages that were visited during the task (pages that are visited several times only count once); (2) $S$: the total number of Web pages visited during the task, including page revisits; (3) $R$: the (optimal) number of pages that must be visited to complete the task. These three elements are then used in the following formula to calculate the lostness metric noted $L$:

$$L = \mathrm{sqrt}((N / S - 1)^2 + (R / N - 1)^2).$$

Smith (1996) found that the score $L$ of less than 0.4 shows no sign of being lost. In contrast, participants with a score above 0.5 appear disoriented. When the $L$ value was calculated for each participant, it is possible to obtain an average score for each task.

The use of eye-tracking techniques makes it possible to know precisely where the participant's gaze lands throughout the test session (Bergstrom & Schall, 2014). This technique can be used, for example, to analyze cognitive processing, stimulation and interest using the user's pupillary response, or to determine whether the user, while browsing, correctly saw the Web link to successfully complete the task or whether the user took it into account but did not click on it. From the eye-tracking data, it is possible to obtain the following: (a) The scanpath which allows the visual representation of the participant's eye path on the interface. This technique takes into account two types of data: fixations and saccades. The fixations, which are a pause in the eye's movement over an area, are usually expressed in numbered circles, while saccades, which are brief, rapid eye movements, are represented by lines joining two fixations. (b) The heat map which is used to represent the eye movements of several participants on the Web page. The colors of the heat map indicate the density of eye fixations. Usually, the warmer the color, the higher the fixation density and, conversely, the colder the color, the lower the fixation density. The heat map is an excellent way to know which area(s) of the page is attracting more (or less) attention from participants. (c) The focus map which makes areas that have received the most visual attention transparent, while it darkens areas that have received little or no visual attention.

It is also possible to make analyses of eye-tracking data according to specific areas (called areas of interest [AOI]) that have been delineated by the experts. From these areas of interest, experts can have dwell times, number of fixations within an AOI, the sequence, time to first fixation, revisits, hit ratio, etc. From these analyses, two types of visualizations are possible: (1) binning charts which show the percentage of time spent

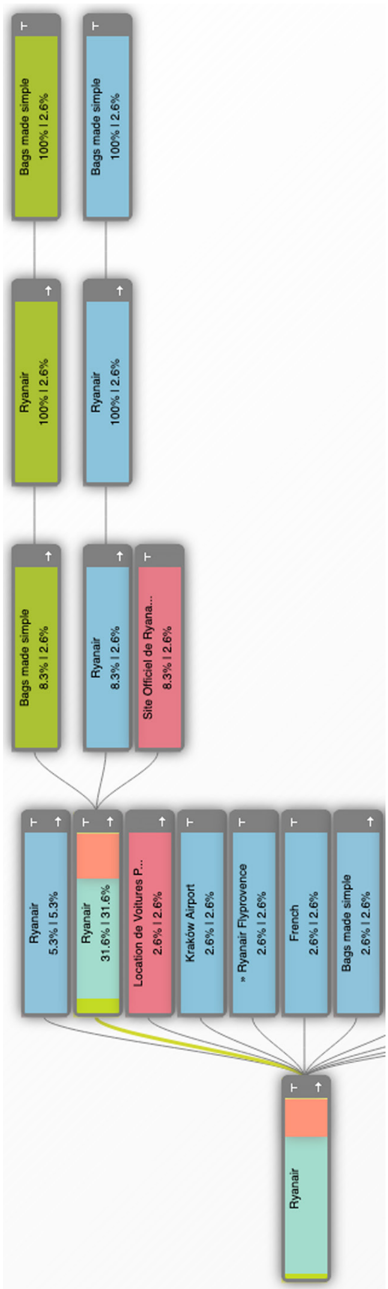


**FIGURE 4.1** Schematic example of a clickstream taken from a test conducted with Evalyzer (www.evalyzer.com).

looking at each area of interest according to a time interval; (2) areas of interest grids which show the amount of visual attention given to cut out cells of equal size.

**Physiological data.** The most common physiological measures used in user tests are facial expressions, skin conductance and electroencephalography (EEG). Software such as FaceReader[1] can determine the emotional state of the participant based on his or her facial expressions (based on the taxonomy of Ekman and Friesen (1975)). The conductance (or electrodermal activity) of the skin is measured using sensors to detect emotional activation or stimulation. Three types of activation exist: an increase in mental load, an increase in emotion/emotional state and/or an increase in physical activity. Emotional states associated with increased electrodermal activity include fear, anger and joy. Knowing the emotional states of participants during the user testing session can be useful not only in evaluating the user experience, but also in detecting usability problems.

Brain waves measured by electroencephalogram are associated with cognitive and emotional states. For example, they can detect states of activation or excitement or calm in users (Alfimtsev, Basarab, Devyatkov, & Levanov, 2015).

**Self-reported data**. Most of the time, self-reported data used in user testing are collected in three different ways: with the think-aloud protocol, with questionnaires and with standardized satisfaction questionnaires.

User verbalizations are collected by the think-aloud protocol method. The think-aloud protocol involves asking participants to think aloud while interacting with the system. Users are invited to express anything that comes to their mind, i.e., their ways of doing things, their opinions, their reactions and so on. Experts can have users perform verbalizations during the test session (which is called concurrent think-aloud protocol) or after the test session accompanied with a video recording of their performance (which is called retrospective think-aloud protocol).

Written and oral comments are collected with open-ended, closed-ended, single choice, multiple-choice questions, scales and ranking questions (e.g., Likert scale [Likert, 1932] and semantic differentiators (Osgood, Suci, & Tannenbaum, 1957)). In addition, from the 1980s onward, authors have developed satisfaction questionnaires. These questionnaires can be categorized globally by their number of items, the usability dimensions they evaluate, the scale format and the type of systems they are designed for. Some examples of satisfaction questionnaires are the ASQ (*After Scenario Questionnaire*) (Lewis, 1995), the AttrakDiff (Hassenzahl, Burmester, & Koller, 2003), the CSUQ (*Computer Usability Questionnaire*) (Lewis, 1995), the meCUE (Minge & Riedel, 2013), the PSSUQ (Post-Study System Usability Questionnaire) (Lewis, 2002), the PUTQ (Purdue Usability Testing Questionnaire) (Lin, Choong, & Salvendy, 1997), the QUIS (*Questionnaire for User Interface Satisfaction*) (Chin, Diehl, & Norman, 1988), the SUMI (Software Usability Measurement Inventory) (Kirakowski & Corbett, 1993), the SUS (System Usability Scale) (Brooke, 1996), the UEQ (User Experience Questionnaire) (Laugwitz, Held, & Schrepp, 2008; Laugwitz, Schrepp, & Held, 2006), the UMUX (Usability Metric for User Experience) (Finstad, 2010), the UMUX-LITE (Usability Metric for User Experience) (Lewis, Utesch, & Maher, 2013) and the USE (Usefulness, Satisfaction and Ease of Use) (Lund, 2001).

Some satisfaction questionnaires are more dedicated to Web sites: e.g., DEEP (Design-oriented Evaluation of Perceived Usability) (Yang, Linder, & Bolchini, 2012), EUCS (End User Computing Satisfaction) (Doll & Torkzadeh, 1988), the perceived Web site usability measurement scale (Wang & Senecal, 2007), SUPR-Q (Sauro, 2015), the user-perceived Web quality instrument (Aladwani & Palvia, 2002) and WAMMI (Web Analysis and Measurement Inventory, www.wammi.com).

### 4.2.5 The Preparation of the Test Material and the Test Environment (Test Laboratory)

The structure of a test laboratory is usually composed of several rooms. Although the number of rooms differs from laboratory to laboratory, there is a minimum of two rooms (Nielsen, 1994): a testing room for the participant(s) and an observation room for usability professionals. In this first room, you will find materials for conducting the test, such as a computer, tablet or smartphone, for presenting the interface (Web site, application) to be evaluated. The instructions, usage scenarios and questionnaires are generally provided in paper or online version or eventually verbally given by a facilitator.

The test room also contains recording devices allowing the user's actions on the interface to be collected through software snapshots, cameras for observing the users, user verbalizations with the help of microphones and physiological measurements using specific devices (e.g., cardio-frequency meters and electrodermal sensors).

This room is usually separated by a one-way glass. The observation room contains equipment for the observation of the users and instruments to interact with the user (i.e., microphones).

Sometimes additional rooms are used in some laboratories (Figure 4.2): an observation room where additional people can observe the test without interfering with the users or assessors, a reception room and audiovisual control room.

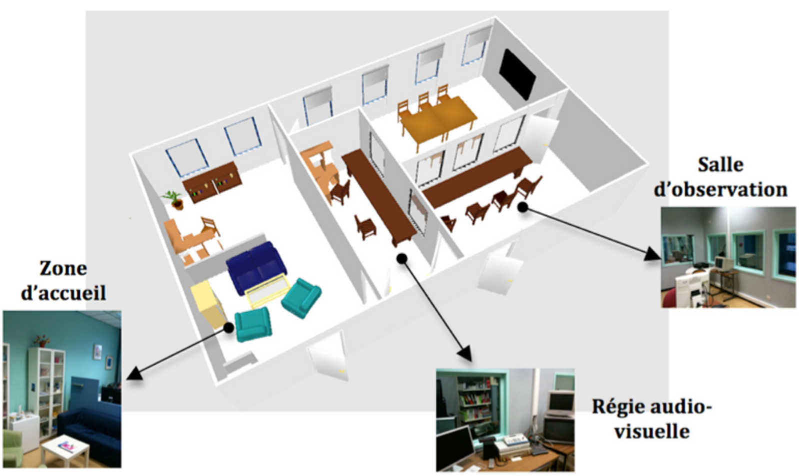


**FIGURE 4.2** Pergolab user test laboratory (Metz, France).

### 4.2.6 The Presentation and Communication of Test Results

Although the presentation and communication of test results can be left to the choice of the usability professionals, a template (the CIF[2]) has been proposed (American National Standard, 2001; International Organization for Standardization, 2010). The purpose of this template is to standardize the writing of test reports.

## 4.3 REMOTE USER TESTING

In the previous sections, the preparation of the test session, as well as the tools used during the laboratory sessions, has been presented. In this and the following sections, we will address the remote user testing and the tools used. We will also ask ourselves if this kind of test allows gathering the same kind of data that are gathered in a laboratory and if the results of these tests compare to those obtained in a laboratory.

Over the past two decades or so, the Internet has made it possible to conduct user tests remotely. Thus, "the evaluator, performing observation and analysis, is separated in space and/or time from the user" (Hartson, Castillo, Kelso, & Neale, 1996). Remote user testing addresses several issues encountered in laboratory settings. In fact, remote testing does not require testers to travel to the testing labs, saving time and money. It also makes it possible to involve testers who are far away, and to reduce the costs of traditional lab. Moreover, users are in their natural environment (i.e., they use their own hardware and software). However, the remote user test may face some new issues such as installation and configuration of the software to perform the test as well as confidentiality issues (De Bleecker & Okoroji, 2018).

Two ways of conducting remote user testing have been used by experts: (1) User tests that involve the supervision of an evaluator (synchronous and moderated testing). (2) User tests that do not require the presence of a moderator (asynchronous and unmoderated).

### 4.3.1 Moderated User Testing

Moderated remote user testing was born in the 1990s, thanks to the development of information sharing and collaborative tools (Hammontree, Weiler, & Nayak, 1994). Like user testing labs, evaluators conduct the tests and collect information while users perform different actions on the system, but in this context evaluators are just geographically separated from users. Evaluators interact directly with test participants.

To perform user tests, three key elements are required (Dumas & Loring, 2008): the system being evaluated, a sharing application and a recording application.

Nowadays, evaluators usually use videoconferencing tools (e.g., WebEx,[3] Zoom,[4] etc.) in order to collect user screen actions, user verbalizations and user facial expressions. Commercial tools such as Lookback[5] and Loop11[6] can be used in moderated remote user testing.

### 4.3.2 Unmoderated User Testing

Unmoderated remote testing appeared in the late 1990s (Scholtz, Laskowski, & Downey, 1998). In unmoderated testing, the evaluators are physically and temporally separated from the users. In other words, evaluators are replaced by a platform which is in charge to conduct user tests and to collect data from users (and in some circumstances analyzes them). The advantages are that many users may participate at the same time, thus more participants can be recruited in a given period of time, reducing the duration of the test campaign. The test is also independent of time zones. In this situation, users are not influenced by the expert's comments or behaviors and the test situation is less impressive because the user is in a familiar environment at home or at work.

But there are some drawbacks. In fact, users may not be able to get assistance if needed. Experts cannot observe test participants while they are running the test and cannot interact with them. But some of these drawbacks can be mitigated depending on the technology used.

Over the last 20 years, unmoderated remote user testing tools have evolved significantly in terms of the architecture used to collect data, the type of data collected, the skills and amount of effort required by usability experts.

Three approaches have been adopted to conduct remote testing: server-based, proxy-based or client-based approach.

Server-based approaches are normally able to collect navigation data and even interaction data by adding some JavaScript code on Web pages which require access to the Web server. With this approach, it may be difficult to interpret users' actions, paths and goals. Nevertheless, a possible solution has been proposed to address these drawbacks. This solution combines users' actions data and subjective data collected through questionnaires in the same tool (Winckler, Freitas, & Valdeni de Lima, 2000).

Proxy-based approaches consist in adding an "intermediary" between the client which sends requests to obtain Web pages and the server which provides specific Web pages according to the requests. By being located between the two, the proxy can retrieve some data. Like server-based tools, this approach gathers navigation data (Hong & Landay, 2001), interaction data (Atterer & Schmidt, 2007; Atterer, Wnuk, & Schmidt, 2006; Baravalle & Lanfranchi, 2003) as well as subjective data (Baravalle & Lanfranchi, 2003). This approach solves the main issue related to the server-based approach, i.e., the access to the server.

Client-based approaches consist in using either an instrumented browser (e.g., Uzilla) (Edmonds, 2003) or browser plugins (e.g., Evalyzer[7] and Loop11[8]). Thanks to this approach, not only the above-mentioned data but also the user's actions on the Web browser (e.g., backward and forward buttons) can be recorded. With this approach, however, the user must have a compatible operating system or Web browser, the required privileges and the aptitude or the inclination to install a browser or plugins on his machine.

Recent commercial tools mainly use the plugin approach and (try to) integrate all the steps required to conduct user tests for reducing the amount of effort needed by usability experts (e.g., Evalyzer,[9] Lookback,[10] Loop11[11] and UserTesting[12]).

To a certain extent, these tools can manage the different steps that were described in the previous sections for preparing and conducting a user test. For instance, user selection and description can be done by a screening questionnaire. Evalyzer and UserTesting, for example, offer this functionality. All the platforms mentioned above allow defining tasks. However, given that the test is conducted without supervision, experts or evaluators cannot know when participants have succeeded a task or not. Thus, conditions of success must be defined in order for the tool to be able to calculate success rates and failures. Some of the tools provide this functionality (Evalyzer and Loop11). To our knowledge, only one of them allows the evaluator to randomize the task order (Evalyzer). At the end of the test, satisfaction questionnaires are provided as well as the possibility to develop different types of questions both after each task and at the end of the test (e.g., Evalyzer, Loop11 and UserTesting).

The measures, their analyses and their representation may vary depending on the platform. Behavioral data, self-reported data and user software and hardware environment information can also be collected. However, no platforms allow capturing physiological data. The use of Webcams has been attempted to record the position of the gaze on Web pages on the desktop of the remote participant, but the data collected is not very reliable (Chynał & Szymański, 2011) and the software used may compete with the remote testing application for the Webcam resources.

After collecting user data, some platforms provide automatic analyses and representations of the results. Individual results are provided as well as group statistics on each task and questionnaire responses. Thus, it is possible to know for each user the number of tasks on which he failed, the task duration, the efforts (e.g., number of clicks, scrolls, pages consulted), the pages consulted (i.e., clickstream) and the lostness coefficients. In addition, the results of standardized satisfaction questionnaire (e.g., the SUS) can be computed automatically. At the level of the tasks, we get the number of users which have failed on the task, the average duration of the task, the average effort on the task, the clickstream on the task and the average of the lostness metric.

These platforms allow not only exploring data and visualizing the analyses but also exporting data in spreadsheet format, the figures, and the video recordings of the test session which may contain the comments made by the participants and the participants' faces in picture-in-picture if the participants are allowed the use of the Webcam and the microphone. Finally, some platforms allow generating a PowerPoint report.

### 4.3.3 Comparing In Situ and Remote User Testing

Several studies have examined the effects of user test situations (i.e., laboratory testing, remote and supervised testing, remote and unsupervised testing) on dependent variables such as the number of usability issues identified and their severity, task duration, task completion, number of errors, satisfaction, etc.

As for the number of usability problems, five studies found that the lab situation and the remote testing situation were comparable (Andreasen, Nielsen, Schrøder, & Stage, 2007; Brush, Ames, & Davis, 2004; Chalil Madathil & Greenstein, 2017;

Hartson et al., 1996; Thompson, Rozanski, & Haake, 2004). In the same way, the severity of the problems found was similar in both situations (Andreasen et al., 2007; Brush et al., 2004; Chalil Madathil & Greenstein, 2017).

Among the four studies which have measured the task duration, three of them showed that there were no significant statistical differences (Andreasen et al., 2007; Brush et al., 2004; Chalil Madathil & Greenstein, 2017) and only one study showed that local participants took less time (Thompson et al., 2004). One of the studies reported that the setup and wrap-up of the test took significantly more time for remote moderated testing and the discussion was slightly longer in the laboratory condition (Brush et al., 2004).

One study reported that the task completion time was not different between the two test contexts (Andreasen et al., 2007) and another one reported that the number of errors was less for the local participants (Thompson et al., 2004).

Two studies measured satisfaction through questionnaires (Hartson et al., 1996; Thompson et al., 2004). They concluded that the results were comparable.

A point to note is that "the majority of participants felt that the remote condition was more convenient" and "half would prefer to be involved in remote studies over local studies in the future, while none preferred local over remote condition" (Brush et al., 2004).

Only one study compared the laboratory and the unmoderated remote testing (Tullis, Fleischman, McNulty, Cianchette, & Bergel, 2002), and in this study both configurations allowed identification of the most critical usability issues. Task completion rates and task duration were found comparable.

However, the results of these comparisons should be considered with caution as the technologies used are different.

## 4.4 CONCLUSION

The aim of this chapter was to give the reader an overview of the state of the art in remote usability testing. To do so, we first presented the different steps an evaluator has to go through in order to prepare and conduct the usability test and to analyze the data captured. These steps were described as they are usually conducted in a local usability laboratory. They were thus used as a reference. We then gave a brief overview of the evolution of the technologies used to conduct remote usability tests and presented some commercial platforms. Studies comparing the local laboratory test session with the remote testing situation were then presented. We conclude that with recent technologies, the data that can be obtained from remote testing is no longer different from the data captured in a local usability laboratory except for physiological data and eye-tracking recordings. But remote usability platforms which allow conducting usability tests remotely can also be used in a local laboratory so as to complete the test campaign with other kinds of measures. What emerges from these comparisons and comparative analyses of the platforms is that the most recent ones use plugin technologies which allow the evaluators to capture performance data (quantitative) as well as subjective data. The platforms differ from one another in the way they allow, for example, managing the tasks presented to the users as well as the way they analyze the data. It can be expected that these will continue to evolve and will make it possible to integrate other measurement tools whether in a remote situation or as a complement to it.

## NOTES

1. https://www.noldus.com/facereader
2. Common Industry Format (for usability test reports).
3. https://www.webex.com/
4. https://zoom.us/
5. https://lookback.io/
6. https://www.loop11.com/
7. https://www.evalyzer.com/
8. https://www.loop11.com
9. https://www.evalyzer.com/
10. https://www.lookback.com/
11. https://www.loop11.com/
12. https://www.usertesting.com/

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# 5 Helping Them to See It: Using Full Size Mock-Ups to Achieve Usability

*David Hitchcock, Miskeen Rahman and Benjamin Holmes*

## CONTENTS



## 5.1 INTRODUCTION

Ergonomists have for decades repeatedly used mock-ups and task simulations in order to test design concepts. In the early stages of the complex design and buildup of a brand new metro (railway) in Riyadh, Kingdom of Saudi Arabia, Siemens elected to do just this to validate the design concept for the Operational Control Centre (OCC) or Central Control Room (CCR).

As might be expected with major multi-consortia projects of this nature, there is a mixture of agendas, experience and topics competence involved in the decision-making process. Anecdotal evidence suggests that in such circumstances, inappropriate designs can be accepted on the basis of impressive design drawings and renders, sometimes compromised by eleventh-hour "HIPPO" (highest paid person's opinion) decisions!

DOI: 10.1201/9780429343490-6

In an operational and safety-critical setting such as an OCC/CCR, the design must be validated on a more robust basis. So, to produce the necessary evidence and serve as a demonstrator for the unfamiliar—to help them to see it—a classical method was adopted for concept approval which sought to evaluate the design through the use of intentionally rudimentary mock-ups of the concept workstation and the control room layout.

The metro being designed was an automatic one with Grade of Automation Four (GoA4), which meant in normal operation the operators simply have to observe (or supervise) the screens and monitors. In order to satisfy project requirements, the aim of the exercise was to demonstrate to the client (The Riyadh Metro Authority) and their consultants that the OCC/CCR design satisfied the requirements of ISO 11064-4: 2013—Ergonomic design of control centers.

This approach of using a full-size mock-up allowed the project team to evaluate and validate the intended design to minimize, and where possible to eliminate, potential human errors during the operation of the metro.

The trials were witnessed by the client's consultant and their human factors expert to assess and comment on the human–machine interface (HMI) as well as the visibility of the visual display panel. A video was made to explain the methodology applied to a wider audience of engineers, operational experts and architects—it is often a challenge to convince people with different visions of a CC/OCC; the engineers wants it to be functional, the operation experts want ease of operation and the architect requires the internal walls, ceiling and the operator's desks to be aesthetically designed. The approach adopted was one by which each of these could be somewhat immersed in the requirements and solutions of the design proposed.

## 5.2 A PSYCHOPHYSICAL "OLD SCHOOL" APPROACH

The use of crude—foam board—mock-ups gives participants clear indication that the design is unfinished and, therefore, presents the opportunity for changes, even minor ones to be considered. The use of basic seating also added to the appreciation of the "unfinished" nature of the design, reducing assessment distraction which may arise through unintentional assessment of the chair quality. Similarly, the provision of personal storage and the like (albeit important) was avoided in the mock-up.

The benefit of creating a full-size representation of the OCC enables a "see and feel" experience for the participants which cannot be simulated by on-screen visuals. As a result, participants gain an appreciation of size and space which presents the opportunity to evaluate both the fit (e.g., reach, clearance) and acceptability of the designs.

This typically enables those involved in the evaluation to rate and comment on the designs in an interactive and critical manner to identify any necessary changes and validate the concept(s).

### 5.2.1 The Mock-Up Brief

To obtain real albeit raw data, a brief was agreed to manufacture, deliver and assemble crude, full-scale mock-ups (made from 3–10 mm foamcore board) of the proposed room workstation designs, including their desktop items (Figure 5.1).

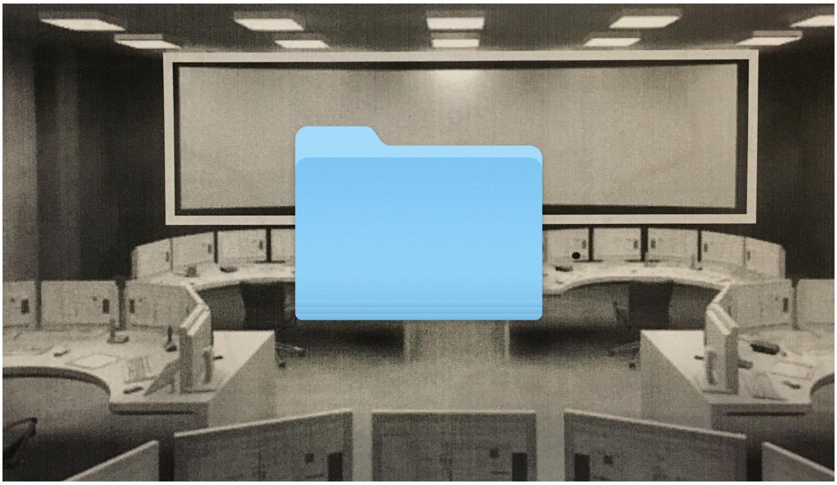


**FIGURE 5.1** Proposed room design intent.

### 5.2.2 Supervisor Workstations

Two Supervisor Workstations (3000 mm wide × 1500 mm deep × 740 mm high) with accompanying equipment (see Figures 5.2 and 5.3) were required. One workstation needed to be raised off the ground to mimic the rise in floor level toward the back of the OCC and it was to have six freestanding monitors on its desktop. Although not part of the proposed room layout, the other workstation was to sit to

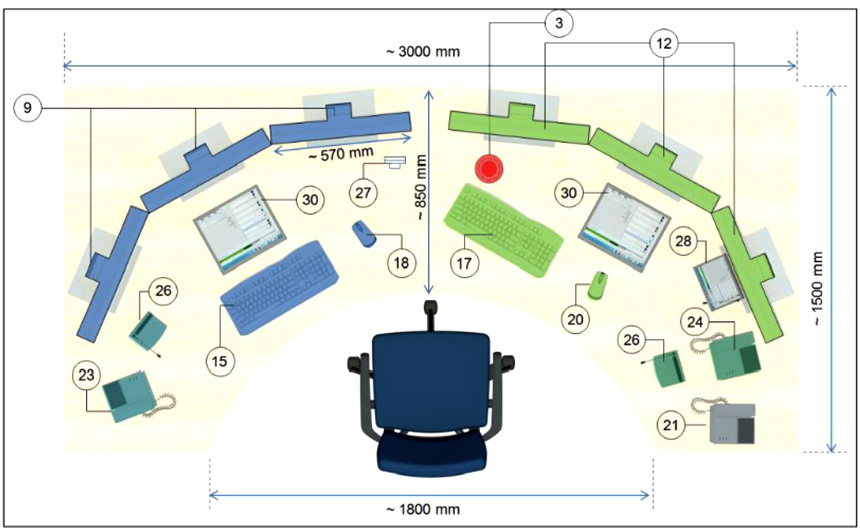



**FIGURE 5.2** Proposed Supervisor Workstation brief plan.

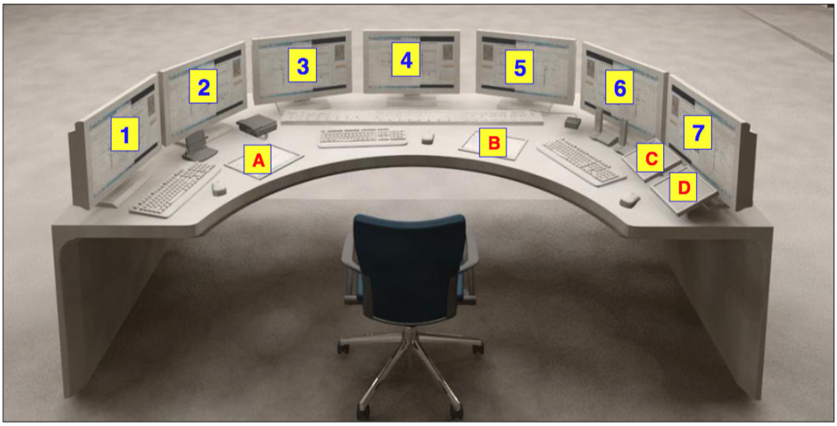



**FIGURE 5.3** Proposed Supervisor Workstation design intent.

one side in the trials room for additional data collection considering the application of seven monitors on its desktop. In both cases, the desktop items were regular-size keyboard (×2), regular-size mouse (×2), 10″ CCTV monitor (×2), "TETRA" monitor (×1), radio communicator (×2) and regular-size telephone set (×2). All of the items were freestanding so that they could be moved around during the trials. Both workstation tops were completely covered in graph paper in order to record the positions of the desktop items as they were positioned according to the preferences of each trial participant.

### 5.2.3 Operator Workstations

Five Operator Workstations (3000 mm wide × 1500 mm deep × 740 mm high) were required. These workstations were only required to hold seven freestanding monitors.

### 5.2.4 Manager Workstations

Two Operator Workstations (1600 mm wide × 800 mm deep × 740 mm high) were required. These workstations were required to hold two freestanding monitors, one keyboard, one mouse and one inkjet printer.

### 5.2.5 Large Curved Display

The large curved display (see Figure 5.4) was to consist of multiple panels, 2 panels high × 8 panels wide. Each panel was 750 mm high × 1000 mm wide. The panels needed to be mounted so that the overall height of the curved screen could be adjusted easily and quickly during the trials. The adjustment of the top of the screen was between 2 and 4 m.

**FIGURE 5.4** Large Curved Screen design intent. [Alt text: Rear three-dimensional digitally produced render showing a close-up of the large curved display at the front of the room. This has a thick yellow line round it to highlight the subject.]

### 5.2.6 Mock-Up Production

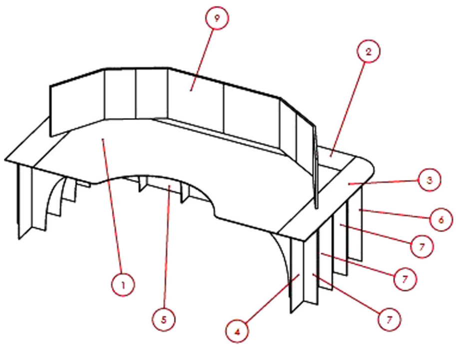
It was clear from the outset that some of the manufacturing and material logistics would be challenging. The facilities available to manufacture the items were small, with limited access in and out of the property. This meant that comprehensive planning, along with detailed design for manufacture, was essential in order to deliver to the trial site, damage free and with minimal setup times.

The mock-ups were predominantly manufactured using foam board, a material with suitable properties; white, rigid, strong, lightweight, manufactured in large sheets 2440 mm × 1220 mm and of varying thickness (3, 5 and 10 mm); properties that allow the optimization of separate parts and delivery in flat-pack form.

The first obstacle to overcome was that the sheet material was smaller than the overall size of the workstation tops—3000 mm × 1500 mm (Figure 5.5). A digital 3D model was required to split the workstations into smaller parts. Individual part drawings were produced in order to speed up the production process and increase accuracy.

Once a solid design was produced, an optimization of all elements was created. This allowed us to calculate the amount of foam board required and to minimize waste. The material and all other elements were ordered and delivered so that production could begin, including foam board, graph paper and printed graphics.

Printed graphics were bonded to desktop items, allowing participants to identify each item in the trial—monitor screens, labeled imagery for desktop items and the large curved display digital screen. The graphics helped finalize the required size for all the freestanding desktop items for the Supervisor Workstations. All items were




| ITEM NO. | PART NUMBER | DIMS | SHEET | QTY. |
|---|---|---|---|---|
| 1 | Desk Top - Main | 1220x2440 | 6 | 1 |
| 2 | Desk Top - Top Panel | 280x2440 | 4&5 | 1 |
| 3 | Desk Top - Side Panel | 1500x280 | 1 | 2 |
| 4 | Desk Side Panel leg | 775x1220 | 2 | 2 |
| 5 | Desk Long Panel leg | 775x2440 | 1 | 1 |
| 6 | Desk Side Panel Strutt | 775x1120 | 3 | 2 |
| 7 | Desk Side Panel Strutt 2 | 775x700 | 4 | 8 |
| 8 | Desk Side Panel Strutt3 | 775x1120 | 3 | 2 |
| 9 | Screens | 514x1677 | A0 - 4 SHEETS PER DESK | 2 |

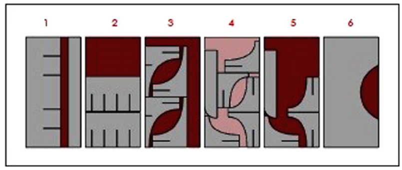



**FIGURE 5.5** Workstation 3D model, bill of materials and optimization of workstation piece parts.

created in a two-dimensional state, enabling them to be moved around the desks during the trial.

Once production of the workstations began, the significant overall size of the worktops became apparent! The workstation part shown in Figure 5.6 was a full sheet of foam board and, therefore, too large to maneuver to the production room in order to cut in the curved recess. The decision was made that this part be split down the middle and to use pre-cut, small, rectangular bracing pieces to bond the workstation desktop parts together from the underside.

The large curved display consisted of the foam board panels which were bonded to metal poles that could be extended and retracted to suit the heights required.

All items were numbered and labeled to assist on-site assembly.

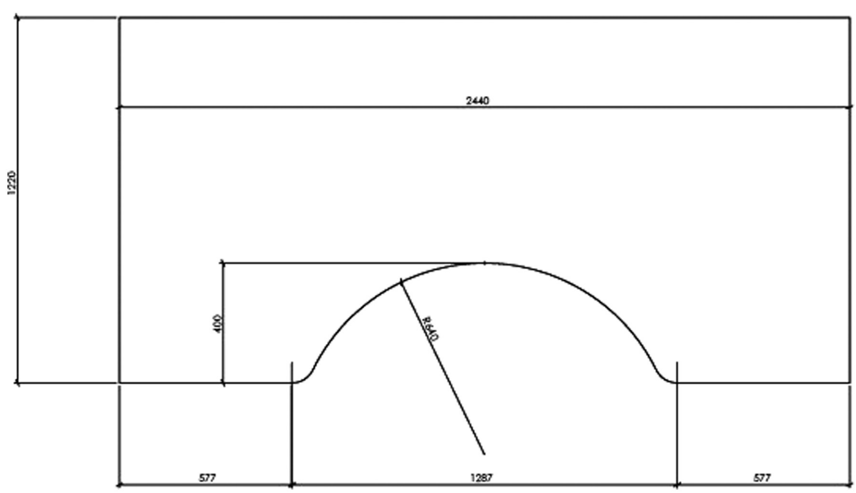



**FIGURE 5.6** Desktop main body drawing.

**FIGURE 5.7** Workstation 3D model, bill of materials and optimization of workstation piece parts.

### 5.2.7 Mock-Up Erection

Once production was complete, all parts were transported to a site where they were laid out, face down, in position. The bracing pieces were then used to bond these together using a hot glue gun which allowed for quick application and drying time. The legs were assembled using half-lap, finger joints designed to allow quick on-site assembly. The workstations were assembled quickly and hassle-free. The final, full mock-up is shown in Figure 5.7.

### 5.2.8 During the Trials

The nature of the trials required a mock-up which allowed participants to freely maneuver workstation items into places to suit their specific needs and anthropometry. At each workstation, participants were encouraged to behave as if it was their place of work.

Varying human behavior, along with the flimsy nature of foam board, meant that the workstations required regular attention and adjustment during the trials. For example, a participant may have leaned on the desktop where joints were weak, and this required fixing with a glue gun or roll of tape or even the production of new parts.

It was apparent on day 1 of the trials that the monitor screens were not robust enough to withstand constant moving by the participants; this led to the production and application of supporting flanges.

### 5.2.9 Waste Management

Once the trials were successfully completed, all materials and tools needed to be removed from the trial site. Unfortunately, the high volume of foam board was underestimated, along with the disposal challenge it presented! Ultimately, a local church and children's craft charity took the majority of the foam board, enabling around 65% of it to be used rather than discarded.

## 5.3 THE TRIALS APPROACH

These trials adopted two prime methods of investigation:

- **"Fitting Trials" of the Supervisor Workstation** were conducted to establish commonality of layout. In practice, this type of psychophysical experiment means identifying the acceptable limits and optimum positions of items within a piece of equipment to satisfy the needs of the target user population. In this case, having assumed a neutral sitting posture, each participant was asked to sit at a mock-up of the 6-Screen Supervisor Workstation shown in Figure 5.2 to arrange 21 items of desktop equipment in their "closest acceptable," "preferred" and "furthest acceptable" positions.
- **"Use and Comfort" Trials** were conducted to assess the ability to view the large front panel display, the visual and communication links between the different workstations and the comfort of operation. Two room layouts were rated by the participants; "2-3-1" (two desks on the front row, three on the second row and the Supervisors Workstation at the rear) and "3-2-1."

### 5.3.1 A Sample of Headline Findings

Participants were drawn from 24 people who, in the absence of anthropometry data for Riyadh, represented an extensive stature range for UK males (aged 18–64) of less than 1 percentile to over 99 percentile (Open Ergonomics, 2008).

Trials which integrate the physical issues such as reach, clearance and visibility with psychological factors such as communication, social interaction and perception of comfort can yield a wide range of detailed feedback to be considered in subsequent iterations of a design—and these trials were no exception.

The following two key findings are presented to illustrate the type of feedback gathered. First, Figure 5.8 shows the final plots for acceptable monitor and keyboard positions which revealed that the proposed workstation size of 3000 mm × 1500 mm would be sufficient.

Alongside tests of viewing accuracy, using a points-based rating to help assess participant's perception of comfort of viewing the large curved display (Visual Display Panel [VDP]) of CCTV and other information helped identify the most appropriate positions for those who needed most visual interaction with it. The results are summarized in Table 5.1.

## 5.4 HOW DID THE APPROACH HELP THEM TO SEE IT?

The one-to-one mock-up approach was used to validate the design of the Central Control Room and allow the designer as well as the client and their consultant as the

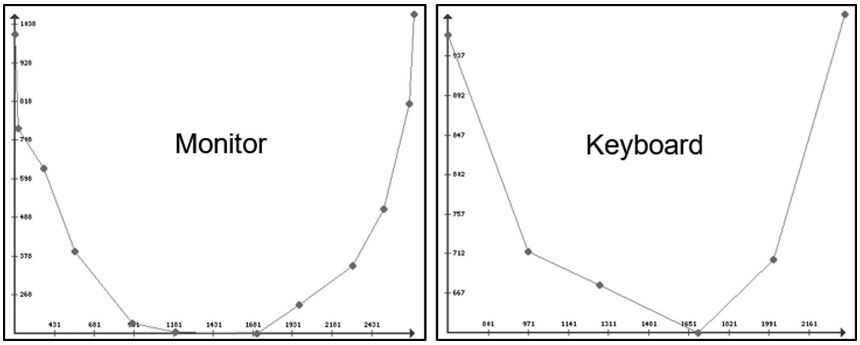



**FIGURE 5.8** Plots showing acceptable monitor and keyboard positions.

approver, the thinking behind the layout and dimensions of the CCR and workstations. The layout and the dimensions of the VDP in relation to the operators' workstations were also assessed.

This approach helped not only to identify the interfaces with the other disciplines and the impact of human factors on the design, and the layout of the workstations and VDP in the CCR, but also to create a comfortable environment for the staff to operate a safe and reliable service.

It enabled the realization that the layout configuration of 3-2-1 of workstations had restrictive viewing of the VDP from the two side workstations on the front row and to change the workstations to a 2-3-1 configuration and angling the first two rows of the workstations inward to the center of the slightly curve shape VDP to achieve better viewing.

Adjusting the mock-up also demonstrated viewing improvements in both comfort and visibility.

In addition, moving workstations around to accommodate clearance requirements (minimum 1200 mm) for an individual with crutches or wheelchair also served to demonstrate the need for an overall increase in the size of the CCR. The physical nature of the demonstration was particularly useful in validating the need because an increase in the size of the CCR from 12 m × 12 m (144 m$^2$) to 12 m × 15 m (180 m$^2$) due to the rearranged workstations necessitated an unexpected change in the building plans.

The project requirements identified that an individual user be provided with a working space of 15 m$^2$ but due to the improvement of the visibility of the VDP from the front row, this individual working space has been enhanced to more than 25 m$^2$ within the core operational floor. This enhancement created a better individual working space for the operator but adversely affected the verbal communication between the front row operators and supervisor slightly. Also, the increased distance between the VDP and middle row workstations plus the supervisor's workstation reduced the visibility and readability of the displayed information such as the train number, track section number and traction zones numbers on the VDP. To validate this new layout with the increased length of the CCR, the trials were repeated.

**TABLE 5.1**
**Summary of Comfort Ratings for Viewing the VDP**

<table>
<tr><th></th><th colspan="2">"Lower" panel height</th><th colspan="2">"Higher" panel height</th></tr>
<tr><td>Best</td><td>1st (19 points)</td><td>Middle row (Workstation 5)</td><td>1st (24 points)</td><td>Front row (Workstation 2)</td></tr>
<tr><td></td><td>2nd (18 points)</td><td>Middle row (Workstation 4)</td><td rowspan="3">= 2nd (21 points)</td><td>Front row (workstation 3)</td></tr>
<tr><td></td><td rowspan="2">= 3rd (16 points)</td><td>Front row (Workstation 2)</td><td>Middle row (workstation 4)</td></tr>
<tr><td></td><td>Back row (Workstation 6)</td><td>Middle row (workstation 5)</td></tr>
<tr><td></td><td>4th (15 points)</td><td>Middle row (Workstation 3)</td><td>3rd (18 points)</td><td>Front row (workstation 1)</td></tr>
<tr><td>Worst</td><td>5th (13 points)</td><td>Front row (Workstation 1)</td><td>4th (16 points)</td><td>Back row (workstation 6)</td></tr>
</table>

For the rerun of the trail, the VDP size was increased from two rows to three rows and the font size for the displayed information on the VDP was also increased. The redesigned VDP still had the top row for the CCTV streaming and the middle row displayed the track schematic (Line Diagram) and train movement information while the bottom row was utilized for traction power zones and associated switching arrangement.

A knock-on impact of these changes was reflected in the height of the bottom of the VDP, so it became necessary to test and validate the maximum height of the workstations with all six display screens at maximum height to maintain visibility of the bottom row of the VDP from the middle row workstations.

The rerun of the mock-up confirmed the improvement in readability of the altered VDP and specified workstation height and reaffirmed the validity of the original trial for the rest of the CCR.

These, and other examples illustrate how the mock-up approach highlighted issues that may have been missed otherwise and prompted timely and achievable resolutions in the early design stage of the CCR. Ultimately, with confidence, a Building Information Management (BIM) model was created for presentation to the client.

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# 6 Qualitative Techniques and Design

## *Using Sequential and Thematic Analysis to Investigate Focus Group in the Problem's Exploration Phase*

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**CONTENTS**



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## 6.1 INTRODUCTION

We live in a world where technologies are embedded into, centered on and connected with people's everyday lives and related to their problems, contingencies, needs and specific or sometimes unknown wishes. Therefore, there is a need in Design to comprehend how research methods work, which one can be applied and the quality of data one can expect when the goal is to get a deep and detailed understanding about these interactions and behaviors.

Some authors argue about the use of quantitative and qualitative methods in the Design Process (Banu Hatice Gurcum 2016; Shavelson et al. 2003; Wright et al. 2009). While quantitative methods can be employed when the main goal is to generalize or validate some piece of data, qualitative methods are used to investigate, detail or understand an experience, behavior or interaction; to discover the quality of data that are part of the studied research scenario; to understand complex phenomena, problems, people's motivation; and to gather insights (Castro et al. 2010; Klotins 2017; Krohwinkel 2015; Pardo, Ellis, and Calvo 2015).

In the problem's exploration step, a phase in the Design Process in which one should analyze the problem, situation or research scenario, several qualitative techniques (such as Observations, Individual Interviews, Surveys, Focus Groups and Cultural Probes) are used to dive into data, understand behaviors and gather insights into the following Design Process steps (Michael Agar and MacDonald 1995; Williams et al. 2006).

However, even the Design literature reveals the use of qualitative techniques, when the Designer decides to choose one to apply, there are few publications, recommendations or guidelines from structured research that describe what could be the best practices, the quality of data that arises and the condition in which each technique could be employed.

Thus, comprehending the importance to research how those methods and techniques are employed in practice in the Design Process, this chapter seeks to investigate the technique of "Focus Group" in the problem's exploration step.

Aiming to provide structured research, this chapter presents the investigation using both techniques: the "Sequential Analysis" and the "Thematic Analysis" to understand the quality of data that arises from four workshops, in which Focus Group was taught and employed, with Graduate and Postgraduate Design students, from two institutions of higher education, in a city, in Brazil.

To go deep in this discussion, the next sections will present concepts about the problem's exploration step and Focus Group, including its practice in Design. Next we will describe the research context, data documentation and analysis and main results obtained such as "Pre-Application," "Application" and "Post-Application"; "reports, interaction and in-depth data" and "interaction and collective sensemaking." We will finally discuss those findings to propose several suggestions on best practices when using Focus Groups.

## 6.2 THE PROBLEM'S EXPLORATION STEP, FOCUS GROUP AND DESIGN

This chapter research scope interest, to apply a qualitative technique, was the problem's exploration step. This phase is characterized by the analysis of the user environment, including people, artifacts, behaviors and interactions. It is already applied in several Design methodologies through different denominations such as problem definition (Alexander et al. 1977), problem analysis or data collection (Löbach 2001, p.141). Although before the 70s, the phase (in Design) was connected with requirements related to product/project, currently the understanding of user problems, situations and/or behaviors is one of the main topics.

Other steps in the Design Process are ideation, or creativity, and prototyping. The first is characterized by using creativity methods (e.g., brainwriting 635[1] and bodystorming[2]) and as an idea's generation step. The second can be described as the use of evaluation methods (e.g., usability testing[3]). These steps nowadays are increasingly manageable and cyclical.

Back to this chapter's research scope, the problem's exploration step, the interest to investigate Focus Group arose from the argument that this traditional technique is widely used in both Design market and research. Focus Group is mentioned in existing Design literature as a qualitative technique to collect data (Agar 2014; BARNES; et al. 1996; Castro et al. 2010; Lord, Susan M., Michelle M. Camacho, Catherine E. Brawner, Catherine Mobley 2017; Mckenna et al. 2013), and it is shown as one of the most used techniques in Design, according to the site "MeasuringU" (Jeff Sauro 2019).

Research also indicates this technique was applied by sociologists and psychologists for more than half a century (Merton and Kendall 1946; Merton, Fiske and Kendall, 1956 apud Wilkinson 1998). Moreover, at the end of the 1970s decade, Focus Group was used in marketing research (WILKINSON, 1998), and in the 1980s it became an emergent practice in Design (STAPPERS et al., 2009).

Focus Group can be described as a group interview or a collective chat, reflecting on the variation about how the group is moderated (Ryan et al. 2014). When applying the technique, it is suggested to engage six to eight participants (Wilkinson 1998) for 1–2 hours to discuss about the topics. The practice also might have one moderator who conducts the research using audio or video recordings (Wilkinson 1998), when permitted by participants.

Ryan et al. (2014) reported two kinds of Focus Group: an *Individualist Social Psychology* perspective, characterized by objectives and more structured questions, and a *Social Constructionist Perspective*, an exploratory approach and dynamic social process in which opinions are shared or tacit knowledge is generated through social participation (Gergen 1985; Kamberelis and Dimitriadis 2011; Wilkinson 1998). As the purpose is to apply Focus Group in Design to understand interactions and behaviors in everyday activities, we choose to use the *Social Constructivist Perspective*, which will be detailed in the next section.

## 6.3 THE RESEARCH CONTEXT AND FOCUS GROUP APPLICATION

This section describes a research study that investigated the technique of "Focus Group" in the problem's exploration step. The investigation was applied through an exploratory qualitative methodology (Lakatos and Marconi 2003/1985), in which pilot studies generated a protocol (Figure 6.1) used to structure the practices. This protocol divided the practices into three moments:

- First, "*questions and simulation*"—when participants should expose their questions and the researcher should simulate the technique.
- Second, "*technique application*"—which would be the technique application itself.

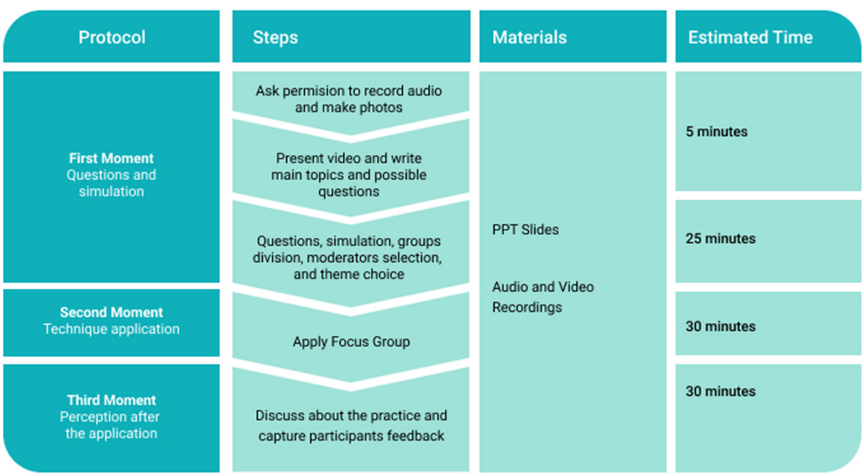



**FIGURE 6.1** The protocol applied in this work. *Source*: Created by the author.

- Third, "*perception after the application*"—participants should expose their perception about the technique and understandings related to the moderator's role.

We discuss these moments in detail in the following sections and also describe the research scenario, participants' approach and application. Then, both data documentation and analysis will be discussed.

### 6.3.1 Research Scenario

The workshops applied in this research took place in two different institutions of higher education: UFPE—Universidade Federal de Pernambuco and CESAR School. Both were located in Recife, a city in the state of Pernambuco, in Brazil.

In Recife is located "Porto Digital," one of the main technology parks and innovation environments in Brazil, whose main areas are Information and Communication Software and Creative Economy. Besides, Design is one of the main segments emphasized ("Porto Digital" 2019).

Back to the institutions in which this work took place, both had a different building structure. While CESAR School provided a climatized room, with round tables, and participants who previously worked together; in UFPE, participants didn't work together, so some improvizations were needed. For example, the workshop presentation was conducted on a 14″ computer screen, because the room's structure was not the one planned and there was no multimedia projector.

### 6.3.2 Participants Approach

The research was applied with Design students pursuing graduation (41 participants) and postgraduate students at both institutions UFPE (6 participants from master's and Ph.D. course) and CESAR School (18 participants from master's course).

Participants were selected in different ways for CESAR School and UFPE: in CESAR School, workshops were applied with graduation and postgraduation classes, and in UFPE students were recruited through a form sent by email, to which nine participants answered and six participated in the workshops.

Both participants pursuing graduation and postgraduation participants already had, even minimal, previous experience with interviews and observation techniques. The majority of graduation students in the beginning of the course, however, didn't have previous experience with those techniques.

### 6.3.3 Focus Group Workshops

The workshops were conducted in 1.5 hours with graduation and postgraduation students.

For privacy issues, at the beginning of the workshops, the researcher explained and gave to each participant a Research Agreement Term, in the Portuguese language called "*TCLE*," in which participants could understand the research information, risks and benefits. The researchers also emphasized that they could ask anything about the "*TCLE*," and further requested them to record audio and take pictures in order to help with the documentation related to the data researched. It was also reinforced by the researcher that all the data would be collected exclusively for research and publications about the technique application, and that participants could turn the audio record off at any time they want.

#### 6.3.3.1 First Moment

As planned in the protocol (Figure 6.1), in the first moment of the workshop, the researcher gave an introduction about Design and qualitative methods and techniques to further present and detail the Focus Group. In order to provide a more structured approach, in each technique presentation workshop, the researcher used a video to display the main concepts and explain how participants should conduct the Focus Group. After the video, there was a moment in which participants exposed their questions and the researcher invited some participants to simulate the technique application.

After the simulation, three themes ("journey to the university," "breaks between classes" and "lunchtime") were exposed to participants, so they could choose which one to apply in the Focus Group. Even though they chose to apply the theme journey to the university in all workshops.

Participants also divided themselves into groups of four to seven persons. In CESAR School, the groups were formed by affinity relationship, and in UFPE as there were only six people, they assembled themselves in one group. As predicted in the protocol, each group also chose one person to moderate the Focus Group practice.

#### 6.3.3.2 The Second and the Third Moment

In the second moment, participants applied the technique. This application lasted for 15–30 minutes, depending on the group. Then when all practices had finished, in the third moment, the researcher grouped all participants and discussed about the Focus Group technique to gather their feedback.

### 6.3.4 Data Documentation and Analysis

After the workshops, the data was stored in the researcher's computer, documented, transcribed, using Google Docs®, and coded through the software MaxQDA®, to further be analyzed and interpreted. All research materials collected were in the Brazilian Portuguese language. The next sections will describe transcription, description and analysis of the data.

#### 6.3.4.1 Transcription

Understanding that interview transcriptions can provide a better database to further analysis (MERIAM, 2009), three moments in the workshops were transcribed. This choice that occurred when the results emerged in the pilot studies showed: valuable understandings about the participants' previous experience with Focus Group; their perception related to the practices; and the visualization of details in each technique application, for example, the moderator's behavior.

#### 6.3.4.2 Description Narratives

In this research, in order to give validity and confidence, also following some requirements described by Meriam (2009) when analyzing qualitative data, description narratives were chosen to document the data collected.

Two important points that contributed to this choice were privacy issues and research observations that need to be considered. When transcribing this research data, we identified moments such as situations related to participants' identity, everyday activities or personal perceptions, which, for privacy issues, should not be exposed or published. Besides, we also realized that the researcher's observation throughout the practices could be lost if only the transcriptions were taken into account in the codification phase.

Thus, our description narratives included both the researcher's observation and a large part of the transcription by leaving out participants' personal data.

#### 6.3.4.3 Data Codification

Following up the narrative's description, all raw data were coded. The codification here was used to provide structured data and validity to the research results. Authors defend the use of codification to analyze qualitative data when the goal is to structure the analysis and/or use scientific rigor (Benson et al. 2012; Castro et al. 2010; Karlesky and Isbister 2016; Creswell 2009, p.190). In this codification, we used the MaxQDA® software to divide the practice sequences and create themes for further analysis.

#### 6.3.4.4 Sequential and Thematic Analysis

In order to provide a structured analysis, understanding that the technique was applied in different contexts with constant social interaction, we used as a method the Content Analysis, proposed by Laurence Bardin (2011/1977). As Bardin describes that different techniques can be used according to the research approach, the ones we decided to apply were as follows:

- Sequential Analysis, used to understand the Focus Group process
- Enunciation Analysis, applied to understand the participants' discourse, and how did they speak
- Thematic Analysis, employed to synthesize the main themes that emerged in the technique practices
- Relations Analysis, chosen to relate and interpret the main themes and their occurrences, the participants' perception and the sequential and enunciation analysis.

In this chapter, both the Sequential Analysis and Thematic Analysis will be detailed, once they brought relevant results for Focus Group technique. The next topics will describe the analysis techniques concepts and how they were employed.

##### *6.3.4.4.1 Sequential Analysis*

This technique can be described as the “rhythm of the discuss” or the two steps that reveal the dynamics of the interview (Bardin 2011/1977). This analysis visualizes some patterns and three phases along the Focus Group: “Pre-Application,” “Application” and “Post-Application.” Those phases will be detailed in the next section.

##### *6.3.4.4.2 Thematic Analysis*

This “analysis of the meanings” (Bardin 2011/1977) provided ways to visualize and detail the main patterns found throughout the Sequential Analysis. These were analyzed, observing the occurrences verbally expressed (a total of 529) and synthesized in five themes, which raised few questions.

Below are the themes and the questions that they tried to answer:

- The theme “*planning before the technique application*” can be described as a moment in which people organize themselves to the Focus Group practice. The main questions used to analyze this theme was: “how participants planned the Focus Group practices?”; “what is the relation of the occurrences in each workshop?”
- The theme “*creation of an empathy scenario between participants*” aimed to understand the relationship between moderators and participants, and arose from the following questions: “how participants interact before, along and after the practice?” “how this relationship made possible to create a smooth scenario?”; “which characteristics can influence in a non-natural dialog between them?”; “what is the relationship between the occurrences of those facts in each workshop?”
- The theme “*kind of questions that participants employed*” aimed to understand the main questions that participants used. The questions used to analyze this theme were: “what kind of questions participants used?”; “how did they use?”; “what intention could be inferred from the questions?”; “which question was employed in the beginning of the practice?”; how they ask about feeling questions?”; “what kind of question inferred some bias on the answer?”; “what is the relation of the occurrences in each workshop?”
- The theme “*kind of data that arose*” intended to understand the data that emerged through participants, and was described by the following questions: “what kind of data arose from the Focus Group?”; “which characteristics they expressed?”; “how everyday experience was described?”; “how they interact with the scenario described”; “what is the relation of the occurrences in each workshop?”
- The theme “*interaction between participants*” aimed to understand the main interactions that occurred in Focus Group, besides the relationship between this interaction and the theme scope. The main questions used to

analyze this theme were: "what participants interact?"; "how did they interact?"; "in which workshop participants missed the theme scope, and how it occurred?"; "what is the relationship between the occurrences related to the interactions and the moments when participants missed the theme scope in each workshop?"

With regard to the Focus Group technique, we analyzed the following themes: "planning before the technique application"; "creation of an empathy scenario between participants"; "the kind of data that arose"; and the "interaction between participants." The next sections will describe the main results that emerged from the Sequential Analysis, and its triangulation with those themes.

## 6.4 PRE-APPLICATION, APPLICATION AND POST-APPLICATION

Throughout this *Social Constructivist Perspective*, the majority of participants interacted constantly and showed interest in the technique. They discussed about how the journey happened, what they did in this journey, the feelings that arose, their perceptions, thoughts, besides specific stories, and convergent or divergent points of view.

When we analyzed the Focus Group sequences, even each practice had its own specificities, some convergence was found in different aspects along the workshops such as the above-mentioned phases "Pre-Application," "Application" and "Post-Application" (Figure 6.2). It is worth highlighting that these phases might not be understood as three distinct steps, once they were smooth and natural. In the next section, we will discuss these phases and describe the related moments or themes.

### 6.4.1 Pre-Application

The "Pre-Application" phase was a convergent moment in which participants organized themselves for the technique application, here described as the "planning before the technique application" theme.

At this moment they decided who would be the Focus Group moderator (in three of four workshops), validated the theme chosen (in two workshops) and decided the Focus Group purpose (in one workshop). We emphasize that in the


**FIGURE 6.2** The "Pre-Application," "Application" and "Post-Application" phases. *Source*: Created by the author.

first three workshops, the researcher did not approach this Focus Group purpose issue, but, as in those workshops participants were confused about the "focus" in the theme they discussed, the researcher decided to change the approach in the fourth workshop. Another point emphasized by participants was the necessity to have a defined script before the application. Those evidence can be seen in the following transcription:

#### Workshop 2: Participants Discussion After Practice

Moderator FG3: I can describe myself as an example. As a moderator, I could not direct the questions, because I didn't know … like … What I really wanted to know with this? Then there was a problem regarding focus. … So, I did questions like … comprehensive. I asked, for example, I want to know how he feels. Like the bus experience. Then I started. It is like a comprehensive thing.

Workshop 1: After Practice

Moderator FG1: So … the difficulty was because I had to create the questions without a script. Then I got confused. …

Another pattern found in this phase was the initial presentation by the moderators, when they introduced themselves, saluted participants and explained the practice guidelines. This moment is described as the theme "creation of an empathy scenario between participants" and was present in the Pre-Application phase in some workshops (Figure 6.3).

### 6.4.2 Application

The application's phase is described as the moment when Focus Group started. This moment was interesting because in four workshops, the two moments—"reports" and "interactions"—were evident (Figure 6.3). This is further detailed in the following sections.

### 6.4.3 Post-Application

This phase, although not visualized in each workshop, was seen after the end of some practices (Figure 6.3). At Post-Application participants still interacted, or added some forgotten or omitted issue, subject and/or even talked about the Focus Group practice, as can be seen in the following sentence:

Moderator FG1: I tried to ask the same question to everybody.

P11: And we muddled you. I did it myself twice.

Moderator FG1: No, but you can do it. It isn't something that diverted us at all. Otherwise the moderator can bring us back to questions.

P11: My impression was …. Even I arrived late. … The moderator here acted like a person who mediates a round table.

It is worth highlighting that some participants turned the audio recorder off when they thought the Focus Group had finished, so we cannot presume that it did not happen in other workshops.

| Sequences | Moments | Occurences |
|---|---|---|
| Pre application | Planning before the technique application | Workshop 1- Groups 1, 3, 4<br>Workshop 2 - Groups 1, 2, 3<br>Workshop 3 - Group 1<br>Workshop 4 - Groups 1, 2, 3 |
| | Creation of an empathy scenario between participants | Workshop 2 - Group 2, 3<br>Workshop 4 - Groups 1, 2, 3 |
| Application | Reports | Workshop 1 - Groups 1, 2, 3, 4<br>Workshop 2 - Groups 1, 2, 3<br>Workshop 3 - Group 1<br>Workshop 4 - Groups 1, 2, 3 |
| | Interaction between participants | Workshop 1 - Groups 2, 3, 4<br>Workshop 2 - Groups 1, 2, 3<br>Workshop 3 - Group 1<br>Workshop 4 - Groups 1, 2, 3 |
| Post application | Interaction between participants | Workshop 1 - Group 3<br>Workshop 2 - Group 2<br>Workshop 3 - Group 1<br>Workshop 4 - Groups 1, 3 |

**FIGURE 6.3** The Focus Groups main sequences and their moments and occurrences. *Source*: Created by the author.

## 6.5 REPORTS, INTERACTION AND IN-DEPTH DATA IN THE FOCUS GROUP SEQUENCES

Regarding the application's phase, this section will detail both moments "Reports" and "Interactions between participant" and analyze the sequences in Focus Group practices. We also investigate how the data was detailed throughout those sequences.

### 6.5.1 Reports and Interaction Moments

Reports were characterized by the moment when the moderator invited participants to tell their testimonial about a subject or some questions. At this moment, they explained their journey, or gave specific in-depth data about their particularities, experiences or the environment. One example of participant's reports can be seen in the following:

#### Workshop 4

P14: My commuting already has two options. One of them is a very tiring journey. I leave from (omitted for privacy issues) at 11/11:30 pm to arrive at the

> bus station at 7 am. Then I wait until 8:30/9 am to go to the Recife Station or get an Uber. The other option is to get a ride with a friend, as I did today (omitted for privacy issues). When we can combine both commuting, I get his ride. Then he brings me here and it is easier.

The “interactions between participants,” here synthesized as “Interaction,” occurred in the middle or end of some practices when two or more participants talked about some subject, common experiences, participant’s story, point of view or convergent or divergent perceptions. It can be observed in the following transcription:

#### Workshop 2

> P10: I seat on the steps.
> P13: So … normally the bus is too crowded. I cannot even pass from the Baffle gate.
> P10: I cannot work in the bus. Actually, I cannot work through my smartphone. “Like,” I need my computer to do my work. …
> P16: Not if I wanted … I would have a headache, “did you get it?”
> P14: It is what I would say that I have.

### 6.5.2 Linear and Interspersed Sequencing

When we analyzed both Reports and Interactions sequences in the Focus Groups workshops, two different kinds of processes in the practices were visualized:

- The first is here described as “*linear sequencing*,” characterized by moments in which each participant had their own testimonies and, at the end of practices, when the moderator asked the group to talk about the theme, participants interacted naturally. This sequencing was the most visualized (in 6 of 11 group practices) and is shown in Figure 6.4.
- The second, described as “*interspersed sequencing*,” was observed by “reports” interspersed with punctual “interactions,” which increased according to the following “reports.” This kind of sequence was present in 4 of the 11 practices and is shown in Figure 6.5.

### 6.5.3 Focus Group Sequences and In-Depth Data

Once we knew how the Focus Group sequences occurred in a *Social Constructivist Perspective*, and we triangulated this result with the “kind of data that arose” theme, we understood how the data were generated and detailed in those practices.

In the linear sequencings of Focus Group, reports showed a specific amount of detailed data through each participant’s testimony. Moreover, when the interaction occurred, there was a great amount and variety of detailed data, when participants discussed about different subjects, and experiences, as can be visualized in Figure 6.6.

In the interspersed sequencings, the majority of the initial reports that showed a small amount of detailed data visualized how that data was in-depth and how it increased in amount and variety through each interaction and report. It happened

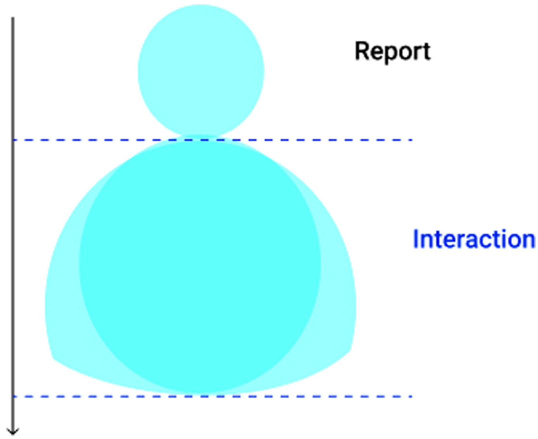



**FIGURE 6.4** Resume of the linear sequencings. *Source*: Created by the author.

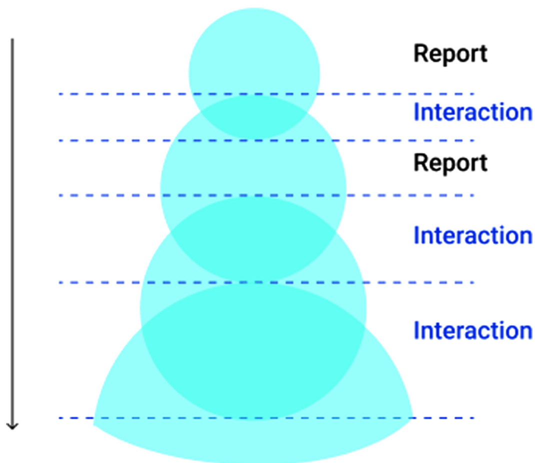



**FIGURE 6.5** Resume of the interspersed sequencings. *Source*: Created by the author.

when one participant complemented an aspect or a case before spoken by other participants, as can be seen in Figure 6.7.

With this in mind, we can hypothesize that the Focus Group has the potential to bring in-depth data that can occur in a disordered manner, with a variety of subjects and in-depth levels.

## 6.6 INTERACTION AND COLLECTIVE SENSEMAKING

As the moment "interaction between participants" emerged as one of the main patterns found in the Focus Group Sequential Analysis, we decided to analyze it in

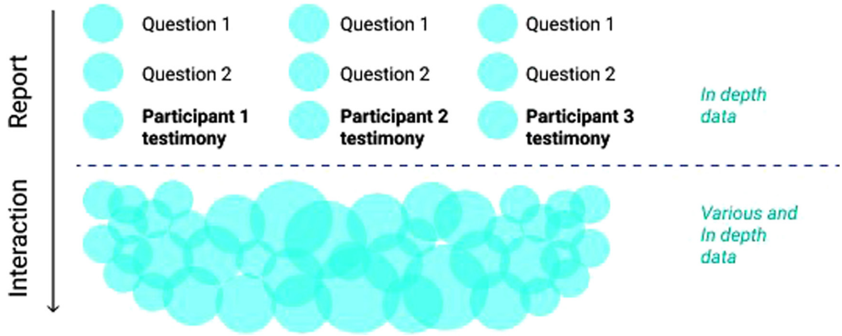



**FIGURE 6.6** Showing how the data were generated and detailed on linear sequencings. *Source*: Created by the author.

detail as a theme. The next section will describe "how this interaction began" and "what participants interacted" to further detail the "Collaborative Sensemaking" generated through this interaction by some groups.

## 6.6.1 How the Interaction Began

When we analyzed how the interaction began in the Focus Groups workshops, we realized that it started naturally both by participants and when the moderator asked them to talk about the theme or some subject. When we analyzed how this interaction started naturally, three patterns emerged:

- First, when some participants revealed some particularities about their everyday activities or improvizations that they found interesting; this is illustrated by the following example:

### Workshop 2

P10: I seat on the steps.
P13: So … normally the bus is too crowded. I cannot even pass from the Baffle gate.
P10: I cannot work in the bus. Actually, I cannot work through my smartphone. "Like," I need my computer to do my work. …
P16: Not if I wanted … I have headache, "did you get it?"
P14: It is what I would say that I have."

- Second, when a punctual interaction (by some participant or even the moderator) occurred, i.e., when one participant told something and other participants added their point of view. This example can be visualized in the following transcription:

### Workshop 3

P5: How long is your journey by metro? Do you prefer using metro rather than car?
P3: Dude, I use metro at rush hour.

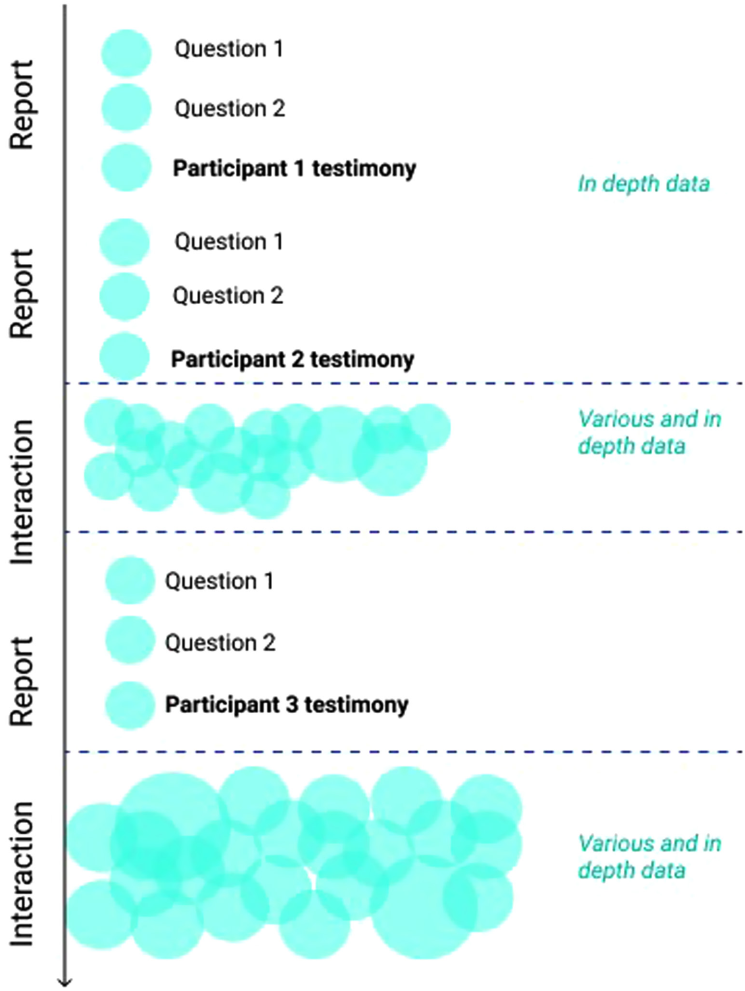



**FIGURE 6.7** Showing how the data were generated and detailed on interspersed sequencings. *Source*: Created by the author.

P5: Really, you are a hero.
P3: The person who survives using metro in São Paulo, survives anywhere. It is really hostile.
P4: Once I survived at 6 pm in. …

- Third, when a participant told a story and others complemented his/her argument with questions, points of view or another story, as can be seen in the following example.

### Workshop 4

I would prefer to go by bike, but last week two friends suffered a bike accident.
P12: Really? Where? In South Zone?

P3: I don't know where exactly. One was a guy from my (omitted for privacy issues) and other was a girl who was (omitted for privacy issues) and suffered an accident.
P12: I lost a friend on a bike accident. He was hit by (omitted for privacy issues).
P9: I know who was.

### 6.6.2 What Participants Interacted

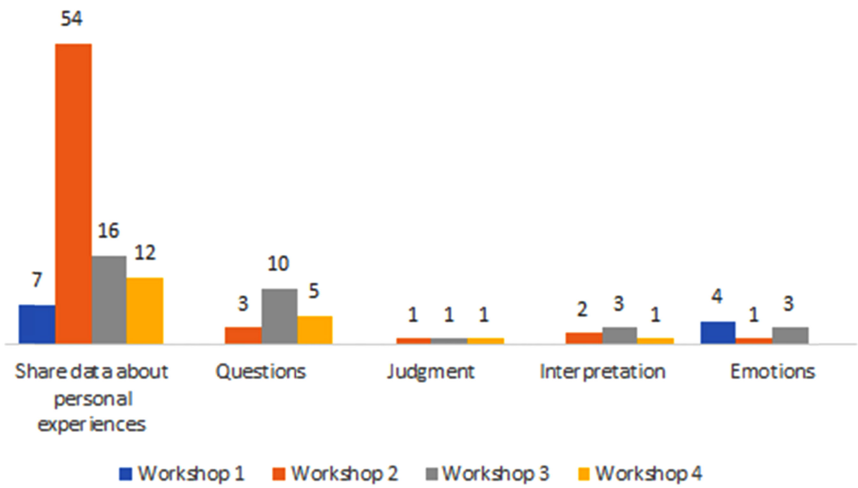
In order to detail what participants interacted, we analyzed the theme "data that arose" and related it with the participants interaction theme. We found some evidence (97 occurrences) about the kind of information on which people interacted. The data showed that participants expressed emotions, interpreted and/or judged others' reports, asked questions and shared personal experiences, as can be seen in Graph 6.1.

It is worth highlighting that those data can be related to the context in which workshops were applied, where the majority of participants had previous empathy between themselves. Thus, we recommend that future research must analyze those practices in different contexts to validate, improve or refute this hypothesis.

Another interesting result was the variety of subjects discussed throughout the interactions. After the practices, participants emphasized both the importance of visualizing different characteristics (e.g., when they shared their personal data) and the variety of subjects that emerged in the interaction along the Focus Groups. This evidence can be visualized in the following transcription:

#### Workshop 1

Focus Group is freer …. And the practice also generates more themes to be discussed.




**GRAPH 6.1** Participants interactions. *Source*: Created by the author.

**Workshop 3**

> The Focus Group provides us a bigger picture. We saw different ways to go to college. On foot, by car, by Uber, and by metro. … Focus Group actually let you change experiences and to listen to other people's experiences.

### 6.6.3 The Collective Sensemaking

The results of the above-mentioned "kind of information that participants interacted" and the "variety of subjects" that some of them mentioned in the "What participants interact" topic arose a hypothesis related to the "Collective Sensemaking" concept in Focus Group (Wilkinson, 1998): along the interactions in the applications, the data shared between participants (emotions, questions, personal experiences and interpretations) provide this "collaborative sensemaking." It means Collective Sensemaking can be generated when participants share data such as personal experiences (stories, personal perceptions, common or non-common feelings, information about what they do, know, think, sensorial aspects, or even improvizations), questions, emotions and interpretations, as can be visualized in Figure 6.8. We emphasize the need for future research to involve more exploratory applications of Focus Group technique in different contexts and scenarios to validate, improve or even refute this hypothesis.

## 6.7 Discussion and Best Practices When Using Focus Groups

In this section we discuss both Sequential and Thematic Analysis findings and hypotheses to propose suggestions on best practices, when using Focus Groups. The following sections will detail those findings and propose best practices.

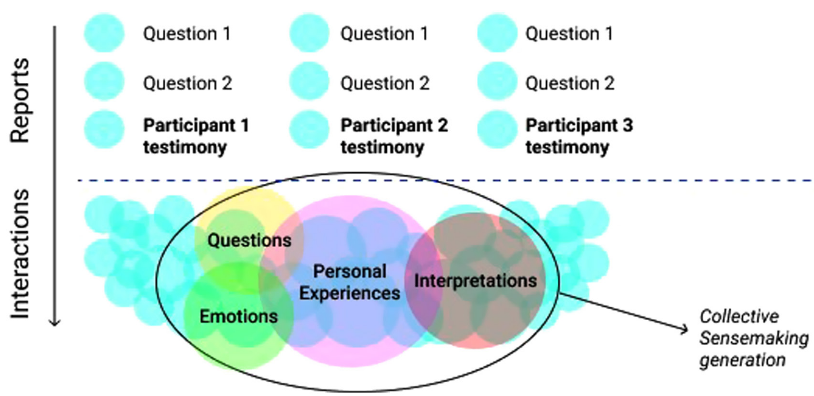



**FIGURE 6.8** Showing hypothesis about how collective sensemaking can be generated. *Source*: Created by the author.

### 6.7.1 Discussing the Findings

As was presented in the above-mentioned topics, three smooth phases, with different moments and themes, arose from the Sequential Analysis of Focus Group practices.

#### 6.7.1.1 "Pre-Application," "Application" and "Post-Application"

These sequences and their themes helped us to better understand the findings and hypotheses presented on above-mentioned topics and also discuss the following ones: (i) how Focus Group practices worked, (ii) some topics that appeared in the planning before application, (iii) how participants behaved and interacted and (iv) how the data was in depth along those moments.

##### *6.7.1.1.1 How Focus Group Practices Worked*

When we analyzed the Focus Group sequences, we understood how an exploratory Focus Group practice might work. The data showed it occurred through the Application phase, where its "Reports" and "Interaction" moments raised the hypothesis that Focus Group can be combined by different sequences (linear and interspersed sequences). Those sequences include moments where participants mention their testimonials and moments where they interact between themselves, discussing about different subjects. Thus, we can conclude Focus Groups can occur through linear or interspersed sequences of multiple "Reports" and "Interactions."

*6.7.1.1.1.1 Topics That Appeared in the Planning Before Application* In terms of the "Pre-Application" phase, we highlight the importance of both "the planning before application" and "the creation of an empathy scenario between participants" in order to provide control to the moderator throughout the practice flow.

Those appeared from participants' reports mentioning that they felt confused about not having a "focus" in the theme they discussed in the applications; the need to have a predefined script before the practice and the moment when moderators introduced themselves, saluted participants and explained the practice guidelines.

The hypothesis here is that this creation of empathy and planning before application helps the moderator to feel control and create a more fluid scenario for the practices.

##### *6.7.1.1.2 How Participants Behaved and Interacted*

Related to participants' behaviors and interaction, the data showed how the interaction began, what participants shared throughout this interaction—such as personal experiences, questions, judgment and/or emotions—and the Collaborative Sensemaking generated in the interaction.

This result led us to visualize how an interaction process can occur along an exploratory Focus Group practice. The hypothesis here is: in this approach, some interactions can start by punctual interactions, personal stories or particular behaviors, continue when they share experiences, questions, emotions, judgments and/or interpretations and culminate in a Collaborative Sensemaking.

This information can also help moderators in the practice flow control once they know that this process might happen.

###### 6.7.1.1.3 How the Data Was In Depth

Although there were linear and interspersed sequences, when we analyzed how the data was in depth, we found in Focus Group exploratory practices that both sequences provided in-depth and detailed data about people's experiences.

Thus, the above-mentioned hypothesis (in those practices, many types of data and subjects emerged in a disordered manner) raises the assumption that the analysis of those data can be complex and demand time, because the researcher will have to map and interpret these different data and subjects.

### 6.7.2 Best Practices When Using Focus Groups

The above-mentioned sections, findings and hypotheses expose the main results that emerged in this research and lead us to propose suggestions on best practices, here described as guidelines, when using an exploratory Focus Group.

In the following sections, we will detail those guidelines, dividing them into Pre-Application and Application sequences.

#### 6.7.2.1 Guidelines for an Exploratory Focus Group Pre-Application

###### 6.7.2.1.1 Consider Planning and Organize Focus Group Before Starting the Practice

The hypothesis that mentions planning before application helps the moderator to feel in control of the Focus Group supports its moment benefits. With this in mind, we suggest the following *recommendations to plan and organize themselves before starting a Focus Group exploratory practice, in order to feel in control: (i) define who will be the moderator, (ii) define the practice's script and (iii) be clear about the Focus Group's main goal.*

*6.7.2.1.1.1 Define Who Will Be the Moderator* As was visualized in this research, before starting a practice, one of the first definitions *recommended must be related to who will be the moderator*. We recommend that this choice should be taken according to the researcher's previous experience with Focus Group qualitative exploratory approaches, and previous knowledge about the practice main guidelines such as expressed on the following topics related to the practice application.

*6.7.2.1.1.2 Define a Focus Group Script* The necessity emphasized by participants to have a defined script before the application brings along the *recommendation to the moderator to have topics that guide both questions s/he can ask and Focus Group path*. Those topics however should not be specific questions or that rigid to restrict practice's flow or generate superficial data.

*6.7.2.1.1.3 Define and Be Clear About the Practice's Main Goal* In terms of Focus Group purpose, as was mentioned by participants in the first three workshops, before starting an exploratory practice, *we suggest to the moderator to define and be clear about the Focus Group main goal. That should help him to know which subjects to explore in participants' interaction and be in control of the practice flow.*

##### 6.7.2.1.2 When Start the Practice, Create Empathy with Participants

Becuase the Focus Group has the purpose of gathering data about people's everyday lives, *we recommend, when starting the practice, the moderator introduce himself/herself, salute participants and explain the procedures*. Our hypothesis is that this creation of empathy will help the moderator to create a fluid scenario for Focus Group practices, because participants can feel at ease to talk about their everyday activities.

#### 6.7.2.2 Guidelines for an Exploratory Focus Group Application

##### 6.7.2.2.1 Comprehend How the Practice Work and How Participants Interact

As the analysis of an exploratory Focus Group application can be complex, comprehend how the practice work and how participants' interaction can help the moderator to visualize practice flow and feel in control. With this in mind, this research findings lead us to the following guidelines that aim to guide the moderator in this understanding: *(i) observe Focus Group sequences, (ii) observe how the data is in depth and (iii) observe how Collective Sensemaking can be generated in the application interactions.*

*6.7.2.2.1.1 Observe Focus Group Sequences* Our hypothesis (Focus Group can occur through linear or interspersed sequences of multiple Reports and Interactions) can help the moderator to comprehend how the practice works. Thus, we *recommend that the moderators observe the practice sequences to know when an interaction is happening; decide at which moment they can intervene and invite participants to tell another report; or just let the interaction go on naturally.*

*6.7.2.2.1.2 Observe How the Data Is In Depth* The hypothesis, in Focus Group practices, that many types of data and subjects emerge in a disordered manner, and the understanding about how the data is in depth through linear and interspersed sequences, lead us to *recommend the moderator to observe how the data can be in depth in a Focus Group application*. With this in mind, a moderator can understand what are the main subjects that arise and guide participants through those subjects.

*6.7.2.2.1.3 Observe How Collective Sensemaking Can Be Generated in Those Interactions* The hypothesis—Collective Sensemaking can be generated when participants share data such as personal experiences (stories, personal perceptions, common or non-common feelings, information about what they do, know, think, sensorial aspects or even improvizations), questions, emotions and interpretations—leads us to *recommend the designers and moderators, when applying Focus Groups through a Social Constructivist Perspective, to explore and comprehend data, and when sharing data in the interactions, participants can generate this collective sense.*

##### 6.7.2.2.2 Understand That After Practice Participants Can Still Interact

This research data showed that participants still interacted, added some forgotten or omitted issues and/or even talked about the practice at the end of some Focus Group applications. According to this result, we *recommend the moderator and researchers to be ready in case participants keep interacting, complementing or adding data after Focus Group application*.

We also emphasize in this guideline that moderators and researchers take care and act with ethics if some participant does not want to share the data or if the data should not be analyzed (e.g., when the recorder was turned off and a participant decided to speak about something that should not be considered).

## 6.8 FINAL REMARKS

This research's structured investigation related to "Focus Group," in the problem exploration phase, leads us to detailed guidelines and hypotheses applied when the purpose is gathering data about people's everyday activities. As an overview, detailed data showed, besides points of Pre-Application, Application and Post-Application phases, how practices should be planned; how it worked; how participants behaved and interacted and how the data was in depth.

Regarding Sequential and Thematic Analysis, both provided several points to be taken into account when planning and applying Focus Group in the above-mentioned conditions. Analyzing the sequences helped, besides understanding how each one occurred, visualize patterns and details such as Reports and Interactions, and linear and interspersed sequences. Moreover, with those patterns found, we could divide them into themes to observe their occurrences and create questions that investigated them in detail, using a structured approach.

Thus, we can assume Sequential and Thematic Analysis as a path when the purpose is to get evidence and structured guidelines in Design Methods investigation. This method can help future analysis of other subjective or qualitative Design techniques, methods and tools.

Future research can also validate that hypothesis using a mixed method approach or applying other Content Analysis techniques described by Bardin such as Relation Analysis, Enunciation analysis, Categorial Analysis and/or Evaluation Analysis. Another suggestion is to test those Design Methods in different phases of the Design Process.

## NOTES

1. In this tool, six participants write or draw suggestions on a piece of a paper divided into 18 spaces (6 × 3). After 5 minutes, they must switch the paper keeping the same clockwise direction. This tool aims to discover solutions to problems inside the project (Pazmino 2015, p.216).
2. Bodystorming is a physical and situated dynamic, experiential method of informance that combines active role-play with simple prototypes, and in which designers can immerse themselves in user situations (Martin and Hanington 2012, p.20).
3. Usability testing is an evaluative method that helps designers to search for confusing or frustrating parts of an interface by observing a given task (or a set of tasks) through individual use of an application (Martin and Hanington 2012, p. 194).

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# 7 User-Centred Change
## *New Perspectives on Technology Development and Implementation*

*Annabel Zettl, Angelika Trübswetter, Antonia Meißner, Mathias Jenny and Sebastian Glende*

## CONTENTS



## 7.1 INTRODUCTION

Digitalization changes our lives. How we shop, how we listen to music, how we work, how we govern. Digitalization changes our lives—on the social, economic and political level. In 2013, the study "The Future of Employment" by Frey and Osborne from Oxford University provoked excitement. Almost one in two Americans works in a profession that is likely to be automated within the next 20 years. These numbers led to numerous discussions and debates worldwide. Will robots and algorithms take away our work? Will we continue to push humans further and further out of the center of value creation?

In 2021, this debate has become much clearer. Technical potentials are one thing, but what is or can be implemented is another. In this context, Frey and Osborne (2013) speak of "computerisation bottlenecks" (p. 31); perception and manipulation,

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creative intelligence and social intelligence, all qualities that are (still) more attributed to people and workers. Above all, the replacement of individual routine activities by machines has always been a consequence of technical innovations. We would like to recall the beginning of industrialization in the UK, when the weavers were afraid of competition from the automatic loom. Today, taxi drivers and bus drivers fear the self-driving car, retailers fear the self-payers and workers in assembly see their workplace threatened by robots. It remains to be seen how the future will develop exactly, but what is certain is that these technological changes can only succeed in the long run, if they are accepted by the affected workforce. "User-Centred Change" (UCC) as a participative framework for the development and implementation of technology in a work environment can help to achieve this.

## 7.2 DIGITALIZATION: A CHANGE PROCESS

As digitalization proceeds, working environments and demands placed on employees shift: new means of working, communicating and collaborating are possible and necessary. Work and private lives of employees are linked much more closely in many industries than in the previous decades. New competencies are expected of employees as well as of managers. At the same time, digitalization affects the balance of power in organizations, as employees are not only enabled, but in many cases also obliged to take over more responsibility than they were used to (Schwarzmüller et al., 2018). One central challenge is the speed at which these changes take place: while technological progress develops exponentially, human beings only adapt linearly to these changes. In environments in which people are required to use a new technology (i.e., the workplace), the gap between technological development and human adaptation is even larger (Friedman 2017).

All this gives us a first idea of the enormous effect the digitalization of companies can have on their employees. It is not without reason that in the context of digitalization of organizations, experts often speak about "digital transformation" (Hess, Matt et al. 2016, p.126–127; Vey, Fandel-Meyer et al. 2017, p. 23–24), and therefore about a change process (Disselkamp und Heinemann 2018, p. 95).

As all companies and organizations are "social systems" (Pettigrew 1987, p.656), composed inter alia by employees, customers and other stakeholders (de Biasi 2018, p. 24), it is evident that we cannot expect this change to be only of technological nature and to only bring about technological challenges. Behavioral issues regarding the organization have great relevance for the change process, initiated by the implementation of technology (Lorenzi and Riley 2000, p. 116). When introducing technology in such social systems or "social contexts," not only a technological change is provoked, but a sociotechnical transformation, which not only affects the technology but also the context of use:

> Technologies are produced and used in particular social contexts, and the processes of technological change are intrinsically social. … [T]echnological change is always part of a sociotechnical transformation—technology and social arrangements are co-produced in the same process.
>
> **(Russel and Williams 2002, S.45)**

In such social systems, change processes can trigger emotional reactions. If these reactions are not addressed properly, they can lead to the rejection of the change by the people affected (de Biasi 2018, p. 24).

Therefore, the social and organizational components of technological transformation have to be considered to ensure its success (ibid., p. 25).

## 7.3 CHANGE PROCESSES AND THE HUMAN FACTOR

The importance of those "soft factors" (Maucher et al., 2002), "behavioural" (Lorenzi and Riley 2000) or "emotional" (Disselkamp and Heinemann 2018, p.97) aspects proves true, when looking for an overview of common causes for the failure of change processes.

A literature review of de Biasi (2018, S.4) reveals: an average of 70–90% of change processes in organizations fail because of the employees' resistance, because they are not ready for the change yet or do not feel obliged to it. De Biasi traces the failure of organizational change back to social reasons, a major one being the inability to gain the employees' trust. This lack of trust often lies in the history of the companies and their previous handling of the implementation of change. The more change processes have failed in the past, the more resistance to further change is to be expected. For employees to be able to engage in organizational change, they have to endure an uncertain future and possible unexpected consequences. Employees who do not trust their company will not go along with such uncertainty (ibid.).

Van Dijk and van Dick (2009) highlight that most people affected by change do not resist change in general but rather fear the consequences of change, "such as loss of status, loss of pay, or loss of comfort" (p. 5). But not only do people fear personal loss, the apprehension that the change will not benefit or even threaten the organization can also motivate resistance to change. This might originate from the fact that in most cases those planning the change are not the ones who are affected by it and that both groups have very different perspectives on the organizational change. Alas (2015) also assumes that most people do not reject change in general but rather resent the attempt of "being changed" (p. 155). Therefore, resistance to change processes can be an indicator of employees feeling pushed into passivity.

According to a Capgemini study (Schaefer et al., 2017), lack of communication and silo thinking are the biggest obstacles to digital cultural change in organizations. In his textbook *Organization*, Vahs (2003) names communication, in addition to personal reservations, as one of the two main reasons for the resistance against changes in enterprises.

Despite all these findings, the implementation of new technological solutions in organizations is still often technology-driven—at the expense of social aspects. This technological focus frequently leads to problems of acceptance or in extreme cases to resistance and the failure of the whole project (Lorenzi and Riley 2000).

Therefore, the employees' acceptance of the change process is a fundamental condition for its success.

## 7.4 ACCEPTANCE AS A MULTIFACETED PHENOMENON

Acceptance is a widely worded concept whose exact definition is often insufficiently addressed or presented within the discussion about technology implementation. A practical example illustrates the different facets of acceptance: an app maker wants his or her app to be accepted by the target audience, e.g., downloaded as often as possible and also used. In the best case, the users even give a positive rating in the app store. The specific usage behavior, i.e., the download and use of the app, allows conclusions to be drawn about the users' acceptance. However, it becomes more complex when looking into the corporate world. The CEO wants employees to use and accept new technology in the workplace. The starting point is different in this example, as employees are not free to decide whether to use the technology or not. There is a certain compulsion to use the technology, provided that employees care about their job. This situation can be classified as a so-called non-voluntary context of use (Huijts et al., 2012). In the context of work, it is therefore difficult to examine or assess acceptance only through usage behavior. Therefore, it is necessary to look at the employees' attitudes in order to make statements about their acceptance. The usage behavior alone is not sufficient (Brown et al., 2002).

In many studies, acceptance, as a psychological construct, is defined as the result of a process of perception, assessment and decision with three influencing variables: (1) subject (e.g., an employee) which accepts an (2) object (e.g., a digital documentation tool) within a given (3) context (e.g., a company) (e.g., Schäfer and Keppler, 2013) (Figure 7.1).

Technology acceptance is influenced by subject-related factors, such as individual attitudes, norms and values, sociodemographic factors or experiences. Moreover, acceptance is affected by object-related factors, such as costs and benefits, risks, usability, task adequacy and aesthetics. Finally, context-related factors, such as the task at hand, predominant social processes and the organizational environment as well as the macrosocial context might influence acceptance (ibid.).

According to this concept, acceptance depends on the *interplay* of these three dimensions. The object has to be "acceptable" in order to "achieve" acceptance, but acceptability is not the only condition for user acceptance. Only through the (positive) interplay of subject, object and context, acceptance can arise (Sauer et al., 2005). The three components interact and influence each other. The result of the process depends on their relationship (Schäfer and Keppler 2013, S.23).

## 7.5 USER-CENTRED CHANGE

To facilitate acceptance of technological solutions at the workplace, a one-sided focus on the design of the technology, on the object-related factors, is insufficient. This approach can lead to misinterpretations of the reasons for resistance, expecting it to be caused by a misfit of the system and therefore ignoring possible individual

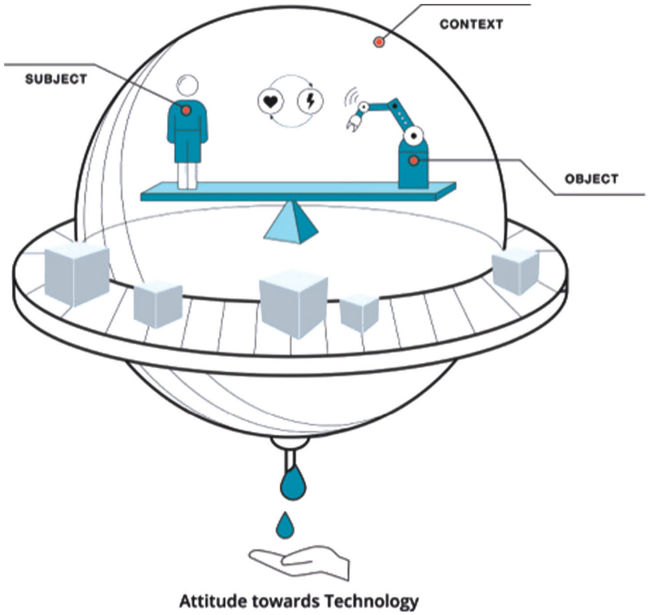


**FIGURE 7.1** Qualitative acceptance model. YOUSE GmbH, based on Schäfer and Keppler (2013).

or organizational factors. The success of a certain system depends not only on technological but also on (inter)personal aspects, which are not always associated with the system use.

The standard ISO 9241-210 "Human-centred design for interactive systems" defines a process for the human-centred design of usable and useful interactive systems, the so-called Human- or User-Centred Design (UCD) process. Although this process puts the human at the center of the design process and acknowledges the context of use as a relevant design factor, the process focuses primarily on the system design, not on the system implementation. Furthermore, the approach aims at "understanding" the use of context (ibid. p. 16–17) but requirements derived from this analysis are supposed to be solved through the design of the object, not through the design of the implementation process or the implementation context. The User-Centred Change (UCC) approach presented here is thought to fill this gap by expanding the design focus by subject and context factors. Combining UCD with participative change management expertise allows the user-friendly design of new technologies while simultaneously designing the transformation process in the best interest of all involved actors. The decisive factor is not the acceptance of the particular technology but rather the acceptance of the change process. Therefore, change processes must be suited to human needs.

UCC is based on the conviction that bottom-up communication and participation can help employees to understand the need for change, diminish their fears and build trust in the change project. It is expected that a participatory approach allows harnessing the know-how of those affected and that employees who are involved or feel involved in the process will more often take over responsibility for these changes. Hence, participatory measures play an important role in the change process and represent a central success factor for organizational change and the implementation of new concepts (Will 2015, p. 146).

## 7.6 THE FOUR PHASES OF USER-CENTRED CHANGE

Instead of a sole top-down approach, UCC focuses on a bottom-up, iterative approach, which enables affected actors to become participants in the change process and which allows considering their needs and fears and helping them to build or maintain trust into the organization and the change at hand. Quick evaluation cycles ensure a reflective change process and prompt readjustment as a reaction to changed requirements or unexpected events. UCC is a human-centred and participative approach which fosters the acceptance of technology and the change process. Inspired by the UCD process, UCC consists of four phases: (1) insight, (2) path making, (3) evaluation and (4) realization, which will be presented in the following sections (Figure 7.2).

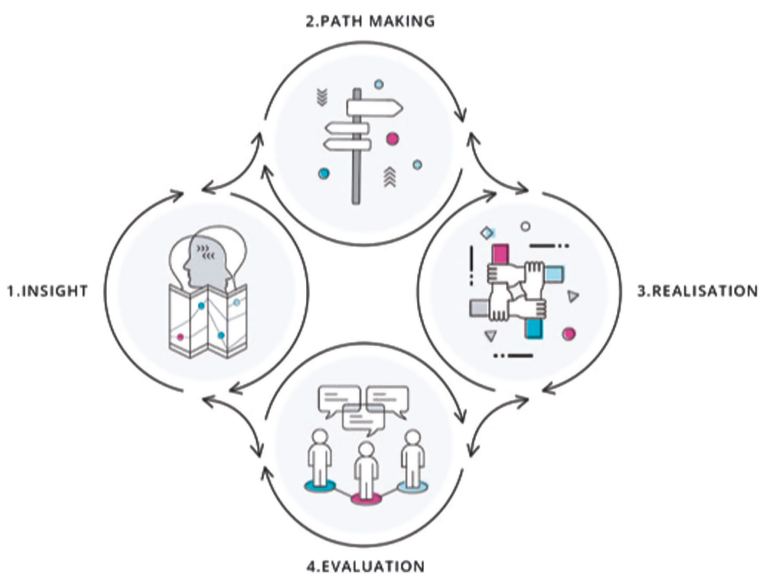


**FIGURE 7.2** The User-Centred Change process. YOUSE GmbH.

### 7.6.1 Insight

The aim of the first phase is a comprehensive analysis of the status quo, both on object and on subject and contextual levels. At the object-related level, for example, it is important to check the applicability of potential technical applications. On subject level, respectively contextual level, it is about mapping the attitudes of those involved, disclosing potential conflicts in the company. This creates a realistic, current picture of the organization, which is an important basis for the design of the change process, as the existing conditions, on the basis of which a technical restructuring takes place, have a substantial impact on the success of the restructuring. Incorrect basic hypotheses and assumptions regarding the technology to be implemented, but also regarding the attitudes of those involved, can impede the implementation and change process and should therefore be checked at an early stage. The focus in this phase is on the corporate culture and the relationship between all actors involved. UCC extends the technologically focused UCD approach to understand the way in which individual actors will be affected by the technical change and over and above all, how threatened they feel by it and why. The methodology here is based on traditional methods from UCD, empirical social research as well as design.

### 7.6.2 Path Making

The second phase aims at a shared understanding of the restructuring as well as a common vision for its design. If employees do not understand the context and goals of a change, the process is likely to come to a standstill. In setting the course, concrete topics, goals and KPIs of the transformation should be identified and defined across teams and hierarchies. In addition to the development of the technological concept at the object level, it is important to design a roadmap for the participation of the actors at the subject and context levels. That means identifying the individually appropriate path for the transformation activities. This roadmap also includes suitable concepts and formats for qualifying employees. The roadmap design takes place in participatory workshops with the help of co-creation and/or design-thinking methods with the inclusion of different hierarchy and status groups. This approach allows getting everyone involved and jointly defining measures for the implementation and change process. Through the participatory roadmap, the change process is systematically structured and made transparent. This approach minimizes feelings of uncertainty and helplessness from the start, which often lead to resistance. Instead, the perceived control over the process is strengthened, laying the foundation for its acceptance.

### 7.6.3 Realization

In the third step, the restructuring is designed and carried out. The technology is integrated into the existing work processes. For this purpose, the roadmap planned within the path making is implemented to support the change process. The continued existence of participatory elements plays a crucial role here: they ensure that the technology implementation is carried out closely to the requirements of the workplace and the needs of the employees. During the implementation, early practical experience coupled with training measures is of great importance in order to build trust in the technical system. The right communication is central here. For effective participation, there should be sensible communication channels in both top-down and bottom-up directions during the implementation.

### 7.6.4 Evaluation

The aim of the fourth phase is to continuously evaluate the measures taken in order to assess the change process and its impact. Appropriate evaluation measures are necessary. At the same time, organizational processes and participatory processes must also be checked for their effectiveness and efficiency. In the technology-related evaluation, classic methods from the UCD are used to assess the suitability of use and the fit of the systems to the existing work processes. This includes, among other things, usability tests and field observations, directly involving users and thus providing information on the specific design and optimization of the technical systems. Such evaluation approaches are borrowed from software development, where they have a long history and are applied widely. In contextual evaluation, the overall organizational context is considered. Among other things, the satisfaction of those involved with the process and potential points of attack are evaluated and necessary adjustments are identified.

## 7.7 CONCLUSIONS

Digitalization offers great changes for organizations, but also comes with risks. The transformation processes, triggered by digitalization, have to be treated as change processes and should be accompanied by well-grounded communication measures and participatory approaches. The employees affected by the change and their needs and fears have to be put at the center of all implementation strategies. Not only the acceptance of the technology to be implemented is ought to be fostered, but also the acceptance for the change itself.

The UCC-approach, with its four iterative phases, allows designing this change proactively and employee-oriented. The approach helps to identify the requirements in regard to the change process on object-, subject- and contextual levels. It suggests the participatory design of a shared vision and implementation roadmap. This way, the affected parties gain back a feeling of control and the know-how of all involved can be harnessed for a successful implementation process. Enabling employees to discover and test the technologies to be implemented can dispel fear and can promote the development of new skillsets of the employees early on in the process. Sensitive and continuous communication can help to maintain the employees' feeling of control during the actual technical implementation. Frequent evaluation measures allow testing the effectiveness and efficiency of the change process, as well as the satisfaction of the involved parties and also allows the identification of necessary modifications in the implementation approach.

The User-Centred Change approach is constantly refined and optimized. At the moment, the authors are successfully applying the approach to the fields of industry 4.0, especially focusing on human-robot collaboration (HRC), health, elderly care and banking. Further areas of application could be public administration and retail.

This chapter aimed to give insight into the theoretical basis of UCC and to encourage UX and usability experts to not only focus on the User-Centred Design of technology, but also on the User-Centred Design of its implementation, to ensure its success.

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# Section 2

## Usability and UX in the Health Sector

# 8 Usability to Improve Healthcare

*Christopher P. Nemeth, COL Jeremy C. Pamplin, Sena Veazey and LTC Christopher Colombo*

## CONTENTS



## 8.1 INTRODUCTION

Decision support system (DSS) development and evaluation in healthcare is essential but challenging. Prior research shows that introduction of a poorly conceived DSS can impede care and clinician confidence to adopt it (Bright et al. 2012; Woods 1988). The US Food and Drug Administration encourages the comprehensive evaluation of DSS before being considered for approval to use in healthcare settings (US FDA 2002). Completing valid evaluations that reflect the care setting a particular DSS intends to support is difficult because clinician or staff time is scarce and difficult to

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obtain due to factors such as a high patient census. Development of contextually relevant evaluation scenarios requires substantial effort to effectively reflect actual care.

This chapter reports on two different projects using usability assessment to improve healthcare. The Cooperative Communication System (CCS) project assessed a DSS created for use in a Burn Intensive Care Unit (BICU) in two separate evaluations (Nemeth et al. 2016a). The first evaluated usability for individual clinicians. A sample of respiratory therapists, nurses and physicians performed tasks using the new DSS in two scenarios: new patient admission and preparation for surgery. The second evaluated usability at the team level. Two teams, each comprised of a nurse, resident and attending physician, performed in two scenarios: abdominal sepsis and acute respiratory distress syndrome (ARDS). The objective was to collect quantitative data (e.g., time to complete task, steps to complete task) and qualitative data (e.g., confidence in decisions made, ease of use). Results from the evaluations showed that the new DSS compared favorably to a legacy electronic medical record (EMR) system that the clinicians had used for years. Evaluation results were used to improve the DSS prototype and make the case for advancement into full-scale development.

Another project assessed the effect of another form of DSS, telemedicine, on clinical decision-making and care delivery during prolonged pre-hospital care by junior physicians and medics under simulated conditions at two research sites. The research team assessed participant clinical decision-making, procedure quality, cognitive workload, confidence and stress while participants used either printed guidelines or "tele-mentoring" during extended (6–14 hours) simulated pre-hospital care scenarios. Participants also reported their subjective sense of cognitive workload under each test condition.

Healthcare evaluations require rigorous planning and execution. Use of a consistent methodology such as Cognitive Systems Engineering (CSE) (Woods and Roth 1988; Woods and Hollnagel 2006) ensures thorough and accurate DSS development. The approach also ensures that solutions are defensible, by tracing features back through requirements and analyses to the original data. CSE mixed methods research designs triangulate collection of quantitative and qualitative data. Conducting studies in a setting with staff, equipment and procedures as close as possible to actual practice ensures results have high validity.

## 8.2 THE COOPERATIVE COMMUNICATION SYSTEM (CCS)

We conducted both research and usability assessments at a 16-bed BICU in a 450-bed tertiary care military academic medical center, that is widely considered to be one of the best of its kind in the country. Two of the beds are reserved to serve as a post-anesthesia care unit (PACU). One bed is dedicated to the center's extracorporeal membrane oxygenation (ECMO) program. Nearby support facilities include a step-down unit, a dedicated burn operating room and an outpatient clinic. The BICU census averages around 8 patients, but rose as high as 13 during the project. Length of stay ranges from days to months. Patients admitted to the unit have the most severe affliction from chemical, thermal or electrical burns. Patients can also be admitted with burn-like diseases of the skin, such as toxic epidermal necrolysis

(TENS), Stevens-Johnson syndrome and the autoimmune disorder pemphigus vulgaris. The unit also treats patients who have infections or trauma that causes extensive soft tissue damage or loss, such as necrotizing fasciitis, severe degloving injuries and some war-related trauma.

Care for fragile BICU patients requires clinicians and clinical teams to perform complex cognitive work. This includes cognitive activity such as attention, memory and decision-making (Nemeth 2004). It also includes a range of macrocognitive activities such as problem detection, planning and replanning and developing common ground (Cacciabue and Hollnagel 1995; Klein et al. 2003). Individuals and teams are compelled to make time-pressured diagnostic and therapeutic decisions based on emergent and interrelated patient information from multiple sources. Their decisions about how to manage patient care rely on their ability to get the most important, or *salient*, information about the patient when performing the activities. Clinicians cope with many barriers to effective care, such as having to mentally integrate multiple sources of data. An effective DSS can spare clinicians from having to overcome such barriers, which can reduce the opportunity for misadventures and shorten patients' length of stay by making better care possible sooner.

Care providers, cognitive artifacts and information systems in this work setting comprise a joint cognitive system that can be studied, modeled and evaluated using CSE methods such as cognitive task analysis (Crandall, Klein and Hoffman 2006). CSE methods are used to design technology, training and processes that help people to manage cognitive complexity in sociotechnical systems (Millitello et al. 2010). In the first year of the project, our team used a selection of CSE methods to develop an in-depth understanding of the BICU people, tasks and work context. In the second year, we used them to develop rough and increasingly refined prototypes, including features from scheduling to unit view, order tracking, task checklists, messaging and patient view (shown in Figure 8.1). All of the features in the CCS reflect 39 requirements that field research revealed. The "parent-child" tab and center field configuration enables the user to scan key variables and choose detailed data of interest in either graph or table form.

We performed two assessments, one at the individual level and the other at the team level, to determine whether the CCS prototype improved clinician performance and whether clinicians accepted it. Our usability assessment evaluated how well the CCS supported individual clinician needs to find and use key patient data. CCS team collaboration features, such as communication through an integrated messaging application designed with healthcare team accountability in mind, were evaluated in a validation assessment the following year.

### 8.2.1 Design

Both usability and validation assessments followed protocols that had been approved by the local institutional review board (IRB) and the Department of Defense Human Research Protection Office (HRPO). To ensure the highest fidelity to the actual work setting and users, we conducted sessions on the BICU with clinicians who were assigned there. Evaluation is intended to verify how well the solution fulfills

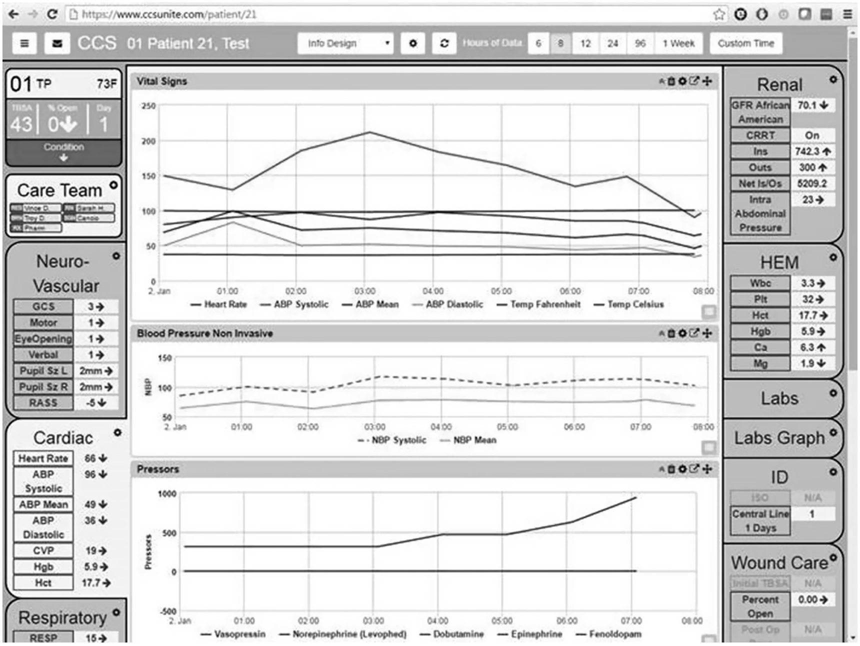


**FIGURE 8.1** CCS prototype patient view. Copyright © 2015 Applied Research Associates. Used by permission.

objectives that were derived during prior knowledge elicitation and analysis phases (Nemeth et al. 2015, 2016b).

## 8.2.2 Methods

### 8.2.2.1 Individual Usability Assessment

We recruited 11 physicians, 20 nurses and 10 respiratory therapists (RTs) of various experience levels from the BICU staff. Ninety percent of the nurses, 53% of the physicians and 50% of the RTs had more than 7 years of service in the BICU. Each participant received a 5-minute orientation to the CCS, and then used it to perform tasks in two typical clinical scenarios. The CCS was populated with previous patient data. In the first, the participant was to complete a patient admission to the BICU. In the second, the participant was asked to determine if a patient was ready for the operating room. RTs only completed the second preoperative scenario, as they do not complete the entire admission process. Participants were then asked to indicate responses on a one-page sheet to statements about the usability of the CCS versus their experience with the legacy EMR.

The usability assessment followed Rubin's (1994) guidance on how to conduct a usability assessment. We collected quantitative data by having those who would be expected to use the end product perform normal tasks using the prototype. We also

**FIGURE 8.2** Individual usability assessment. Copyright © 2016 Applied Research Associates. Used by permission.

used verbal protocol analysis (also known as “thinking aloud”) to reveal information they considered, how they found it, and how they interpreted it.

The participant sat in front of a laptop showing the CCS patient view (Figure 8.2). A small video camera was placed behind the chair to capture user navigation and comments. The session facilitator sat to the right with a log to track times, noted comments and steps taken to complete the task and how the participant used patient information to make clinical decisions.

After completing each scenario, participants used a 7-point Likert scale to rate the CCS according to its ease of use, how it affected their ability and speed finding information, their confidence in decisions they made using the system and how CCS compared to legacy IT systems for support of cognitive work.

#### 8.2.2.2 Team Validation Assessment

The purpose of the validation assessment was to determine how the CCS affected team performance. The research team collected quantitative data such as how long it took to get to a decision (efficiency). It also collected qualitative data such as expert evaluation of how accurate participant decisions were, and participants’ subjective

**FIGURE 8.3** Team validation assessment. Copyright © 2016 Applied Research Associates. Used by permission.

experience with the CCS. Researchers observed two three-member clinician teams (attending burn surgeon, a bedside nurse and a resident physician) (Figure 8.3).

Table 8.1 shows that while Team 1 had more experience than Team 2, experience in the BICU work setting was similar for both teams. Ranges represent how data were collected to maintain anonymity of a small population of participants. Team 1 had one female member and Team 2 was all male.

Both teams cared for one simulated patient using a high-fidelity manikin (SimMan 3G, Laerdal®, Stavanger, Norway) in each scenario, which lasted about 6 hours. Researchers performed any consulting roles that teams would need: respiratory therapist, rehabilitation specialist, nutritionist, pharmacist, family member and subspecialty consultants.

**TABLE 8.1**

**Validation Assessment Team Member Experience**

| Team | Role | Years in practice | Years in the BICU |
|---|---|---|---|
| **One** | Attending physician | 10+ | 10+ |
| | Resident | 4–6 | <1 |
| | Nurse | 10+ | 1–3 |
| **Two** | Attending physician | 10+ | 7–9 |
| | Resident | <1 | <1 |
| | Nurse | 7–9 | 1–3 |

We developed two scenarios in advance that called for teams to treat a "patient" with ARDS and a "patient" with intraabdominal sepsis. We then piloted and refined scenarios with input from experienced burn care providers. We chose these two conditions because therapeutic interventions in both are challenging to implement, potentially risky and require team decision-making. Scenarios were designed to help determine how well either the CCS or a legacy IT system in use at the BICU for years system supported the teams' key decisions. Scripts were designed to branch depending on clinician decisions. This required a substantial amount of advance preparation to develop various tasks, lab values, imaging, notes, patient care needs and changes in patient condition.

Each team was oriented to the systems and the simulation room for about an hour the night before their first assessment. Scenarios started at 6:45 a.m. when researchers, simulating the "night-shift," gave standardized handoffs to the resident and nurse subjects starting the "day shift." This gave the members time to prepare for multidisciplinary rounds, to conduct rounds and to perform patient care after rounds were done.

IT systems and scenarios were counterbalanced to avoid transfer of training. We used simulated patient data and the legacy EMR system to enter and record all patient data so that CCS could display it real time. Team 1 first used the CCS (entering data through the legacy EMR system) for the ARDS scenario and then used the legacy EMR system only for the sepsis scenario. Team 2 used the legacy EMR system for the ARDS scenario and then the CCS (entering data through the legacy EMR system) for the sepsis scenario.

Three observers collected data on six outcome measures: activities performed, the time it took the team to arrive at key decisions, information seeking behaviors, communication patterns, decision-making processes and use of the CCS messaging feature. Care that was provided at the same level of quality in a shorter timeframe was considered more efficient.

After each scenario, we collected data using a brief survey, including statements that invited responses using a 7-point Likert scale and open questions so that participants could rate their own team's performance, decision-making and communication, and compare both IT systems. They also provided feedback about their experience in a semistructured group interview.

### 8.2.3 Results

#### 8.2.3.1 Individual Usability Assessment

All participants were able to complete all tasks successfully. Results of the assessment included responses to questions comparing the CCS with the legacy electronic healthcare record that has been used at the site for years (Nemeth et al. 2016c). Table 8.2 shows data for participant responses by role.

When compared to RTs and to nurses, physicians rated the CCS as easier to use and easier to find information ($p < 0.05$). All of the participants rated themselves confident in their decisions and found the effort needed to use the CCS low compared to the legacy system. Table 8.3 shows participants' responses on a 7-point

**TABLE 8.2**
**Participant Ratings of the CCS and Legacy System by Role (Mean [SD])**

| **Scenario 1: preparing for surgery** | **Overall ($n$ = 41)** | **Physician ($n$ = 11)** | **Nurse ($n$ = 20)** | **RT ($n$ = 10)** |
|---|---|---|---|---|
| I am *confident* in my decision/ recommendation | 5.4 (1.2) | 5.7 (1.1) | 5.2 (1.3) | N/A |
| The system was *easy to use* to make this decision | 4.9 (1.4) | 5.6 (1.1) | 4.7 (1.7) | N/A |
| The system enabled me *to quickly find* the information I needed | 5.18 (1.6) | 5.7 (1.4) | 4.9 (1.8) | N/A |
| It was *straightforward to find the information* I needed | 4.95 (1.6) | 5.3 (1.4) | 4.75 (1.8) | N/A |
| **Scenario 2: new admission** | | | | |
| I am *confident* in my decision/ recommendation | 5.9 (0.75) | 6.1 (0.73) | 5.85 (0.67) | 5.7 (0.76) |
| The system was *easy to use* to make this decision | 5.5 (0.95) | 6.1 (0.57)[a] | 5.6 (1.2) | 4.8 (1.3)[a] |
| The system enabled me *to quickly find* the information I needed | 5.1(1.2) | 5.7 (1.2)[a] | 5.5 (1.2) | 4.8 (1.3)[a] |
| It was *straightforward to find the information* I needed | 5.2(1.1) | 6.2 (0.92)[a,b] | 5.5 (1.1)[b] | 4.9 (1.4)[a] |

a. Indicates significant difference between identified groups ($p < 0.05$) by MANOVA.
b. Indicates significant difference between identified groups ($p < 0.05$) by MANOVA.

**TABLE 8.3**
**Participant Ratings Comparing the CCS and Legacy Systems**

| | **Disagree (1–3)** | **Neutral 4** | **Agree (5–7)** |
|---|---|---|---|
| ***Information search*** | 24.4% | 9.7% | 65.9% |
| I can find the information I need in (the CCS) *more quickly than* I can using (the legacy system) | | | |
| I can find the information I need *more easily than* I can using (the legacy system) | 14.6% | 19.5% | 65.9% |
| ***Usability*** | | | |
| The CCS *is easier to use than* (the legacy system) | 14.5% | 19.0% | 66.0% |
| I would *feel more confident* making future clinical decisions and recommendations using the CCS than using (the legacy system) | 19.5% | 22.0% | 58.5% |
| The CCS *supports the way I do my work* better than (the legacy system) | 17.1% | 19.5% | 63.4% |

Likert scale to five comparison statements according to the percentage of those who responded *strongly agree* or *agree (5–7), neutral (4)* or *disagree (1–3).*

A number of comments pointed out features that the earlier knowledge elicitation phase had shown were important, such as simultaneous display of all salient data, support for a shared mental model of patient status and sparing clinicians from having to do work that the system can handle. For example:

*Respiratory therapist:* "Having the information right there makes you think, when you can see the trends. It helps to pull the information together in one place."

*Nurse:* "I like that CCS may bring us together and on the same page. All members on the team may see things the same way."

*Attending physician:* "Nice to have actual and ideal or adjusted body weight-to-dose drugs."

Qualitative data also included participant recommendations for improvement. For example, nurses preferred to have a view that included all laboratory values for a patient. Respiratory therapists favored a view that summarized all of a patient's ventilator settings.

#### 8.2.3.2 Team Validation Assessment

Table 8.4 shows how teams and systems were counterbalanced to avoid training effect.

Interestingly, in the sepsis scenario, the less experienced team using the CCS was able to reach a decision to perform an exploratory laparotomy at essentially the same time as the more experienced team. During the ARDS scenario, the more experienced team using the CCS decided on ECMO treatment over a half hour sooner compared with the team using the legacy system. While the more experienced team (Team One) consistently gave antibiotics faster, decision-making efficiency was similar (Pamplin et al. *in press*).

Participants were able to use the CCS messaging feature to check the status of the patient, tests, consult requests and medication orders and found that it made communication easier compared with traditional means (pager, phone, face to face). We discovered teams used that feature in different ways. The more experienced Team 1

**TABLE 8.4**
**Validation Scenario Time to Decide**

| Scenario | Team | IT system | Time to decision |
|---|---|---|---|
| Sepsis | One | Legacy | 6:38 |
| | Two | CCS | 6:43 |
| ARDS | One | CCS | 4:33 |
| | Two | Legacy | 5:07 |

had 11 communication threads: 82% received replies, and team members communicated one-to-one (e.g., resident to attending) in 9 of the 11 threads. The less experienced Team 2 used messaging to broadcast information one-to-many (e.g., nurse to resident, charge nurse, pharmacist) for 70% of their 10 threads.

Participants consistently found the scenarios were "real." During post-scenario interviews, members of both teams mentioned how clinically challenging the scenarios were and that, because the "patient" was "so sick," team members relied on the DSS/IT systems less and spent more time at the bedside.

Responses in surveys after the validation assessment showed that all but one participant rated the CCS superior to legacy systems for ease of use and information finding, and for improving team performance, communication and decision-making. Team 2 rated both systems as equal for finding information and decision confidence.

Orientation to use the CCS was minimal, and use cases did not lend themselves to statistical analysis. Results did show participants rated the CCS easier to use than the legacy system, and resulted in better diagnostic performance by a novice clinician and slightly improved efficiency.

## 8.3 TELEMEDICINE PROLONGED FIELD CARE (TELEPFC)

Future military deployment scenarios anticipate circumstances in which rapid evacuation will not be the norm. Evacuation delays will require extended care for casualties, including prolonged field care (PFC) over hours to days (PFC 2015). PFC will involve more severe afflictions such as shock (which can cause organ failure), and a care provider will need to make complex diagnoses and treatment decisions under austere conditions. An inexperienced clinician's decision-making (and by extension, casualty care) can be improved through the use of advanced telemedicine tools with audiovisual capabilities during prolonged Field Care (PFC) (Lilly et al. 2014).

Advanced telecommunication devices that enhance communication and situational awareness in such conditions may provide essential critical care expertise in real time, decrease mental task load and provide comfort to clinicians faced with unfamiliar, challenging problems (Pickering et al. 2015). We developed a simulation platform to determine whether telemedicine improves clinical decision-making and management of complex casualties during PFC, compared to care provided without telemedicine support.

Physicians in academic medical centers regularly provide telemedicine for critically ill and injured patients when supervising physician trainees and consulting with subspecialty providers or colleagues (Croteau and Vieru 2002). Enabling this type of two-way exchange using reliable communications (i.e., e-mail and telephone) could significantly improve the care of casualties and improve local provider confidence in clinical decisions. Its benefits would be greatest in remote areas of operation where clinical experts such as intensivists and surgeons are not physically available (see Norris et al. 2002). While the technology is relatively simple, the human aspects of telemedicine are more challenging and beg a number of questions. What clinical encounters benefit from remote assistance? What are the best practices for tele-mentoring? When should clinicians employ synchronous vs. asynchronous technology?

What level of complexity is appropriate? What is the best timing to engage in remote support? Answering these questions would verify that remote expert consultation could actually improve patient care and reveal aspects of care are the best for remote consultants to assist.

### 8.3.1 Design

We designed high-fidelity simulations to mimic real patient care to ensure validity and conducted several pilot tests. This ensured that we could conduct reliable and reproducible long-term simulations at multiple study sites without compromising on data collection. We sought to determine how one aspect of telemedicine, expert presence, using audio or video can aid clinicians who have limited knowledge, skills and experience to provide optimal care for critically ill patients in austere environments. To learn the answer, we conducted a randomized controlled study to measure clinician performance related to critical care management of complex casualties in simulated PFC scenarios with, and without, telemedicine ("reach back") support. Table 8.5 shows how the simulation was organized at both of the research sites.

Our study was designed to test the effect of telemedicine on participant clinical decision-making, procedure quality, cognitive workload, confidence and stress. Our hypothesis was that tele-mentoring would:

- increase accuracy of decisions,
- have no impact or decrease efficiency of decisions,

**TABLE 8.5**
**TelePFC Simulation Study Timeline and Tasks**

| | Participant | Research team |
|---|---|---|
| Day T-1 | Orientation to simulation and research study | Set up for testing: simulation room, telemedicine workstation, video camera, manikin |
| | | Test: hardware, software and network connectivity |
| | | Conduct orientation |
| Day 1 (during) | Handoff of scenario, patient history and allow questions prior to simulation | Simulation technician will deploy manikin |
| | Will be equipped with physiological monitor and telemedicine equipment | Research team and Subject Matter Expert (SME) will role-play as needed "roles" to assist subject |
| | May stop or remove themselves from the study at any time | Paper and video recording of data points |
| Day 1 (after) | Will attend after actions review meeting to discuss simulation and fill out surveys | Conduct after action review meeting to allow discussion and handoff surveys |
| | | Data review and analysis |

- increase reliability of decisions across subjects,
- increase procedural quality,
- decrease cognitive workload,
- increase confidence,
- decrease stress.

### 8.3.2 Methods

In year 1, we explored three levels of telemedicine support:

- Comprehensive telemedicine (CT) support that includes remote casualty monitoring using synchronous telemedicine (real-time video and audio communication) and asynchronous e-mails.
- Partial telemedicine (PT) support that includes access to a remote expert with only asynchronous e-mails and synchronous phone calls (but no video).
- No telemedical (NT) support. Subjects complete scenarios without help from a remote expert and only access to hard copy clinical practice guidelines.

We conducted simulation testing at the US Army Institute of Surgical Research (US AISR) and at Madigan Army Medical Center Andersen Simulation Center (ASC). The telementor role was supported with:

- Standardized scripts, with straightforward language designed to guide an inexperienced clinician.
- Checklists to ensure complete data collection and thorough management.
- Procedure guides, complete with visual aids, to be sent to the subject. Guides would ensure tele-mentoring reliability.

The study design consisted of six steps using the following methods.

#### 8.3.2.1 Recruitment

In accordance with an approved IRB protocol, we recruited and enrolled participants at San Antonio Military Medical Center (US Army Institute Surgical Research and Brooke Army Medical Center) (BAMC) and Madigan Army Medical Center (MAMC). We recruited active duty military clinicians with no formal surgical or anesthesia training such as family medicine, emergency medicine and internal medicine physicians, physician assistants or medics representing the types of clinicians likely to encounter PFC during military deployments. Our goal was to recruit at least 20 subjects per site (40 in all). Assuming a 20% dropout rate, 24 subjects would comprise the sample at each site (48 in all). We also used a survey to collect demographic information through a survey on the day before the simulation experiment. After providing consent, each subject was assigned a unique identifier and was assigned to a testing calendar.

#### 8.3.2.2 Randomization Block Design Strategy

We conducted block randomization to randomly sort participants into one of the three telemedicine groups. Each block ensured that all three groups were represented to eliminate the risk that certain groups were not conducted in case of significant dropout or low subject recruitment.

#### 8.3.2.3 Scheduling Strategy and Requirements of Subjects

We asked each participant to allow one full day to complete the simulation tests and aligned the schedule date and time for both participants and telementors.

#### 8.3.2.4 Subject, Telementor, Proctor and Role-Player Orientation

The day before subject testing, we gave the participant a brief orientation about the research study without revealing which of the four simulations would be used, and an orientation to the simulation manikin, equipment and environment. Subjects were also encouraged to use the concurrent “think aloud” method to reveal their thoughts throughout the simulation.

#### 8.3.2.5 Simulation Tests and Analysis

We performed all tests using a manikin (SimMan 3G, Laerdal®, Inc., Stavanger, Norway) in a high-fidelity simulation to mimic an austere PFC setting, and developed scenarios that simulated patient care over 14 hours. Scenario time was compressed into simulation events lasting from 6 to 8 hours and recorded on video. Participants wore smart shirt sensors (Hexoskin, Carré Technologies, Montreal, CA, https://www.hexoskin.com) during the sessions to monitor and analyze cognitive workload and stress, based on the physiological responses. We randomized each participant to conduct one scenario which was either comprehensive (CT) or partial (PT) or no telemedical support (NT). All groups used standardized medical supplies, equipment and had access to the Joint Trauma Systems Clinical Practice Guidelines.

The research investigators and primary proctor monitored the simulation, noted key tasks completed and times and asked the participant to use the validated workload assessment form NASA-TLX (Hart and Staveland 1988) to report their physical and cognitive workload after major intervention and at the end of each scenario. Investigators collected data on the following:

- *Decision-making accuracy:* Did the participant perform the correct procedure/make the correct decision?
- *Decision-making efficiency:* How fast was the participant able to perform a procedure? How quickly could each participant determine key decision points?
- *Decision-making reliability:* Measurement of consistency between various groups
- *Procedure quality:* Percent of key and supportive procedural tasks completed
- *Cognitive workload:* Physical and cognitive workload, measured using validated surveys and physiological measurements

- *Stress/confidence:* Perception (survey) and measurement (physiological measurement) of stress and confidence (survey).

#### 8.3.2.6 Data Analysis

Analysis sought to answer several questions: was there a difference in cognitive workload (of specific task) between the three telemedicine groups? Was there a difference in cognitive workload of the tasks performed in the same scenario between various demographics? Which telemedicine platform had the highest efficiency in decisions made, accurate decisions made and reliability of decisions made between study groups? Which group had the highest perceived and modeled confidence between the telemedicine groups? Which telemedicine group had the highest percentage completion of critical tasks completed and of whom? What was the quality, and are there differences in quality between study groups? Answers were based on data collected from performance observation, coding of videos of clinical performant, the physiological measurement system (which provided a cognitive workload model and stress model), NASA-TLX surveys response, custom surveys and after action review report.

### 8.3.3 Results

While the project is still in progress, we can report on preliminary results for ten participants who completed the severe hypoxia scenario in one of three groups: comprehensive telemedicine (CT), partial telemedicine (PT) and no telemedicine (NT) (Table 8.6). We coded timing of decision to place an advanced airway (AA), time to complete AA placement and specific quality and safety tasks. We analyzed quality scores using Analysis of Variance (ANOVA) with a Tukey adjustment for pairwise comparisons.

Procedural quality scores indicate the percent of quality indicators completed (e.g., prepares equipment before starting procedure, has backup/alternative airway equipment available). Scores for the advanced airway task differed between the CT vs. NT (86% vs. 30%, $p < 0.002$) and PT vs. NT group (71% vs. 30%, $p < 0.001$).

**TABLE 8.6**
**TelePFC Results for Advanced Airway (AA) Task**

| Task | CT ($n$ = 4) | PT ($n$ = 4) | NT ($n$ = 2) |
|---|---|---|---|
| Timing of the decision to place AA (minutes) | 135 | 147 | 135 |
| Time to complete AA placement (minutes) | 36 | 26 | 11 |
| Procedural quality scores (percent of completed quality indicators) | 86% | 71% | 30% |
| "Patient" outcomes/survival | 100% (4/4) | 66% (2/3) | 0% (0/2) |
| NASA-TLX score (higher indicates greater cognitive load) | 70 | 58 | 73 |

These initial results suggest that clinicians who received no telemedicine guidance had a significantly lower advanced airway quality score compared to both groups that received partial (PT) or comprehensive (CT) telemedicine guidance, indicating lower quality, and potential safety, of the procedure. Compared with the CT and PT groups, the NT group also had slightly higher cognitive workload, but little difference in timing of decisions.

## 8.4 DISCUSSION

Both the examples of this chapter provide ample evidence for how usability can help to improve healthcare.

The CCS project demonstrates inclusion of evaluation at multiple points in the system development life cycle. The research team conducted other interim evaluations before the individual and team assessments described above. For example, team members reviewed results with BICU clinicians to verify the accuracy of first-year observations and interviews (Nemeth et al. 2015, 2016b). The team also conducted participatory design sessions (Clemensen et al. 2007) with BICU clinicians at the start of interface concept development. These and the final assessments verified the development solution and clinician needs were aligned. It also enabled clinicians to invest themselves in the solution.

While clinically accurate scenarios are a challenge to develop, they are worth the effort. The scenario was so believable to the outside observer that the participant roles can easily be reversed by writing scripts for the subject and evaluating telementor responses. Much like the physical setting, the clinical ecology needs to include all of the cues and results that participants are used to experiencing in actual practice.

Participants who would use the eventual solution, rather than proxies or stand-ins, speak from experience. Their task performance is more likely to be authentic, yielding more accurate data. The knowledge that they would benefit from the eventual solution is an incentive to be candid. The practice reflects insights developed early in evaluation of user-computer interaction (Molich and Nielsen 1990), such as “speak the user’s language,” “minimize the user’s memory load” and avoidance of “irrelevant or rarely needed information.”

While models that seek to improve healthcare (see Carayon et al. 2014) offer helpful insights, most rely on observation and qualitative data for evidence. Comparative interface assessments such as by Zahabi et al. (2016) focus more on the interface than how it affects task performance. Those who review such assessments can dismiss them as “just opinions.” Approaches to improve healthcare need to include both quantitative and qualitative data to build a defensible case. Results from both of the studies in this chapter include quantifiable data such as time to complete task or number of steps taken. These data provide a warrant for claims that performance using the solution improves care quality. Minimal need for orientation also suggests time and funds for training how to use the system could be substantially reduced.

Conducting studies in circumstances as close to actual conditions as possible maximizes the assessment’s validity. Greater validity lessens the needs for imagination on the participant’s part and evokes more genuine behavior. For example, team members in the CCS validation study found the scenario engaging to the point that when the simulated patients' condition deteriorated rapidly, team members spent more time at bedside. While this limited the amount of time members spent using the DSS and IT systems later in the scenario, it also provided data on how clinicians use IT systems that other study methods like interviews and surveys might not.

Scheduling and resource constraints can make sample recruitment difficult. For example, the CCS validation assessment had two small teams and two clinical scenarios. A focus on process descriptions and consistent themes across the data made the most of the exercise.

## 8.5 CONCLUSIONS

Those who provide and get healthcare deserve the best possible systems to support them. While other sectors might lend themselves to "quick and dirty" studies, healthcare does not. Managing tight schedules and resources makes efficient research design necessary to make the most of the effort. Use of a methodical approach such as CSE is essential for this, as CSE is designed to connect data from the research setting through analyses, requirements and solutions to evaluation that includes usability.

Both of the projects in this chapter demonstrate how use of the CSE approach to health IT development can produce solutions that match clinical priorities and workflows and minimize the need for training through intuitive design. Our findings also complement the growing body of research that shows how rigorous research in individual and team cognitive work can produce technology that is acceptable to clinicians, may improve their care performance and, as a result, may enhance care quality, safety and ultimately patient outcomes.

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# 9 Considering Users' Experience in the Design of Animated Instructions for Medicines Usage

## *Listening to Patients and Health Professionals*

*Carla Galvão Spinillo*

**CONTENTS**



## 9.1 INTRODUCTION

Instructional animation is considered a valuable resource for representing contents in many fields. It allows visualization of abstract concepts/processes and of things that cannot be easily seen in the real world (e.g., interior of the human body). In order to design effective instructional animations, Mayer (2019, 2020) proposes the following three goals: *reduce extraneous processing; manage*

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*essential processing* and *foster generative processing.* Extraneous processing is usually caused by poor information design which uses unnecessary elements in the animation (e.g., decorative images, background music). The instructional goal of managing essential processing refers to the use of complex contents that require greater cognitive effort. To facilitate cognitive processing, both the media and the way a content is structured should be taken into account in the design of animations. Lastly, the goal of fostering generative processing refers to the aspects of social behavior to be considered in order to achieve greater engagement between users and the instructional animations. To reach those goals, Mayer (2019, 2020) recommends six instructional principles. He considers these principles essential for information design, particularly for the design of instructional animations:

1. **Principle of Coherence**: present elements which convey instructional content only;
2. **Indication** or **Signaling**: highlight key information on narration and/or on screen;
3. **Segmentation**: structure contents in parts relevant to learners;
4. **Personalization:** use language in a conversational style rather than a formal or technical style;
5. **Embodiment**: use gestures, movements, facial expressions and eye contact when instructors are on screen; otherwise, use human hand for drawing and pointing and/or first-person perspective; and
6. **Spatial contiguity**: present related elements next to each other (e.g., words as labels in parts of graphics).

It is worth mentioning that in previous studies (Mayer & Moreno, 2002) the principle of spatial contiguity is presented as part of the contiguity principle which also includes temporal contiguity. This refers to the simultaneous presentation of words and images in animations to enhance learning. In this sense, words should be presented as narration rather than a text on screen, which is referred to as the modality principle (Mayer & Moreno, 2002).

The above-mentioned goals and principles for designing instructional animations have been employed in both analytical and empirical studies in the health field. For example, Almeida et al. (2014) employed these goals and principles to evaluate the animations about the digestive system used in distance learning courses. Their results indicated deficiencies in the representation of contents, such as the use of on-screen text rather than narrations, which contradicts the principle of modality. Similarly, Lima et al. (2019) identified problems in the animations about clinical cases used for training health professionals. They found that these animations were not in accordance with the principles of Coherence and Signaling as they contained unnecessary elements and did not highlight relevant instructional contents. The authors also state that the weaknesses in the animations analyzed might demand a greater cognitive effort from the health professionals and this may negatively affect their learning experience.

Although the goals and principles mentioned herein do not explicitly take into account the learner/user's experience (UX), observing them in the design process may significantly enhance the learning experience.

## 9.2 ASPECTS OF USER EXPERIENCE (UX)

The literature on user experience (UX) is comprehensive, embracing services, products and digital artifacts, such as instructional animations. Hassenzahl (2013) considers that UX occurs at three levels: in the actions that the user can perform in the interaction with an artifact/product (*what*), in the way that user interacts (*how*) and in the users' motivation to use/interact with an artifact (*why*). The latter relates to users' goals when interacting with an artifact. With similar concern, Lowdermilk (2013) states that users seek engaging and pleasurable experiences in their interaction with/use of artifacts, which they see as the means to achieve their objectives. For instance, in the health field, medical students could use animations with a view to learning how to perform a medical procedure.

Moreover, the expectations of users and how satisfied they are with the representation of contents in instructional animations may also be considered as part of their learning experience. This experience must be positive and motivating, so as to achieve the instructional aims. Considering aspects of UX in the design process is, therefore, crucial. In this sense, Garrett, in his seminal work *The Elements of User Experience* (2011), identifies five planes in the design of digital artifacts which he believes can produce positive experiences in users: the strategy, the scope, the structure, the skeleton and the surface planes. These are bottom-up orientation planes on a continuum that goes from abstract (strategy plane) to concrete (surface plane), each plane being grounded on the previous one.

The *strategy plane* is related to the needs of users and the objectives of the artifact that must meet the demands of users. The *scope plane* refers to the features of the digital artifact, the functional specifications and requirements of the content which are essential to meet the needs of users identified on the previous plane. The *structure plane* organizes and integrates the features and functionality of the artifact, establishing the interaction between design and information architecture. These are then embodied in the navigation elements that are arranged on the *skeleton plane*, along with elements of interface design and information design, resulting, for example, in wireframes of Web sites and apps. Finally, the *surface plane*, the most concrete plane of the continuum, is where the sensory experience (visual, auditory and tactile) of users occurs through the graphic interface. Garrett's five planes (2011) are also relevant to the design of instructional animations, particularly when the animations have interaction and use navigation resources.

Also concerned with the importance of UX in the design of artifacts, Morville (2004) proposes seven qualities which he believes can promote meaningful and positive user experience: to be *useful*, *usable*, *findable*, *accessible*, *desirable*, *credible* and *valuable*. Morville employs the visual metaphor of a honeycomb to present these qualities. The quality of *being useful* refers to how helpful the artifact is to users in a functional sense, which, according to Morville, requires creative solutions from the designer. The quality of *being usable* refers to the usability aspects that should be considered, such as navigation and interaction design. The quality of being *findable* is related to how easy it is for users to locate the elements of the interface to access contents. The quality of being *accessible* regards features that allow people with disabilities to effectively use the artifact**.** It is worth noting that ensuring accessibility to artifacts and services is already regulated by law in many countries, thus being a mandatory requirement. The quality of being *desirable* alludes to emotional/affective aspects that meet the aesthetic expectations and values of users**.** For Morville (2004), this quality is associated with users' appreciation for a brand. The trust and beliefs that users associate with the artifact (and/or its source/brand) constitute the quality of *being credible*. Finally, an artifact must be *valuable*. Morville (2004) considers the quality of being valuable as the central quality of UX, to which the other qualities are to converge. Hence, for an artifact to have *value* for users, it must be useful, usable, desirable, findable, accessible and credible.

Spinillo et al. (2019), in a study on users' experience with an authoring tool for designing e-books, classify the qualities proposed by Morville (2004) as of two types: *extrinsic to users* and *intrinsic to users.* The qualities extrinsic to users are objective qualities within the scope of the artifact design (e.g., interface features), whereas the qualities intrinsic to users are subjective, within the affective/emotional scope, as well as related to values and expectations of users in relation to the artifact. In this way, the authors consider being usable, useful, accessible and findable as qualities extrinsic to users, and being desirable, credible and valuable as qualities intrinsic to users (Figure 9.1).

Both Morville's (2004) and Garrett's (2011) approaches to the design of artifacts aim at promoting meaningful user experience. In this regard, it is possible to relate the extrinsic and intrinsic qualities of the UX *Honeycomb* to the five planes of the design of digital artifacts. The *intrinsic qualities* that make an artifact desirable and credible to users, such as users' expectations and beliefs, would be found on the *strategy plane*. These qualities would define the purpose of the artifact and the demands it should meet. It is worth highlighting that the *quality of being credible*

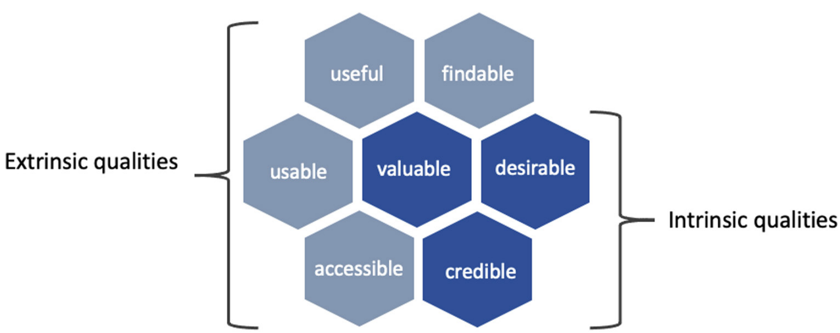



**FIGURE 9.1** Extrinsic and intrinsic qualities regarding the UX *Honeycomb. Source:* Based upon Morville (2004).

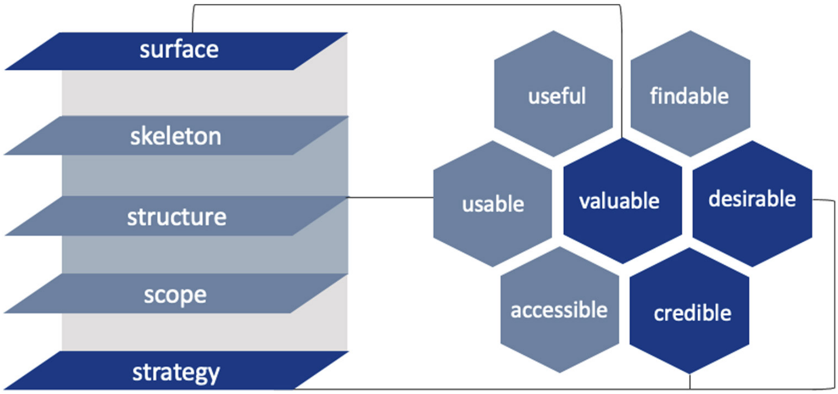



**FIGURE 9.2** Diagram relating extrinsic and intrinsic qualities of the UX *Honeycomb* with the five planes for the design of digital artifacts. *Source:* Based upon Garret (2011) and Morville (2004).

is subjective as it refers to how much users trust a source/brand. In other words, the level of credibility of the artifact varies according to the subjective perception of the user. For example, a healthy eating Web site set up or managed by a company that sells ultra-processed (non-heathy) foods may have its credibility questioned by users/consumers.

On the other hand, *the scope*, *structure and skeleton planes* would accommodate the *extrinsic qualities* of being useful, usable, accessible and findable. This is because these qualities encompass the tangible aspects of interaction and navigation design, as well as information architecture, which are all considered on these planes, together with the functional requirements of the content of digital artifact. Finally, the *surface plane* embraces the quality of being *valuable* to users. Figure 9.2 shows the proposed relations between the five planes and the seven qualities of the UX *Honeycomb*. The color gray is used for the extrinsic qualities and blue for the intrinsic qualities, and the thin lines link the planes to the relevant *honeycomb* units.

In the context of procedural animations, the UX qualities and the planes are equally important to the creation of positive experience. For example, an interactive animation about procedures for preventing the COVID-19 pandemic produced by the Ministry of Health of a country would have the quality of being *credible* with respect to the source of the information, as well as *desirable* (related to the strategy plane). It would also be *useful* for the population to learn about preventive actions/behaviors. If the animation presents an effective interaction design and interface design, and it follows universal design principles, it would also possess the qualities of being *usable*, *findable* and *accessible* to people with disabilities. These are qualities related to the scope, structure and skeleton planes in the design process of the animation. Finally, as a result, the animation about procedures for preventing the COVID-19 pandemic would be *valuable* (related to the surface plane) as an instructional resource in health, and would possibly produce a positive UX, aiding users to

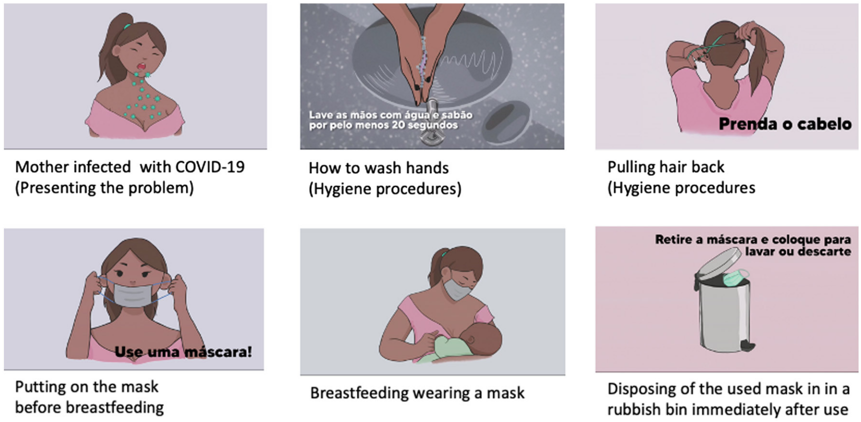



**FIGURE 9.3** Screenshots from animation about breastfeeding procedures addressed to mothers infected with coronavirus by Allisson D. Menezes and Heloisa P. Machado (2020).

perform the steps correctly. Figure 9.3 shows an example of a procedural animation for preventing the spread of COVID-19. The animation is aimed at breastfeeding mothers who are infected by the coronavirus and shows how they can keep their babies protected from COVID-19 while breastfeeding. Figure 9.3 shows a sequence of print screens from the animation. The animation content is from instructional material issued by a local health authority in Brazil, and it was designed by students from the Federal University of Paraná State in accordance with UX and information design principles and guidelines.

It is worth highlighting that the dynamic character of animations allows for a more realistic depiction of steps/actions. It facilitates the visualization and understanding of the information presented and can support users' task performance. Thus, procedural animations should be useful resources for the promotion of acuity in users' action plan for carrying out steps (Höffler & Leutner, 2007; Ainsworth 2008).

## 9.3 A STUDY ON ANIMATIONS ABOUT PROCEDURES FOR MEDICINES USAGE

On the assumption that animations representing instructions can promote a positive UX, a study on the effectiveness of animations to convey information about the use of medicines was conducted in Brazil. The study aimed to propose recommendations for the design of animations focused on user-patients and took into account the views of health professionals and the mandatory information provided in PILs (patient information leaflets). With that in mind, the contents of the animations were taken from the PILs of medicines provided on the portal of the Brazilian Ministry of Health, ANVISA (www4.anvisa.gov.br/BularioEletronico/). Initially, a study on the perception of the importance of the information provided in medicines leaflets was conducted with users, physicians and pharmacists. Then, based upon the results of this initial study, prototypes of animations on medicines usage were produced for testing. Lastly, a further study was carried out to verify how effective the animations produced were, and how satisfied users, physicians and pharmacists were with them. These studies are briefly described next.

### 9.3.1 Study with Health Professionals and Patient/Users

A study was conducted to verify how important the information provided in the PILs was for health professionals and patients/users of medications. The study consisted of a semistructured interview with 120 participants, with $N = 80$ medicine users and 40 health professionals ($N = 20$ physicians and $N = 20$ pharmacists). The participants were asked to rank the level of importance of the following nine types of information provided in PILs: (a) dosage; (b) adverse reactions/side effects; (c) how to use the medicine; (d) indication (what it is for); (e) medicine interaction; (f) components of the formula; (g) contraindication; (h) overdose and (i) warnings.

## 9.4 Summary of the Results of the Interviews with Health Professionals and Users

Overall, the results indicate little agreement between physicians, pharmacists and users regarding the importance given to the different types of information in PILs. The results also suggest that there is more concurrence between pharmacists and users than between physicians and users. This may have implications for physician–patient communication regarding information on medicines. However, this aspect is beyond the scope of this investigation. It is worth noticing that none of the participants considered all nine types of information in their rankings. Users and physicians considered eight types of information and pharmacists, seven. “Components of the formula” was disregarded by all three groups of participants, this probably being due to the technical nature of such information. In addition, information on “overdose” was not ranked by physicians and pharmacists, “drug interaction” was only ranked by pharmacists and “warning” was only ranked by users. Participants also differed in the number of hierarchical levels they used to rank the information. Physicians and pharmacists used five levels of hierarchy when ranking the information provided in PILs, while users made use of seven levels. This may indicate that users consider having more types of information about medicine usage more valuable than physicians and pharmacists do.

Table 9.1 shows the hierarchical position assigned by each group of participants and where there is agreement. When participants assign the same level of importance to different kinds of information, these are presented within the same cell in the table, for example, “warnings” and “indication” were both ranked third by physicians.

*“Dosage”* was the only type of information provided in PILs to be considered as the most important by all three groups of participants. This suggests a common concern about the quantity and frequency of medicine usage and a general consensus that it is crucial for the efficacy of health treatment. Dosage errors may not only jeopardize the treatment, but can also be fatal. It is important to stress that information

**TABLE 9.1**
**Order of Importance Assigned by the Participants to the Information in the Package Leaflet**

| Order | Physicians/Doctors (8 types) | Pharmacists (7 types) | Users (8 types) |
|---|---|---|---|
| **1st** | **Dosage** | **Dosage** | Dosage |
| 2nd | How to use the medicine | Indication (what the medicine is for) | Contraindication |
| | Adverse reactions/side effects | | |
| **3rd** | Warnings | **Adverse reactions/side effects** | **Adverse reactions/side effects** |
| | Indication (what the medicine is for) | | |
| **4th** | Drug interaction | **How to use the medicine** | **How to use the medicine** |
| | Contraindication | | |
| **5th** | **Medicine formula** | **Medicine formula** | Indication (what the medicine is for) |
| | | Contraindication | |
| | | Warnings | |
| 6th | | | Drug interaction |
| | | | Medicine formula |
| 7th | | | Overdose |

on medication dosage should also be provided by doctors through prescriptions to patients. Prescriptions to patients, however, do not provide information on how to use the medicine; this type of information is provided only in the PILs. Such information is of great relevance to users, as they need it to carry out the steps for using/taking medicines correctly. The importance of this type of information is acknowledged by the physicians, who ranked it second. However, pharmacists and users ranked "how to use medicine" fourth. These results suggest that users as well as pharmacists consider procedures for medicine usage as something intuitive and/or easy to carry out, which seems to be a misperception about the complexity of medicine usage (e.g., Spinillo et al., 2011; Spinillo, 2016, 2017; Waarde, 2004, 2019).

Similarly, the results of the study also show that participants attach little importance to "warnings" about medicine usage, although this type of information plays an important role in preventing errors in task performance (e.g., Wogalter, 2006). Warnings were ranked third by physicians, fifth by pharmacists (last position) and not ranked at all by users. These results seem to indicate that all three groups have little or no concern about possible errors and/or risks of medicines use.

The data provided by the interviews greatly contributed to the understanding of how pharmacists, physicians and users perceive the information provided in PILs. This study made it possible to identify what information should be considered in the animations about medicine usage. The related literature was also taken into account and it is summarized below.

## 9.5 THE DESIGN OF ANIMATIONS ABOUT MEDICINE USAGE

The prototypes of the animations conveyed procedures for medicines usage and differed in their pharmaceutical presentation for users: (a) nasal spray, (b) inhaler (asthma pump), (c) injection and (d) vaginal cream. A vaginal cream presentation was chosen because it has been shown that users have difficulties in task performance when using this format (Spinillo, 2017).

The animations followed the principles and design strategies proposed by Mayer (2019, 2020). Thus, they presented only the elements relevant to the content: graphic emphasis on keywords on screen, which were positioned near the animations to which they referred; content represented in audio and animated images; narration synchronized with animation. The contents of the animations about medicine usage were divided into introduction, steps, closing content and disposal information. Human voice and a conversational style were used for the narration in the animations.

The design process was *based* on the five planes proposed by Garrett (2011), starting from the bottom and moving upward: strategy, scope, structure, skeleton and surface. The strategy plane considered the information needs of the pharmacists, physicians and main users (stakeholders). The scope plane outlined the contents of the animations in accordance with the Brazilian PILs for each type of medicine (nasal spray, inhaler, injectable and vaginal cream). When necessary, warnings were also included. The structure and skeleton planes were developed together. This was because the animations would not require navigation or interaction design as they would make use of the functionalities available in the video viewing software (e.g., QuickTime, YouTube). The structure of the animations was as follows: (1) introduction (hygiene, inventory); (2) steps; (3) closing (indication of completion of the task); (4) disposal. Finally, the surface plane provided the graphic interface of the animations. Figure 9.4 shows examples of the structures of the animations and their screens.

The procedural animations about the four types of medicines were evaluated so as to establish how easily understood and how useful they were to users. How satisfied pharmacists, physicians and users were with the design and contents of the animations was also assessed, and this is briefly discussed next.

## 9.6 USERS' AND HEALTH PROFESSIONALS' ASSESSMENT OF THE ANIMATIONS

A study was carried out to evaluate the animations. The study examined how effective the animations were in helping users to understand how the medicine should be used, and how to perform the simulated tasks for each of the medicines. The study also looked into how satisfied users, physicians and pharmacists were with the representation of the procedures in the animations. The health professionals were not required to participate in the comprehension and task performance tests, given their knowledge about medicine usage. A total of 120 participants took part in the study and were divided into two independent samples: $N = 80$ users and $N = 40$ health professionals ($N = 20$ physicians and $N = 20$ pharmacists).

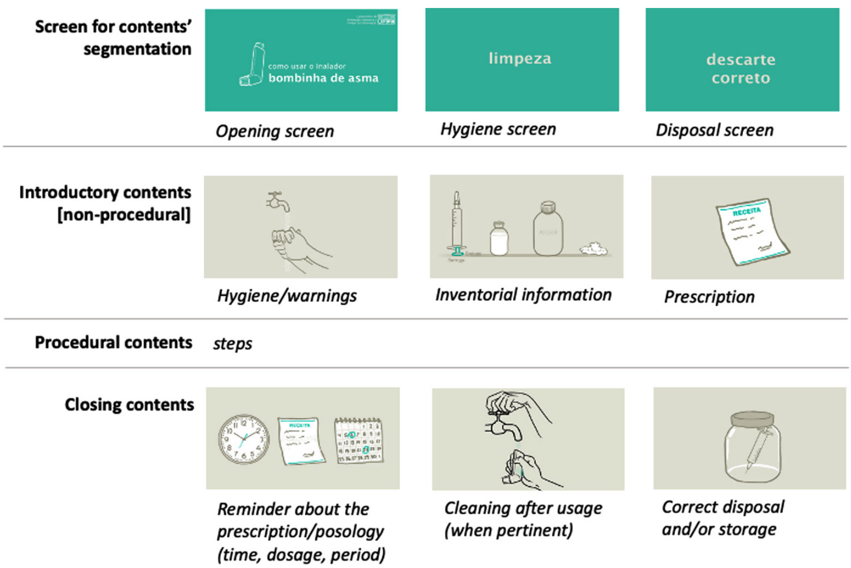



**FIGURE 9.4** Examples of the structures of the animations and their screens.

The users were equally divided into two groups: (a) comprehension test ($N$ = 40, 10 participants per animation) and (b) medicine usage-simulated task ($N$ = 40, 10 participants per animation). It is worth noting that the animation about the use of vaginal cream was assessed by female participants only, due to the nature of the task. Participants assessed the animations individually, and then took part in a semistructured interview. Due to the limited number of participants per animation, the results were analyzed qualitatively. However, figures were considered to indicate possible trends in their responses. Table 9.2 shows the distribution of participants in this study.

## 9.7 SUMMARY OF THE RESULTS OF THE STUDY WITH USERS

The overall results of the study with users indicate that most users fully or partially understood the animations about medicines usage and performed the simulated tasks satisfactorily. All 80 participants ($N$ = 40 comprehension and $N$ = 40 simulated tasks) agreed that both narration and animation helped them to understand and perform the tasks, which is in accordance with the Cognitive Theory of Multimedia Learning (Mayer, 2019, 2020).

Regarding participants' understanding of the animations, the results show that all participants ($N$ = 40) felt that they fully understood and were satisfied with the animations of how to use the medicines, suggesting a positive UX. For instance, eight out of ten participants fully understood the step "breathing through the mouth after spraying" in the animation of how to apply the nasal spray.

On the other hand, when participants were asked to explain the task represented in each animation, most participants failed to mention some of the steps. This occurred

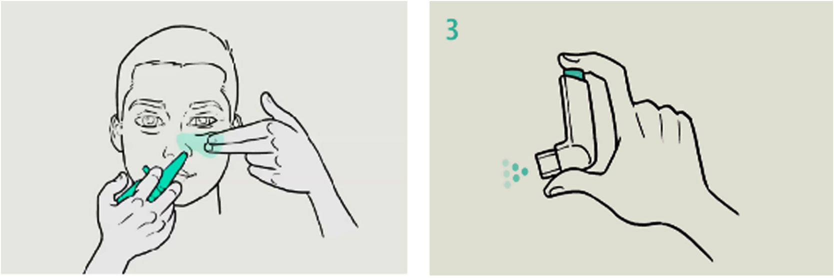
**TABLE 9.2**
**Distribution of Participants in the Studies**

| | Users | | |
|---|---|---|---|
| **Animation** | **Group (a) Understanding** | **Group (b) Simulated task** | **Total** |
| Vaginal cream | 10 | 10 | 20 |
| Insulin injection | 10 | 10 | 20 |
| Nasal spray | 10 | 10 | 20 |
| Inhaler | 10 | 10 | 20 |
| **Total** | **40** | **40** | **80** |
| | **Satisfaction** | | |
| **Animation** | **Doctors** | **Pharmacists** | **Users** |
| Vaginal cream | 05 | 05 | 20 |
| Insulin injection | 05 | 05 | 20 |
| Nasal spray | 05 | 05 | 20 |
| Inhaler | 05 | 05 | 20 |
| **Total** | **20** | **20** | **80** |

with the animation of how *to inject insulin*, where most participants did not mention the step showing the correct manner to compress the skin ($n$ = 7 out of 10 participants) or the step showing the correct angle of the syringe needle for injecting insulin ($n$ = 8 out of 10 participants). Similarly, in the animation of how to use a nasal *spray*, the steps "tightening the nasal spray bottle" and "lowering the head when spraying the medicine" were overlooked by almost all participants ($n$ = 9 out of 10). Although these results do not explain why participants omitted these steps in their responses, they seem to suggest that participants either did not fully grasp the meaning of the steps or considered the steps to be irrelevant to the task and, therefore, not worth mentioning. In either case, this would almost certainly affect participants' success in carrying out the steps.

As for the simulated tasks for using the medicines with the aid of the animations, the results show that all 40 participants completed the tasks, and that the majority carried out most of the steps correctly. Similar to the results of the comprehension study, the results also show that, although participants felt that they had successfully performed the tasks, some of them were not aware of their difficulties with certain steps.

In the simulated use of the nasal spray, nine out of the ten participants made mistakes when carrying out the following steps: shaking the bottle before using the medicine, positioning the bottle correctly so as not to touch the nose bone (Figure 9.5) and lowering the head before spraying the medicine. In the simulated use of the inhaler, most participants ($N$ = 7 out of 10) skip the following steps: shaking the inhaler bottle before using it, pressing the bottle lid to release the medicine, exhale air from the lungs before inhaling, and hold your breath for




[A] Nasal spray [B] Inhaler

**FIGURES 9.5** (a and b) Screenshots of the steps showing the angled positioning of the bottle of the nasal spray and how to press the inhaler to release the medicine.

10 seconds when inhaling (Figure 9.5). Errors also occurred in the simulated use of the insulin injection. Most participants did not measure the glucose level prior to the task ($N = 7$ out of 10). In addition, five participants did not perform the following two steps correctly: rubbing the insulin bottle in between the hands and positioning it correctly to remove the insulin with the syringe. The overall results of the follow-up interviews also show that participants did not seem to pay much attention to the hygiene procedures, or to the inventory contents presented in the animations they saw before performing the tasks, since these were not mentioned in their responses.

### 9.7.1 Understanding the Animations and Performing Simulated Tasks: Comparing the Results of the Two Studies

On the whole, participants performed better in the comprehension study than in the task performance study. This suggests that understanding an animation about medicine usage does not necessarily lead to success in task performance.

Despite these rather disappointing results in both understanding the animations study and carrying out the tasks, all 80 participants felt that they had fully understood the animations and had successfully performed the tasks. They also thought that the animations satisfactorily conveyed how to use the different medicine forms: nasal spray, insulin injection, inhaler and vaginal cream. These results indicate participants' misperception of their understanding of the animations and of their task performance, since they did not seem to be aware of the difficulties they had. Thus, it can be concluded that there seems to be a gap between understanding and performance regarding animations about medicines usage.

In addition, the fact that participants failed to mention the inventory contents and the hygiene procedures suggests that this may be due to such contents not being steps, that is, they are not procedural contents. This seems to reveal that different types of content in animations play a different role in how participants describe and understand task representations. This aspect, however, is outside the scope of this study.

## 9.8 SUMMARY OF THE RESULTS OF THE STUDY WITH PHYSICIANS AND PHARMACISTS

Overall, the results of the study with physicians and pharmacists show that there was agreement between these two groups of health professionals regarding how satisfied they were with the animations representing the use of a nasal spray, insulin injection, inhaler and vaginal cream. Physicians ($N = 20$) and pharmacists ($N = 20$) both found the animations to be simple and clear, and their content adequate to the context of usage of each medicine type. The amount and sequence of information for the tasks, the interaction features and the visualization of the steps in the animations were also considered satisfactory by these health professionals.

For three of the medicine types, namely, nasal spray, insulin injection and vaginal cream, pharmacists showed a higher level of satisfaction with the animations compared to physicians. They were more satisfied with the animation of how to use the *inhaler*. Among the aspects considered, the ease of interaction in the animations had the highest incidences in responses. On the other hand, the interest of health professionals in using animations with patients showed the lowest number of responses, although in general these were positive. These results suggest that physicians and pharmacists seem to be reluctant to employ animation to explain medicine usage to their patients, despite declaring themselves favorable to and satisfied with the animations presented to them.

Regarding how these health professionals viewed and were satisfied with each one of the animations, physicians and pharmacists differed in their opinions as no agreement was found in their responses. It is worth noting that whereas the animation of how to use an inhaler was ranked first by physicians, it was ranked last by pharmacists, who ranked first the animation about insulin injection. The reasons for those responses were not provided by the participants.

## 9.9 CONCLUSIONS AND FINAL CONSIDERATIONS

Overall, the results suggest that the participants (users and health professionals) considered their experience with the animations about the application of insulin injection and vaginal cream and the use of inhaler and nasal spray positive. To a certain extent, this aligns with Lowdermilk's thoughts (2013) about engaging experiences in the interaction with artifacts which meet users' goals. It can also be inferred that the way users and health professionals perceive and interpret their experiences—which in this study was positive despite the difficulties—is influenced by the way the contents in the animations are represented. This idea meets the instructional principles and goals mentioned earlier (Mayer, 2019, 2020). This positive perception seems to corroborate the post by Hassenzahl (2013): not only "what," but also "how" should be considered in the representation of contents, in this case, procedural animations about medicines usage.

It is noteworthy that the results of the study with users suggest that the difficulties identified in the understanding of the animations and performance of the simulated tasks did not negatively affect users' level of satisfaction with the animations. This indicates a possible correlation between satisfaction and perception of performance: an aspect which deserves further inquiry, but which is beyond the scope of the present investigation. Despite the difficulties encountered by some of the users, the results related to their understanding of the animations and their level of satisfaction with them seem to be aligned with the literature on the beneficial effects of animation on motivation and on visualization of procedures (e.g., Lowe, 2019; Spinillo, 2016).

Regarding the design of the animations about medicines usage, considerations can be made about the use of the planes proposed by Garret (2011) and the UX qualities proposed by Morville (2004). The planes of strategy, scope, structure, skeleton and surface proved to be helpful in the production of the animations, enabling the inclusion of aspects related to the stakeholders (doctors and pharmacists, and users) aligned with the design requirements for visual representation of the animations.

As for the UX qualities proposed by Morville (2004), the results of the above-mentioned study on medicines usage seem to corroborate the pertinence of these qualities to the design of procedural animation in health, particularly the quality of being "useful." Overall, participants' responses (users and health professionals) indicated that the animations were simple, and their interaction features were easy to locate, thus having the qualities of being *findable* and *usable* as a multimedia informational resource. The level of satisfaction of the participants with the visual design of the animations suggests that the animations present the quality of being *desirable*. Since the contents of the animations are from medicine inserts made available by the Ministry of Health, the animations have *credibility*. The combination of these qualities allied to participants' (mis)perception of their performance lead to infer that participants *valued* the animations about medicines usage that they saw. Nevertheless, the actual value of the animations with regard to aiding in the usage of medicines can be questioned when considering the results related to content understanding and participants' task performance. These indicated that the animations were not as *useful* as expected. The reasons why participants left out some of the steps when performing the tasks, and for the errors they made when carrying out some of the steps revealed that the animations on medicines usage were not fully understood nor did they fully support the tasks. Therefore, the *usefulness* of the animations was jeopardized. Considering this, it is reasonable to conclude that the quality of being *useful* is a key quality in the design of procedural animations, especially when they represent health-related tasks.

Moreover, the results seem to indicate that how users perceive and value their experience with procedural artifacts should be distinguished from the actual value of their task performance. This is particularly of relevance to procedures in the health area, due to the consequences these procedures have to patients' medical treatments and well-being.

To conclude, it should be highlighted that the animations about medicines usage, even those whose design meet the principles of the Cognitive Theory of Multimedia Learning and the five-plane approach to UX, posed difficulties for participants, both when understanding the animations and when carrying out some of the steps of the task. These difficulties were only identified in empirical studies with users performing tasks mediated by the animations. Accordingly, this study contributes to the literature on procedural animation by pinpointing evidence-based concerns about the effects of UX on the effectiveness of animations about medicines usage.

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# 10 Getting the Benefit from Connecting Health Apps to Complex Healthcare Systems

*Ken Eason, Adam Hoare and William Maton-Howarth*

## CONTENTS



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## 10.1 INTRODUCTION

It is estimated that there are now 325,000 digital health applications available to consumers in the UK (ORCHA 2019), supporting them in everything from exercise regimes and healthy eating to the management of every kind of health condition from diabetes to insomnia. Many of these applications are stand-alone: the consumer can use them to keep a personal check on the exercise they are taking, the calories they are consuming, etc. However, there is another class of applications that serve people who have specific medical conditions and are patients of the health services. These applications depend for their effectiveness on being connected to healthcare systems that can, for example, interpret results and provide expert guidance and care. Applications of this kind have great potential because they can provide new links for the consumer/patient to healthcare systems and render the expertise of health service professionals much more accessible. However, to develop an application that gives a good user experience of interacting with health services is a much more complex design task than the development of a stand-alone consumer product.

This chapter explores the issues to be addressed if the consumer who is a patient is to get an effective service from an application that is linked to a complex healthcare system. There is now an extensive literature that tells the troubled history of getting digital applications embedded as normal practice in health services. The history of telehealth applications is one example. Applications that enable a patient in one location to be in visual contact with clinical staff in another location have been available for many years and have been shown to be of great value to patients who may have difficulty visiting clinical professionals. However, as evaluations consistently show, it is proving very difficult to establish this kind of consultation as a normal part of health service delivery (May et al. 2003, Polisena et al. 2009) and authors such as Wyatt (2011) are left asking: "Why does telehealth fail and what can we do about it?" An extensive randomized control trial of telehealth in the UK (Steventon et al. 2012) failed to reach a definitive view observing only that there was no conclusive systemic evidence of benefits despite widespread anecdotal reporting of enormous benefit to individual patients. There are factors at work that seem to make it difficult to translate the manifest benefits of a new digital application, often demonstrated in early trials and pilots, into sustained and widespread benefits when the application is disseminated more widely in health services.

In an attempt to elucidate the barriers to the successful adoption of these applications, this chapter will review three health applications that depend for their full effectiveness on both the digital application available to the consumer/patient and on the way the application is connected to relevant health service systems. The authors have recently undertaken an evaluation of nine innovations in the English National Health Service and this included two of the case studies below (NIA 2018). The cases have been chosen to illustrate three different kinds of health applications that give rise to different but overlapping sets of issues that have to be resolved if effective and sustained services are to be delivered to patients.

## 10.2 A DIGITAL APPLICATION TO SCREEN FOR ATRIAL FIBRILLATION (AF)

The first case study is an example of a digital application that can be used as a stand-alone device that a consumer can use to monitor their own health but in this case is being used within a health service so that the results can be acted on by healthcare specialists.

### 10.2.1 The Digital Application

Many people have undetected heart problems that are only identified when they have a major problem. A particular example is that people can have undetected disruptions to their heart rhythms known as atrial fibrillation and this can lead to people having strokes. Kardia (2019) is a small, mobile digital application that enables a person to generate their own electrocardiogram (ECG) by simply pressing down on two touch pads. The system is able to analyze an ECG to detect whether there are abnormalities in heart rhythms that might indicate AF. Kardia is available as a stand-alone product and is already in extensive use by people with known heart problems who use it for regular monitoring. However, it is also possible that it could be used for more general screening: to use it for people who have no known heart condition but who might be "at risk." If early signs of AF can be detected, it should be possible to take action that would mean the person would not suffer a stroke. That would obviously provide an enormous benefit to the patient and would probably save the health service the considerable expense involved in providing long-term care for a stroke patient.

### 10.2.2 The Plan

In the southeast of England a trial was set up to use Kardia to screen people over the age of 65 for early signs of heart disease (NIA 2018). The aim was to locate the service in pharmacies that patients visit regularly to buy medicines, to seek advice on medication and to collect medicines prescribed to them by their local General Practitioners (GPs). If the patient was over 65, they would be offered a free ECG screening which was a quick and easy procedure. Figure 10.1 shows the overall plan for the service.

The plan was to undertake the ECG scan and to use the analysis process built-in to the application to assess whether the heart rhythm was normal or abnormal. The patient could be informed of the result and, where there were concerns, would be advised to go and see their General Practitioner. In the event of an anomaly being detected, the pharmacy assistant would also notify the patient's General Practitioner

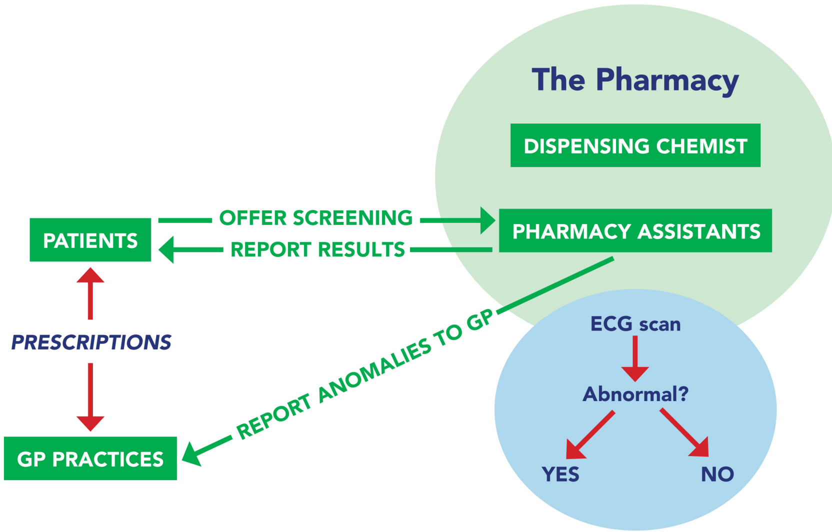


**FIGURE 10.1** ECG screening in a pharmacy.

which was normal procedure in pharmacies if they noted anything of concern about the patient's health.

### 10.2.3 The Implementation and the Result

A trial was undertaken to assess whether patients were happy to use Kardia and whether the pharmacy assistants could capture good quality ECGs that could be analyzed for anomalies. Many patients were indeed happy and willing to take part in this process but many of the ECGs were difficult to analyze and may or may not have indicated an anomaly. Changes were made to the procedure (e.g., quieter locations for the screening, more training for the pharmacy assistants) but there remained a problem in interpreting some of the ECGs. A further problem was identified when anomalies were reported to the patient's GP. Although fully supportive of the purposes of the screening, the GPs felt it was inappropriate to refer the matter of dealing with anomalies to them. They were already overstretched in dealing with an increasing patient load and they were not equipped to undertake definitive tests for heart conditions. It was likely they would not be able to see the patient urgently and, even then, they would have to refer them to the cardiologists in the local hospital to assess whether there was an incipient heart condition. The pharmacy staff were concerned on two counts: first they may be creating anxiety in the minds of the patients and, second, the delay at the GP surgery may mean the patients would have to live with the anxiety for a considerable time. Some estimates were that it might be up to 12 weeks from the time of the screening to an appointment with a cardiologist. In these circumstances, the pharmacy wondered whether they should abandon what had seemed a very beneficial service.

### 10.2.4 The Revised Plan

The project team, which included pharmacists, AF specialists and an innovation testbed, did not want to abandon this beneficial service and they embarked on a wide consultation to find a way forward. A review of the pathway by which anomalous results would be processed was undertaken and, following consultations with the cardiology department of the local hospital and the local Clinical Commissioning Group (that provides the funding for local healthcare), a new system was proposed. In the new system, the cardiology department would set up a "one-stop clinic" to receive ECG traces from Kardia for their cardiologists to review for possible AF or other heart problems. If they considered there might be a problem, they would arrange an outpatient appointment for the patient at the hospital. This plan was adopted. A new computer system was introduced that enabled the pharmacy to send the ECG traces directly to the cardiology department and, when necessary, they arranged appointments to see the patients. Twenty-one pharmacies took part in a second trial in which 672 ECG traces were captured and 110 were referred to the clinic. The clinic concluded that 74 needed no further action and that meant they invited 36 patients to come for further tests. The process was reduced from a possible 12 weeks to 2 weeks.

### 10.2.5 Discussion

This example shows clearly that it is not enough for a digital application in this setting to be able to offer a major health benefit, to be acceptable to patients and usable by the pharmacy assistants. If the goals of confirming AF and of treating the patient in question are to be achieved, an acceptable process or "pathway" in the local healthcare system is also to be created. This is a change in the "socio-technical system" (Eason 2014, Hoare 2019) by which healthcare is delivered. In this case, it required the development of a new computer system to transmit ECG traces from Kardia to the cardiology department and changes not only to the role of the pharmacy assistants but also to the cardiologists in the local hospital. It was the realization by the project team that this was not just a technical innovation but required a revision to the existing sociotechnical system that made this possible. If a substantial review had not been undertaken and a new sociotechnical plan put in place, this promising development could have become just another innovation that did not become embedded in normal practice.

## 10.3 A DIGITAL APPLICATION FOR THE MANAGEMENT OF OUTPATIENT APPOINTMENTS

Many people are now actively engaged with the convenience of ordering and managing services using mobile applications. Whether ordering takeaway food, a taxi or bidding for products in online auctions, the immediacy and interactivity of apps has been embraced by a wide cross section of the public. In the context of outpatient appointments, including the problems of "did not attends" (sometimes called DNAs) and the need to manage precious resources, it would seem that a digital app that optimized appointment bookings would bring convenience to many people and make economic sense for hospitals.

It turns out that this particular application, in its requirement to integrate systemically with current ways of working, reveals some of the fundamental challenges of interoperating technology platforms and the sociotechnical nature of such change. That is, the successful adoption of such an approach is not just a matter of overcoming the technology challenges of getting different computer-based systems to share data in a meaningful way. It also requires change in the way that staff interact with the systems and with patients using them. These challenges can be better understood through the process by which the DrDoctor platform was adopted.

### 10.3.1 The Digital Application

DrDoctor (2019) is an online and text-based service that allows patients to confirm, cancel and change outpatient clinic bookings digitally. For patients, it means they have an application that enables them to engage quickly and easily with the outpatient clinics of hospitals to manage their appointments. For hospitals, the application means they can maximize and manage patient volume to best fit their capacity. The immediacy and interactivity of being able to offer new appointments and deal quickly with cancellations means that there is much greater flexibility in setting up and filling additional clinics and canceling clinics that become non-viable. This flexibility is not available using postal approaches to communication and it reduces the resource-intensive nature of trading appointments by telephone. Such approaches are therefore beneficial for targeting long waiting lists and more flexibly managing clinic slots. In addition, it also provides the potential for digital assessments before and after appointments, saving time for both patients and caregivers.

### 10.3.2 The Plan

Contact between Guy's and St. Thomas Hospital Trust (GSTT) and DrDoctor began in 2013 when the General Manager for Women's Services in Gynecology identified the high number of missed outpatient appointments (DNAs). DrDoctor was identified as a potential solution. However, the Trust was already underway with a procurement process for a text-only appointment booking solution, and DrDoctor's functionality was broader than the procurement specification.

In 2014, the General Manager for Women's Services developed a short business case that focused on the reduction of DNAs and led to GSTT piloting DrDoctor in gynecology in 2015. A small amount of funding covered the cost of the DrDoctor service as well as paying for some IT integration. The pilot provided sufficient evidence that DrDoctor reduced DNAs to justify a broader roll out across GSTT. At the same time, the Chief Medical Officer at GSTT saw the additional potential of DrDoctor to reduce the cost of postage by replacing letters with electronic communication.

### 10.3.3 The Implementation and the Result

The Chief Medical Officer took the Senior Responsible Officer Role (SRO) for the wider deployment of DrDoctor to all outpatient departments in 2016. A project board was assembled, including the SRO, an operations lead and a finance lead. The data from the pilot was shared with the hospital general managers and they were brought into the project board as the rollout occurred across their department. Each department and IT made funds available to deploy DrDoctor. Integration with the Patient Administration System (PAS), recruitment of clinical and admin staff and training was overseen by the general managers. The process involved:

- Integration with the PAS
- Recruitment of staff to oversee and action reporting
- Recruitment of 142 super users to maintain content and system settings
- Staff training: 224 booking clerks were trained to action patient requests

The level of functionality offered by DrDoctor was directly linked to the ability to integrate the services with the PAS. Initially the sending out of texts capability of the DrDoctor system was fully deployed across the hospital.

Dental services had begun to implement the second-stage capability offering alternative appointments by text. This was due to dental services managing their own clinics and being somewhat independent of other services in the hospital. This introduced some workforce challenges as the manual system of calling patients had to be integrated with the automated alternative appointment offers. This required a two-phase approach of incorporating all automated data into the PAS before any manual calls were made.

Much was learned in the early years about the implementation of the DrDoctor service. For example, early use demonstrated the importance of the accuracy of clinic codes, consultant codes and data generally. For this reason, GSST became proficient at data cleansing and accurate management of coding. With around 750 clinic codes alone, this was a significant aspect of the smooth working of the system. This subsystem was run by the Business Support Manager—Dental Directorate in cooperation with IT.

The PAS was under review during this period and the process of replacing it would have a direct impact upon the DrDoctor deployment. Hence, the full benefits of the DrDoctor service would not be realized until a new PAS was in place and the integration had taken place. This would take several more years pushing out the realization of the full benefits of DrDoctor to 2022 or later.

### 10.3.4 Discussion

Technology platforms, when introduced into care delivery, can be particularly challenging where they are not stand-alone but are required to interoperate with current systems, be that technological or workforce. This is complicated further where impacted systems are old and may be replaced or where full functionality is dependent upon developing both ends of the interoperability capability. The DrDoctor implementation is a good example of these challenges. The old PAS was only capable of supporting the first stage (texting out) of the DrDoctor capabilities. The requirements for DrDoctor to achieve full functionality provided guidance on the potential PAS system that could replace the incumbent, older system. In the meantime, the dental service was able to increase the DrDoctor functionality to include alternative clinic slots offered by text through developing the workforce to provide some of the interoperability as a manual function tied into the regular clinic management activity.

Two things are critical in being able to go on this journey:

1. That the management and resource commitment of the customer is long-term enough for the solution to evolve in terms of impact on current systems and work practices.
2. That the technology supplier is prepared to develop their offer and provide support for the staged approach which may include work on intermediate interoperability fixes.

In Section 10.5, we develop a "lock and key" model to describe the way a new technological intervention (the "key") has to engage with the current sociotechnical system (the "lock"). In this case, the intervention (DrDoctor) was not able, initially, to deliver all of its capability within the current context of the customer (GSTT in this case). DrDoctor is a "key" that is trying to fit into the "lock" of the GSTT context. To get the full benefit of the new technology, both the "key" and the "lock" need to change through a process of mutual adaptation. In this case, the adaptation of the GSTT context, notably changing the PAS, could not be done quickly and so the early use of DrDoctor was limited to "texting out" for most outpatient departments. Dental services were able to use more of the functionality of DrDoctor because it did not rely on the existing PAS, but in order to accommodate DrDoctor it had to make changes to the roles of the clinic staff and to the processes of clinic management. However, over time the goal remains to have DrDoctor fit exactly the context provided by GSTT such that the optimal functionality can be adopted. The adaptation process is not purely technological, as indicated by the changes to practice in the dental services clinic management. This model of engagement is very different to the idea of buying an "off-the-shelf solution" that works in all contexts and is plug-and-play.

There are two other factors that affected the mutual adaptation between the "key" (intervention) and the "lock" (the sociotechnical context):

1. *Push factors*: These are efforts by the technology supplier to make the key better fit the "lock."
2. *Pull factors*: These are efforts by the customer (GSTT) to adopt and engage with the "key."

In the context of DrDoctor and GSTT, these factors were critical to the level of success achieved:

- *Push factors*: DrDoctor staff took offices close to GSST in the early days of the adoption. The location of DrDoctor staff near to GSST assisted in ensuring that any problems encountered were addressed rapidly with staff available on-site. DrDoctor staff then engaged with the staged approach to interoperability with the current PAS recognizing the need to accommodate a future PAS. They focused on the long-term outcomes sought rather than the delivery of a specified technological implementation.

  DrDoctor also created a bespoke training regime for each of the different operational roles in GSST that would be affected by the implementation. Each person was trained in a series of practical sessions run by the DrDoctor team, where the departments were not only shown how to use the software but how to align their processes with the new system. During the go-live process, "super users," i.e., people in GSST already trained and working in the new way, managed the transition to DrDoctor. Weekly team meetings were held to feedback on progress and early benefits. By 2019, discussions were underway for the DrDoctor applications to develop different reports for different operational roles in order for clinic development management as well as resource management to be greatly improved.
- *Pull factors*: One of the key enablers was the cooperation between DrDoctor and lead champions within GSST in collaborating on the embedding of the technology. This required cooperation with the senior, clinical, operational and IT functions. This required several people to act as advocates for the service, primarily the Chief Medical Officer, the Program Director (Digital Patient Journey) and the Deputy General Manager (Dental Directorate). Without this advocacy within the customer, the approach would have lacked commitment and inevitably withered on the vine.

  The other key pull factor is that the lead champions and other key people in the hospital accepted the need to evolve the solution and engage with a long-term collaboration.

## 10.4 A DIGITAL SYSTEM TO DELIVER GENERAL PRACTITIONER SERVICES

One way in which the suppliers of digital applications can overcome the challenges of interfacing with the existing sociotechnical systems of current services is to bypass them, i.e., not just provide a technical solution but offer customers a completely new service that is based on new technical opportunities. This is the big "disruption" strategy favored by many in Silicon Valley, for example, Amazon disrupts the high street model of the retail trade by offering online retailing services and Uber offers a completely different taxi service. The two digital innovations described above are to some extent disruptive of existing services but in a major disruption approach, the technology developer creates a complete new service that constitutes radical competition to existing services. If it offers a complete service in which the digital application is an integral part, the technology supplier has an opportunity to design all the connections between the application, the social system and other forms of technology itself. It does not have to deal with the inertia caused by having to change existing systems.

### 10.4.1 A Disruption Approach to General Practice Services

The long history of trying to establish digital consultations between GPs and their patients was described in the introduction to this chapter. Although some progress has been made, it has proved very difficult to integrate telehealth conversations between doctors and patients into the daily procedures of General Practice clinics that are primarily based on face-to-face consultations. One way of making faster progress is to offer a new approach to General Practice. In this case, it would be a General Practitioner service in which digital consultations are the norm and face-to-face consultations are only resorted to when necessary. The third case study to be discussed has taken this approach.

### 10.4.2 The Digital Application

Babylon's "GP at Hand" service (2019) replaces the traditional GP service in which patients visit their local GP clinics for face-to-face consultations with a service in which they first book a video consultation with a doctor. A video or audio consultation then takes place within an hour or two of the booking. In most instances, this is sufficient for the patient to be given appropriate medical advice but, if it is necessary, arrangements can be made for the patient to have a face-to-face consultation with a doctor at a later date. The patient can access the "GP at Hand" application via their smartphone and it is available at all hours. It also offers other features such as a symptom checker that in many instances may provide sufficient advice so that even a video consultation is unnecessary.

### 10.4.3 The Implementation Plan

The "GP at Hand" service was launched in London in 2017. Although different in approach to normal GP practices, it was funded by the National Health Service through the Clinical Commissioning Group in the Borough of Hammersmith, which is the body responsible for funding GP services in that area. The majority of the funding for a GP service is per capita: a fixed sum of money is provided for each patient registered for the service. To use the new service, patients had to deregister from their existing GP practice and register with "GP at Hand."

### 10.4.4 The Implementation and the Result

An evaluation of the service in 2019 (Ipsos-MORI 2019) reported a very rapid take-up of the service. The service had 49,000 registered patients by April 2019 and was adding new patients at a rate of 500–1000 per month. It had also contracted a large workforce of qualified GPs who were attracted by the flexibility of the job: they could work part-time from home and choose the hours they worked. The evaluation showed that the service was very popular with commuters who traveled to London each day and who found it difficult to attend GP clinics near their homes during the working day. They found that, using “GP at Hand,” they could get appointments very quickly and conveniently compared with the GP appointment procedures they had been used to. Although most contacts with the service led to video consultations, many patients used the symptom checker or made an audio-only appointment.

The rapid growth of the service was not, however, without problems. On many occasions the first consultation revealed the need for a face-to-face consultation and “GP at Hand” established five locations across the London area where patients could be seen by a GP. However, patients found getting an appointment was much slower than for the initial consultation and it was often inconvenient to get to the location for the face-to-face appointment. Many patients who had conditions that required face-to-face appointments concluded they were better served by the traditional GP service and 1 in 4 of the patients who had registered since July 2017 had de-registered by April 2019.

But a much bigger problem was the disruptive impact the new service was having on the traditional GP services in the London area. Patients were being recruited by “GP at Hand” from 29 GP services across London and these services found they were losing patients who were mostly young, well, working-age commuters. These were patients that GPs tended not to see very frequently and who made very limited demands on their services. The per capita basis of payment to GPs means that they rely on having a large number of their registered patients of this kind. They make few demands on the service and this compensates for the high demand made by the old, the very young and those with long-term conditions. The loss of many of the “working-age well” patients disrupted the financial base of the service: the workload stayed high but the income decreased. Because of this disruption, there have been calls (Downey 2019a) for “GP at Hand” to be refused a license to offer General Practitioner services. The company has plans to extend its operations to other major English cities such as Birmingham and Manchester and the authorities in these cities are looking carefully at the results in London in assessing whether to approve these developments. In Manchester, for example, there are also concerns that the new service may not be able to offer patients effective links into other health services such as cancer screening. A Manchester health authority spokesman (Downey 2019b) reported:

> We are not convinced that Babylon’s GP at Hand model of care is sufficiently integrated with other local and national services to ensure safe and effective care for local people. Areas of concern include screening programs and safeguarding.

### 10.4.5 Discussion

By going beyond being a technology supplier and offering new customer services based on digital technology, “GP at Hand” has been able to avoid the immediate problems of integrating the technology with the existing sociotechnical systems in

GP practices. It has control over the social system, e.g., the roles the GPs play, other technical systems such as the appointment booking system and the process by which patients are provided with healthcare. All these aspects of the service can be integrated with the video system. However, the new service still has to interface with the larger healthcare system that it is part of and problems are emerging on many fronts as experience of its operation grows. For patients, there are problems when they need face-to-face consultations, for other GP practices there are threats to their business model and for the authorities concerned with the integration of health services for patients, there are concerns about how integration can work with a "GP at Hand" type of service. In systems terms, it seems that delivering a service rather than just new technology can avoid local sociotechnical system integration problems, in an open system such as national healthcare, there will be interfaces with the larger system that will still have to be addressed. It is instructive that there is no evidence that these issues were recognized or addressed in the initial design of the new service: for many of the stakeholders, be they patients or existing GP practices, they only become apparent once there is evidence of the service in operation.

## 10.5 THE ADOPTION OF DIGITAL APPLICATIONS AS EVOLUTIONARY SOCIOTECHNICAL SYSTEMS CHANGE

All three of the case studies are success stories to the extent that they are on a path toward embedding digital innovations into normal healthcare provision. However, in every case, there have been complex challenges to address to create an effective link between the new technology and the existing healthcare system. In this section, we review the nature of these challenges and explore the design methods by which they may be met.

### 10.5.1 The Challenges

A first target for technical design is to ensure that the direct user experience is positive and effective. However, when the new digital technology can only be effective if integrated into the existing complex health service system, there are many challenges that go well beyond the design of effective interaction between end users and the new technology. The overall sociotechnical systems challenge is that it may be necessary for the new technology to work with the existing technical systems in the health systems, for changes to be made in the social systems, e.g., changes in the work roles of people in the health services, and adjustments to be made to the processes or pathways by which work gets done. If these adjustments are not made, it is quite likely that, at worse, the new technology will not be adopted or, at best, only the features that are easy to assimilate without making changes in the existing system will be adopted.

The problems of integrating the new technology with the existing sociotechnical system can be avoided if a complete new system is designed as illustrated by the development of "GP at Hand." However, it will still have to deal with the interfaces it requires with existing systems. In a highly regulated large-scale and complex system such as a national health service, that is likely to create many obstacles to the widespread adoption of a radically new system.

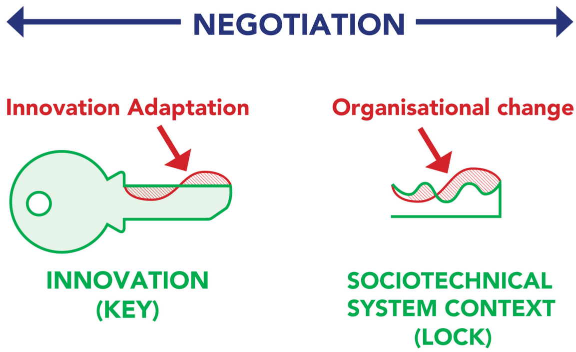


**FIGURE 10.2** The lock and the key.

It is likely that most digital health applications will be adopted into existing healthcare settings as in the first two cases described above. As in these cases, successful adoption will depend upon how the interfaces between the new technology and the existing local sociotechnical system are managed. The process can be likened, as in Figure 10.2, to a "key" (the digital application) being fitted into a "lock" (the existing sociotechnical system). Initially the fit is not likely to be very good and modifications may be needed both to the "key" and the "lock" before the "key can be turned," adoption can take place and the benefits for the patient realized.

Achieving a good fit between the "key" and the "lock" involves a number of specific challenges:

- The "key" will have to be sufficiently flexible to be shaped to the needs of each application setting. While the "lock" will also need to change to accommodate the "key," it is not realistic to expect all the necessary accommodation to come from an existing system which is charged with the ongoing need to deliver care to patients. It will need to remain a viable system capable of the continuous delivery of care through any period of change and significant changes in the short term may well be too disruptive to contemplate. There will have to be mutual accommodation of changes to both the "key" and the "lock" or what sociotechnical theorists have called "joint optimization" (Herbst 1974).
- A significant challenge is the creation of a design team capable of achieving a good fit between the "key" and the "lock." It is likely that the technology supplier will provide experts who are very familiar with the technical capabilities of the "key" but they are unlikely to have detailed knowledge of the specifics of the "lock" and most certainly will not have the sense of ownership of the "lock" that the people responsible for the daily delivery of care in the existing system will have. Those who do understand the "lock," the local stakeholders, will in contrast not have detailed knowledge of the "key." Some form of user-centered design that is a partnership between

those who understand the technology and those who understand the existing systems will be necessary. Achieving a successful partnership is made all the more difficult by the fact that many of the significant stakeholders in the existing system are often very busy with their “day job” and have little time to address the challenge of implementing new technology.

- Another challenge is that it is often not initially apparent, even to the stakeholders in the existing systems, what the ramifications for the existing systems of implementing the new technology might be. The impact on direct users of the new technology might be obvious but, because the impact is on a system, there are likely to be indirect impacts elsewhere. In the case of the adoption of Kardia, for example, the impact on the jobs of the pharmacy assistants was clear but not the impact on the workload of neighboring GP practices who would have to deal with referrals. Identifying where there might be direct and indirect impacts is a precursor to undertaking design work on the “key” and the “lock.”
- A further significant challenge is that while the “key” may remain the same from one application to another, the “lock” changes on each occasion. The design challenge will be different because the local sociotechnical system will have different characteristics in each case. Furthermore, the people who own the “lock” (the local stakeholders) will also be different on each occasion and will come fresh to understanding the “key” and what needs to be done to achieve a good fit with their “lock.” There is always a strong desire to solve the problems of implementation in early pilots and then to “roll out” the new technology to lots of other sites, the assumption being that they will all need the same solution. However, as Tapscott (1982) put it in his second law of office automation:

> The ease of a pilot implementation is inversely related to the complexity of its operational extension.

In practice, each new implementation represents a new sociotechnical design challenge.

Given these significant challenges, it is perhaps less surprising that many digital health applications have struggled to become widely adopted.

### 10.5.2 Meeting the Challenges

Our conclusion from these case studies and many others is that in order to meet these challenges, the process by which a digital application is implemented in a health service setting needs a number of properties.

#### 10.5.2.1 Flexibility in the Digital Application to Meet the Challenge of a Changing Sociotechnical System

We have already referred to the “lock and the key” metaphor for the sociotechnical system context and the intervention. It is important to consider the features of both the "lock" and the "key" in a broader context to better understand how to meet the challenges of technology adoption in specific contexts and across different settings.

The "Lock" (the current sociotechnical system context) is a complex mix of:

- current technology that is being used,
- the workforce deployment into operational work roles and their skills and capabilities,
- current work processes (e.g., "patient pathways" in health services) and healthcare practices,
- pressures for change from other sources, e.g., new regulations, local and national guidance, resources, tendering and procurement.

This means that the "lock" of today is an open system subject to a wide variety of influences and that it will be a different "lock" tomorrow because it is subject to many other pressures to change. It can be argued that the "lock" is never a stable component of any intervention as it is always subject to internal and external organizational factors that are constantly changing. The implication is that the search for accommodation between the "lock" and the "key" has to meet the requirements of the current "lock" and the solution has to be sufficiently flexible to be able to adapt to changes in the future.

The "Key" (the intervention) must therefore adapt to the current sociotechnical systems context and provide useful outcomes that evolve by improving its fit with the "lock." This may include meeting interoperability challenges that exhibit much more complexity than that of the initial requirement to enable the technological exchange of data between systems. The quality, completeness and meaning of the data can be significant factors determining whether different systems are able to utilize data to improve outcomes. Data cleansing is often the term used to indicate the significant work needed to make sure that data is current, accurate and complete. Technological interoperability reflects the ability for systems to communicate with each other. In the GSTT case, the older PAS was able to "write out" files of clinic data but could not import data (without significant modification) other than by manual entry. Hence, the ability to fully integrate with DrDoctor was compromised. This led to a sociotechnical solution that automated outgoing data but required manual entry of incoming data. Technological interoperability can introduce many challenges if it is limited in its ability to exchange data and also in its ability to ensure that, when connections are unavailable, the sociotechnical system recovers elegantly and does not lose data. Finally, we have also seen cases where the connection of the same record-keeping system across separate geographical regions has revealed that identical events or conditions are coded differently. Similarly, the use of free text fields can result in variations in custom and use that makes a joined-up system challenging. These challenges are often referred to as semantic interoperability. The intervention therefore, requires flexibility of approach over time to evolve the fit of the intervention with the sociotechnical context.

#### 10.5.2.2 A Multidisciplinary Design Team

To create a good fit between the “key” and the “lock” will require the expertise and motivation of a joint team of technology suppliers and local people from the existing service. Not only do they bring complementary knowledge and expertise, but they also bring different but essential motivation to the design task. The technology suppliers provide the “push,” the desire to see the application successfully implemented, and the local stakeholders need to supply the “pull”: the energy within the existing service to find an appropriate way of gaining the benefits from the application. If we assume that the technical team is a relatively stable group that stays the same from application to application, then the main question is: “who is involved from within the existing service?” There is a widely held belief that what is needed is a “champion,” someone with some authority who can convince colleagues of the value of the application and mobilize them to get it embedded in the existing system. The evidence from the case studies and from other cases makes clear that to deal with all the potential sociotechnical issues that can arise may need many more than one champion. Many different stakeholder groups may be affected by the development, with some of them acting as gatekeepers on the progress of the intervention. This has led to the idea of “gateholders” (Hoare 2019) rather than stakeholders. Gateholders are people who must be active and positively engaged in the intervention in order for it to succeed. Identifying and managing gateholders is a key aspect of overcoming the systemic issues of complex interventions. In the Kardia case, for example, when it was appreciated that a new pathway was required to process people with suspected AF, the team that designed the new pathway included technologists, pharmacists, cardiologists, GPs and commissioners. In the case of DrDoctor, the team that managed the implementation at GSST included over time the Chief Medical Officer, the Program Director, IT staff, the managers of the Dental Directorate and the managers of other outpatient departments as the implementation reached them. Complex interventions require a clear understanding of the impact of the intervention on a range of stakeholder groups and exploration of what they require in order to engage positively with the change.

#### 10.5.2.3 An Evolutionary Approach

There is a long history in project management of preplanning: of creating a linear program of activities at the outset of a project that is then executed to achieve the desired result. Such an approach will not be effective in the search for a fit between the “key” and the “lock.” This will be an uncertain and exploratory process for most of the people involved: they will not know at the outset what problems, what opportunities and what barriers they might encounter and they will need a design process that is much more evolutionary. It will need to be an iterative process that takes a step forward, reviews progress and then determines the next step forward. It also needs to be a learning process for both the gateholders in the existing sociotechnical system and the technology suppliers. There are well-developed methodologies that take this approach to systems change. Developmental evaluation (Patton 2010), for example, is an approach used in major social systems change programs that work through cycles of implementation, evaluation and review to move toward the implementation of sustainable change. Action research (McNiff and Whitehead 2006) in a similar way involves cycles of action followed by research to gather evidence of the result of the action followed by review and learning followed by a further round of action based on what has been learned. Following a process of this kind, the technology suppliers and the gateholders could explore the space between the digital application and the existing system to seek out the best fit between the "key" and the "lock."

A particular problem for a team that is seeking to adapt the "key" and the "lock" is that many of the problems identified in the adaptation process are not obvious until an attempt is made to change them. In the "GP at Hand" case, for example, it was only after the service had been operating for some time that many of the issues for the wider health service became evident. These discoveries are akin to repeatedly finding weak links in a chain, a process explored in the "theory of constraints" (Goldratt 1999). It is not possible to chart a path in advance from the current status to the solution desired unless these constraints are understood. Project management approaches that assume a linear path to the solution cannot do this and some form of iterative process is necessary to discover these issues and take account of them in solution delivery.

Hoare (2019) describes the process of mutual adaptation of the "key" and the "lock" as a set of activities based on a series of assumptions:

- The process is based on an action research approach that seeks to understand through iteration.
- Rather than taking a reductionist approach to breaking up the problem, the action research process engages with complexity by mapping the context of the intervention through gateholder groups and system levels (understanding the "lock") and evolving the intervention as a negotiation (the "key").
- Gateholder engagement and delivery of systemic outcomes occur through a theory of constraints-type approach to building engagement and lowering barriers to use.
- A developmental approach to evaluation is built into the approach which accepts that the final intervention cannot be fully understood up front.
- Purposeful program theory (Funnell and Rogers 2011) based on a theory of change and a theory of action provides guidance on "what" is being changed and "how" that change is implemented.

It is most likely that, following this process, the impact on the existing system will also be evolutionary. As in the example of DrDoctor, some parts of the existing system may adopt the new digital application before others. The full realization of the capabilities of the intervention may evolve through intermediate stages that deliver partial benefits. This evolutionary approach also has the advantage that it gives the wider stakeholder community time to adjust to the opportunities created by the new technology and to consider the more major sociotechnical changes that may be necessary to get the full benefit of the technological potential.

#### 10.5.2.4 The Tools for the Job

The technology suppliers may come to the development with many tools to help them tailor the application and get it up and running in the existing system. But what tools are available to help them and the internal gateholders play their part in the development of new sociotechnical systems? There are relatively few tools "ready to hand" to help these teams engage in the search for new sociotechnical system design solutions. Many of the approaches referred to above provide methods that can be adopted for these purposes, e.g., action research and the theory of constraints. There are also many techniques that can be borrowed from related domains, for example, from the evaluation literature. Realistic Evaluation (Pawson and Tilley 1997), for example, follows the impact of a change wherever it goes in an existing system. Similarly, there are concepts in the literature on implementation science that are directly relevant, for example, Normalization Process Theory (NPT) (May and Finch 2009) that identifies the process by which an innovation can become embedded in the normal practice of an existing system. What is needed is a program to convert these approaches into practical tools for technology developers and gateholders to use as normal design practice.

There are methods that are specifically for designing sociotechnical systems, although most of these are for circumstances where the starting point is explicitly to create a new sociotechnical system, for example, Mumford (2000). In most of the cases where a new digital health application is being implemented, there is probably no initial expectation that sociotechnical change will be necessary and so techniques that help identify the extent to which there are sociotechnical issues to be addressed may be more helpful. One of the perennial problems is that there are unexpected consequences when a change is made that become barriers to development and there is a need to be able to identify these "weak links in the chain" as early as possible in the development process. In this context, we have developed a Planning for Change Framework (PfCF) (Eason and Maton-Howarth 2020) which helps people in gateholder roles make an early assessment of the impact of a proposed change on the local existing sociotechnical system, i.e., the work roles of existing staff, the other technical tools they use and the processes by which they engage with one another to get work done.

#### 10.5.2.5 Passing on the Learning

How can the learning from one implementation of a digital health application best be conveyed to those responsible for the implementation of that application in a different location? The assumption may be that the design solution adopted in the first location can be applied directly in the second and this is often where wider dissemination can go wrong because the existing system in the new location may be different in important respects. It may be more important to pass on to the gateholders in the second location, learning about the issues that need addressing and the design processes that are necessary to achieve successful adoption, i.e., not the solutions but the process by which a fit between the "key" and the "lock" may be found.

In most circumstances, it is the team of the technology supplier that carry the learning from one implementation to another: they are usually the only common factor in the move from one location to another. However, as technology specialists, they may not be the ideal people to convey information about sociotechnical issues. It may be better if the new gateholders could meet the old gateholders and hear from them directly what they have learned. One way in which this might be done is by creating a user community forum in which the people who use an application can get together and share their learning about how best to get the benefit from it.

## 10.6 CONCLUSION

Many promising digital healthcare applications fail when they are used within the context of existing health services. The three cases described demonstrate why achieving success in this context can be difficult and what needs to be done to make progress. When the adoption of digital health applications involves engagement with an existing health service, the issues that need to be addressed go well beyond the technical. The cases show that to adopt the health application in a way that achieves its potential benefit, there may be many sociotechnical issues to address that involve changing both the existing sociotechnical system that delivers the health service and the new health technology application. The metaphor of a "lock" and a "key" conveys the sense of interdependence between the two: unless the health application can be embedded in the normal practice of the service delivering system, it is unlikely to achieve its promised benefits. The three cases described reveal the issues involved in seeking a fit between the existing system and the new opportunity in different ways. In the case of the use of Kardia, the "lock" had to be redesigned to cope with a new source of referrals for cardiological diagnosis. In the case of DrDoctor, only a limited part of its functionality could be used initially because of the changes that were necessary to existing systems to provide full interoperability. In the case of GP at Hand, the design of a totally new service avoided any requirement to integrate new technology with existing sociotechnical systems but experience of use has revealed many more strategic issues when the new service impacted upon the existing national health services with which it has to integrate.

In order to achieve a good fit between the new technology and the receiving sociotechnical system, there is a need, first, for flexibility in the technology and in the existing sociotechnical system so that an accommodation can be found. Second, to identify an appropriate accommodation, a design team has to be assembled that includes technical experts and gateholders who can work on sociotechnical issues on behalf of all of the stakeholders who are interested parties in the development. Third, the process by which the design team work toward solutions will need to involve exploration and learning and we need evolutionary models of change to enable these developments. Fourth, we need tools that are specifically designed for this purpose. There are few readily to hand but there are approaches in the wider literature of organizational change, evaluation and implementation that can be utilized for this purpose and can help to realize the potential of these applications. The challenge for future implementations of digital applications in healthcare services is to offer the multidisciplinary teams who find themselves, often to their surprise, engaged in the iterative development of new sociotechnical solutions a practical toolset to support their work.

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# *Section 3*

## *Usability and UX in the Built Environment*

# 11 Usability and User Experience of the Built Environment
## *Concepts, Methods and Techniques*

*Ermínia Attaianese and Thaisa Sampaio Sarmento*

**CONTENTS**



## 11.1 INTRODUCTION

Usability studies started in the 1950s, emerging from diverse backgrounds, and were widely known in relation to applications within product design, information technology and human-computer interaction. Buildings are built for a purpose, and depending on how well they serve their purpose, they contribute to usability criteria: they may express their usability for users. Usability is measured based on three basic parameters: effectiveness, efficiency and satisfaction (Blakstad et al., 2008; Fenker, 2008; Alexander, 2008). Usability depends on how a product can be used by specified users to achieve specified goals; in this way, usability is a process that can only be understood as a social construction (Fenker, 2008). Hence, usability evaluation is

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connected to user experience and their feedback about the environment design and context of use (Chamorro-Koc, 2007). Usability theory considers that user friendliness, functionality and universal design of the system, buildings or products meet user requirements and expectations in order to offer supportive design for all people. Referred to the built environment, usability studies started as the facilities management (FM) field with the concept of responsibility of the facility manager to fulfill the demand of stakeholders by knowing the action and feedback from users experience to building in use. Consequently, FM related to improvement of surroundings, people and spatial relationships, social, functional aspects, environment and economic (Jensen, 2010; Pheng, 1996).

An important step on usability definition about built environment was done from 2003 to 2006, when an international team of researchers, International Council for Building Research and Documentation (CIB TG51), investigated the application of concepts of usability in order to provide a better understanding of the user experience of buildings. The task group comprised research-based partners from France, Norway, Sweden, the UK and Finland. The results were published as a CIB report—Usability of Workplaces 2005 (CIB, 2006). This report highlights basic principles for a better understanding of not only this concept to be useful in evaluation of in-use buildings, but also what might be relevant knowledge to include usability in the briefing process of building design.

The other two later reports—The Workshop W111: Usability of Workplaces 2 (CIB, 2008) and Usability of Workplace 3 (CIB, 2010)—developed that principles, presenting practical examples of application.

The definition of usability in ISO 9241-210 is as follows:

> Extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.

Gehl (2010) calls for a reflection about humanity's actual moment. It is the first time in history that most of the global population live in urban spaces. All around the world, cities are rapidly increasing and this will be continued for many years. He emphasized that the future's key is a focus on people's needs and how they are using their cities. To architects and urban planners, it is an opportunity to think about including users' opinion about usability of built environment they live on, and how accessible and socially sustainable are cities and buildings to support human activities.

Some questions are essential for our reflection: how usability concepts are applied to the contemporary built environment? Are architects and urban planners prepared to connect usability concepts of the built environment to people's diversity, needs and desires, considering beyond population aging?

More recently, the need to introduce user experience in the design field emerged (Law et al., 2009). The definition of user experience in ISO 9241-210 is as follows:

> A person's perceptions and responses that result from the use and/or anticipated use of a product, system or service.

User experience (UX) is a relatively new concept popularized by Don Norman in 1999 (Hassenzahl & Tractinsky, 2006). Naumann et al. (2009) explain that a growing and large interest in user experience has developed (Forlizzi & Battarbee, 2004) and the term UX has been increasingly used in the relevant design literature. Although user experience is by now a common expression among HCI researchers, it is used in various meanings and a shared definition is still under construction. The ISO definition suggests measures of user experience are like measures of satisfaction in usability (Bevan, 2008). Both suggest that usability or user experience can be measured during or after the use of a product, system or service.

A person's "perceptions and responses" in the definition of user experience are like the concept of satisfaction in usability. From this perspective, Bevan (2008) considered that measures of user experience can be compassed within the three-component model of usability, particularly when the experience is task related.

A shortcoming of both definitions is that they are not explicitly concerned with time. Just as the ISO 9241-11 definition of usability has nothing to say about learnability (where usability changes over time), the ISO 9241-210 definition of user experience has also nothing to say about the way user experience evolves from expectation, through actual interaction, to a total experience that includes reflection on the experience (Roto, 2008).

In this way, other questions need to be done: in built environment field, how can we make connection between usability and user experience concepts, in a way to consider different categories of buildings, different human perceptions and their reflection on living/using that built experience along time? What are the contemporary potentialities in architectural user-centered design for sustainable living and working places for all?

This chapter proposes a theoretical study about the evolution of both usability and user experience (UX) concepts and methods in order to elaborate a framework focused on user (person)-centered building design and evaluation. Moreover, this chapter aims to demonstrate that usability concepts are not only delimited to products or artifacts design but are also useful to architect's technical domain that should apply them to architectural and urban design, as a way to obtain more suitable spaces for all.

## 11.2 THE EVOLUTION OF THE CONCEPT OF USABILITY/UX APPLIED TO THE BUILT ENVIRONMENT

The concepts of usability and user experience applied to the built environment come from studies started between the end of the 19th and early 20th centuries, mainly led by Alexander (2008). Over the last two decades, these concepts have been strengthened, as a consequence of the increase of theoretical and practical research aimed at evaluating and understanding the built environment focused on usability main principles of efficiency, efficacy and satisfaction.

### 11.2.1 Usability Concepts for the Built Environment Field

A CIB working commission on usability of workplaces has operated as an integrated network of researchers and practitioners since its inception in 2001. The first CIB report was published as CIB Report 306, and it synthesized exploratory case studies between 2002 and 2005, sought to investigate the applicability of usability concepts and techniques, adapt them for use in the built environment and to identify methods and tools that would enable a more positive user experience in organizational settings.

The second CIB report was published as CIB Report 316, which included three case studies done between 2006 and 2008, five workshops and a final research seminar. The work that comprised this stage of the project focused on contextual issues that were seen to define the difference in applying usability to the built environment as opposed to other consumer products.

The third CIB report was published as CIB W111, and it is the basis for a theoretical and methodological conception about usability of the built environment. It is the third phase of a complete international research about usability of the built environment, led by Alexander, and focused on usability of learning environments. This report structure is divided into three parts: the first part defines main concepts; the second part describes usability methods and tools; the third part describes the usability managing.

The following are the main explanations in the studies about usability of the built environment:

- Usability is "the extent to which a system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-11).
- Usability is one of the most important, but most often neglected, aspects of building performance (Alexander, 2006).
- Usability focuses on specified users who use a product (the building) to achieve specified goals and on the importance of context (the relationship between building and users) (Vischer, 2008).
- Usability, or the use value, depends on both the physical environment and how the environment is used (Blakstad et al., 2010). So, any evaluation of usability will thus depend on the context, the use, the properties of the building and finally the user's experiences and satisfaction.
- Usability studies are a cultural phenomenon from understanding user's experience (Harun et al., 2011). It is a part of human behavior activities and reaction study or to value the end user's satisfaction.
- It is focused on user perception and on the easiness and efficient usage of facilities—the workplace (Ghani et al., 2016; Alexander, 2006). It can be a tool to evaluate building which requires the total participation of user, and their experiences are incorporated in it.

A building's true purpose is to support and shelter its users while they are performing their activities and living their lives. Depending on how well building supports the users' activities, our physical surroundings contribute to efficiency, effectiveness and satisfaction in the user organizations (Blakstad et al., 2010). On the other hand, building users' behavior is influenced by the space they occupy, by their feelings, intentions, attitudes and expectations as well as by the social context in which they are participating (Vischer, 2008). Both points of view suggested the need of establishing building assessments as a scientific process, precisely maintained by consolidated techniques and methods.

Built environment methods first evolved in the last decade of the 20th century, with researches of Davis et al. (1993) and Preiser et al. (1988). Davis et al. (1993) developed the Serviceability Tool, one of the most widespread practical and theoretical frameworks for the appraisal of building performance (Alexander, 2006). This evaluation distinguishes between performance (actual behavior in service) and serviceability (capability of performing as required). Preiser et al. (1988) and Preiser (2003) defined a post-occupancy evaluation (POE) as the process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied.

During the last decades, POE studies had hugely increased, focusing on physical, technical and psychosocial evaluations. POE and serviceability tools were the first two competing methods to evaluate and rate buildings in relation to the intended use (Alexander, 2006). They focused on both observing and measuring certain physical aspects of the building or the facility and evaluate that in relation to the intended or actual use.

In ISO 9241-11, three factors are described that determine usability: effectiveness (ability to deliver a certain desired effect), efficiency (allows ease of performance with little use of resources) and satisfaction (about users feeling, attitudes and effects). Functionality alone does not make a certain artifact usable, because it also depends on the situation in which the artifact is used, the context the artifact is designed and used and the values of the designers and users. Both context and values change with time, place and cultural conditions, so these aspects are very difficult to be quantitatively measured.

For Bevan (2008), typical usability concerns include the following:

1. Designing and evaluating overall effectiveness and efficiency
2. Designing and evaluating user comfort and satisfaction
3. Designing to make the product easy to use, and evaluating the product in order to identify and fix usability problems
4. When relevant, the temporal aspect leads to a concern for learnability

Afacan and Erbug (2009) studied universal usability and pointed out that people's abilities change over time, and they want to be accommodated within the built environment as efficiently, effectively and satisfactorily as possible, regardless of their health conditions, body size, strength, experience, mobility power or age. In the meantime, they want to expend low physical effort and have security, safety and simplicity (The Center for Universal Design, 1997). In this respect, universal usability in architectural terms is concerned with making buildings and facilities as universally usable as possible for everyone, rather than for the vast majority of a target population. Reviewing the literature on universal design indicates that no recommendations exist in the architectural design context as to how universal usability can be incorporated and implemented to identify, minimize and solve usability problems that can occur during any phase of the design process.

For Bittencourt et al. (2015), usability is inserted into different contexts, first as sociopolitical issues, trade and production quality standards, consumer satisfaction and responsibility of the supplier, and second as the user interaction with desktop environments, education, health, leisure and community and technological context (Nicholls and Boueri Filho, 2001).

### 11.2.2 User Experience Concepts for the Built Environment Field

Although literature review considers significant differences between usability and user experience, these concepts are so close that it needs to be more clearly defined. Naumann et al. (2009) studied people's perception about the differences between usability and user experience. They interviewed around 166 persons, and results showed that the most preferred techniques for both usability and user experience evaluation methods were interviews and questionnaires, to design better products (from 48.5% to 67.7% of respondents). People mostly associated usability concept with these five criteria: efficiency, ease of use, effectiveness, suitability, user satisfaction. When questioned about user experience knowledge and interests, respondents associated user experience with these five criteria: emotion, experience, perception, prior knowledge and ease of use.

Jensen (2010), Blakstad et al. (2010) and Villarouco (2008) agreed that a relevant reason for involving the users in building design process is the fact that the users are experts in relation to their work and experiences within environments. The users have their own history, experiences and perceptions in relation to the building and the activities that take place there. Involving users in design process may represent an important gain in order to attend to people's needs and desires.

Brown et al. (2010) demonstrated the complexity of user experience in buildings, shaped in part by the characteristics and quality of the space, but also influenced by a host of other factors, such as occupant comfort, productivity, health and well-being in interior environments and workplace, suggesting that when these aspects work together in synergistic ways, the benefits should be considerable in any usability assessment model.

Recent researches about concepts and applications of user experience in built environment were made by Harun (2011), Ghani et al. (2016) andCozza et al. (2018). As a product, built environment must correspond to end user expectations and emotional sensations, more than their physical needs.

Bevan (2008) pointed that typical user experience concerns include:

1. Understanding and designing the user's experience with a product: the way in which people interact with a product overtime: what they do and why;
2. Maximizing the achievement of the satisfaction goals of stimulation, identification and evocation and associated emotional responses;
3. The range of human answers that would be measured to include pleasure; and
4. The circumstances in which they would be measured to include anticipated use and reflection on use.

## 11.3 METHODOLOGICAL ISSUES FOR THEIR EVALUATION

In CIB Report 306 (CIB, 2008), they had identified three basic purposes for evaluation of usability of buildings:

- First as feedback to planners, owners, users and Facilities Managers in order to improve usability.
- Second, as a contribution to general knowledge and research.
- Third, an understanding of user needs and usability is developed as input to a briefing or design process.

Blakstad et al. (2010) see usability as a kind of non-definitive formulation of solutions and suggest exploring it in multi-method strategies. In their studies, it was important to differentiate users, actors and stakeholders such as end users, Facility Managers, building owners, visitors and the society at large, because different stakeholders and organizational levels have different perspectives considering usability of buildings (Fenker, 2008). They also conclude that cultural aspects and background played an important role in the different users' evaluation of usability. In addition, Harun (2011) recommended qualitative methods to collect data dealing with human needs, especially when it touched on field experience and reflection of experience.

### 11.3.1 Main Methodological Approaches of Usability Evaluation for the Built Environment

CIB Report 306 (CIB, 2008) described many recommended tools and techniques for usability evaluation:

- *Document analysis:* To establish context and situation of the case. This includes briefs and architectural descriptions and project presentations, minutes, drawings and articles.
- *Interviews:* As individuals or groups, to identify the relationship between users' needs and what the building offered, and also to understand the use of space.
- *Walk-through:* A qualitative and systematic way of assessing different aspects of a building by using different stakeholders as informants as making a tour inside of the building.
- *Surveys and questionnaires:* They are useful if necessary, to obtain specific answers regarding the efficiency and effectiveness of the building.

Based on these main tools and techniques, other researchers developed successful methodological approaches, as described in Table 11.1, such as Davis et al. (1993), Preiser et al. (1988), Warell (2001) and Voordt and Wegen (2005).

In the same way, that there are consistent ways to evaluate the usability of the built environment, researchers also elaborated categories of analyses, which they should be concerned to observe in the object of their studies. Noteworthy are the

**TABLE 11.1**
**Main Methodological Approaches to the Usability of the Built Environment**

| Author(s) | Method | Goal | Description |
|---|---|---|---|
| Davis et al. (1993) | The serviceability tool | Evaluate built environment—practical and theoretical framework | Distinguished performance (actual behavior in service) and serviceability (capability of performing as required) |
| Preiser et al. (1988) | POE: post-occupancy evaluation | Evaluate buildings in a systematic and rigorous manner after occupying | Focused on physical, technical and psychosocial aspects. It is spread all over the world |
| Warell (2001) | – | Evaluate functionality inside buildings | Evaluate technical (operational) and interactive functionality (ergonomic and communicative) |
| NHS | Achieving Excellence Design Evaluation Toolkit (AEDET) | Based on POE | Use a systematic questionnaire related to how building performed; provides three key areas: (1) functionality—use, access and space, (2) impact—character and innovation, form and materials, staff and patient environment, urban and social integration, and (3) build quality and standard performance, engineering and construction |
| Afacan and Erbug (2009) | Heuristic evaluation method for universal building design | Inspection usability method played by experts | Based on seven universal principles, each evaluator inspects the building alone and judges its compliance according to a set of usability principles, based on the heuristic evaluation method by Nielsen (1994, 1992) |
| Cozza et al. (2018) | Usability test | Focus on formative and summative usability aspects | User-centered approach, as an interactive design process, with the goal to gather qualitative information about weaknesses and operation problems of a product, so as to accomplish task goals |

*Source:* Based on Davis et al. (1993), Preiser et al. (1988), Warell (2001), NHS and Cozza et al. (2018).

categories described by Warell (2001), Voordt and Wegen (2005), Voordt (2009), Preiser et al. (1988), Afacan and Erbug (2009) and the Achieving Excellence Design Evaluation Toolkit (AEDET) method, according to Table 11.2. Warell (2001) suggested two categories of functionality; Voordt and Wegen (2005) and Voordt (2009) developed nine dimensions to evaluate architecture in use; AEDET provides three

**TABLE 11.2**
**Main Categories to Consider During Usability Evaluation Process**

| Warell (2001) | Voordt (2005, 2009) | AEDET | Preiser et al. (1988) | Afacan and Erbug (2009) |
|---|---|---|---|---|
| Technical functionality (operational and structural properties) | Reachability and parking facilities<br>Efficiency | Functionality—use, access and space | Physical aspects<br>Technical elements | Equitable use<br>Flexibility in use |
| Interactive functionality (ergonomic with users) and communicative (form, aesthetic, values, sensory aspects) | Accessibility<br>Flexibility<br>Spatial orientation<br>Sustainability<br>Safety | Impact—character and innovation, form and materials, staff and patient environment, urban and social integration | Psychosocial aspects<br>–<br>– | Simple and intuitive use<br>Perceptive information<br>Tolerance for error |
| – | Privacy, territoriality and social contact | Build quality and standard performance, engineering and construction | – | Low physical effort |
| – | Health and physical well-being | – | – | Size and space for approach and use |

*Source:* Based on Warell (2001), Voordt and Wegen (2005), Voordt (2009), Preiser et al. (1988), AEDET and Afacan and Erbug (2009).

key areas of evaluation and Preiser et al. (1988) developed a three-area evaluation method. Afacan and Erbug (2009) proposed seven universal design principles as a set of heuristics for universal usability evaluation. Each of those methods features some advantages and disadvantages.

Nevertheless, usability tests and focus groups are the only methods that consider representatives and end users and provide empirical data as requested in the user-centered design principles (Gould et al., 1985). Therefore, usability testing and focus groups are among the most important and widely applied methods in usability practice.

### 11.3.2 Main Methodological Approaches of User Experience Evaluation for the Built Environment

For Bevan (2008), user experience concepts include all the users' emotions, beliefs, preferences, perceptions, physical and psychological responses, behaviors and accomplishments that occur before, during and after use. If user experience includes all behavior, it presumably includes the user's effectiveness and efficiency. This seems consistent with the methods proposed by many people in the industry (Ketola and Roto, 2008; Roto et al., 2009) who appear to have included usability within user experience.

The fulfillment of human psychological needs is thought to be a main trigger of positive experiences with interactive systems or products. This needs-driven UX approach is a well-explored area in UX research and appears to be a powerful framework for the design of more experiential systems. Methods for optimizing user satisfaction with achieving both pragmatic and satisfaction goals can be categorized as follows:

1. Methods to evaluate and design for the hedonic goals of stimulation, identification and evocation and associated emotional responses.
2. Methods to evaluate and design for the user's perception of achievement of pragmatic goals associated with task success.
3. Methods that support the design of the user's experience (including setting requirements and understanding the context of use).

The second kind of user experience method seems to be very suitable for understanding users' behavior inside an urban space or in an interior built environment, while experts can observe, measure and obtain important data from users' activities, needs and desires. Therefore, main authors developed their methods based on this paradigm, such as Hansen et al. (2010), Bluyssen et al. (2004), Rowley (1994), Villarouco (2011), Villarouco et al. (2016) and Noguchi et al. (2018) (see Table 11.3).

User experience evaluation can be performed in different contexts and operated by different techniques involving users' participation or simple observation, such as contexts, tools and techniques described in Table 11.4, based on Marcus (2009), Lallemand (2015), Villarouco (2011), Sannoff (2001), Ekambi-Scmidt (1974), Sanders (2013) and Koskinen et al. (2011).

An effective user-centered theory needs to be clear about what is being measured when users are asked about their experience of the built environment. Measuring the occupants' experience provides information about:

- Product—how spaces affect behavior in different situations, the effects of buildings systems on comfort;
- Psychological processes—how people feel about and respond to the spaces they occupy, as well as about the process.

The implicit evaluation of built space—of quality—that is inherent in users' judgments links the user-centered approach to the design global process.

Vischer (2008) user-centered approach addresses the complexity of the fact that the user-environment relation is dynamic and interactive. The user is not a passive entity experiencing the built environment statically as input. The users' experience of the environment is itself transformed by the activities they perform in that

**TABLE 11.3**
**Main Methodological Approaches to the User Experience Evaluation Method of the Built Environment**

| Author(s) | Method | Goal | Description |
|---|---|---|---|
| Hansen et al. (2010), Bluyssen et al. (2004), Rowley (1994) | Walk-through surveys technics | Building evaluation in a user perspective | The methodology includes building a customer profile, designing and executing walk-throughs based on this, and analyzing the results from the walk-throughs |
| Villarouco (2011) | EMBE—ergonomic methodology of the built environment | Based on human factors analysis and users' perception evaluation | Evaluate tasks and activities done by users, environmental and dimensional comfort criteria and subjective users' perception about environment in use |
| Noguchi et al. (2018) | Environmental experience design (EXD) | Based on user experience design | Function analysis techniques that help to categorize occupants' requirements, desires and expectations in the built environment |

*Source:* Based on Hansen et al. (2010), Bluyssen et al. (2004), Rowley (1994), Villarouco (2008) and Noguchi et al. (2018).

**TABLE 11.4**
**User Experience Evaluation Context and Techniques Description**

| Evaluation context | Description |
|---|---|
| **Lab test** | Mind maps; prototyping (Sanders, 2013); space syntax analysis; user scenarios |
| **Field observation** | Contextual Inquiry; observation/post-use interview; activity experience sampling; ethnography observation (Koskinen et al., 2011); map of users' behavior; wish poem (Sannoff, 2001); constellation of attributes (Ekambi-Schmidt, 1974); environment layout analysis; field simple observations (audio and video) |
| **Evaluation of users' data** | User opinion data obtained from interviews, mind maps narratives, contextual inquiries, focus group evaluations, surveys questionnaire, emotional cards (Lallemand, 2015), psychological measurements tests, walk-through narratives, workshops |
| **Expert evaluation** | Expert analysis; POE focused on users' satisfaction; heuristic evaluation; accessibility evaluation techniques, ergonomics evaluation of the built environment |

*Source:* Based on CHI (2009), SIG, Marcus (2009), Lallemand (2015), Villarouco (2008), Sannoff (2001), Ekambi-Scmidt (1974), Sanders (2013) and Koskinen et al. (2011).

environment. So, the continuing process of self-transformation impacts directly on the individual quality perception about the environment, equipment and/or furniture.

Lallemand (2015) developed a psychological card-set technique as a pragmatic tool able to support needs-driven UX design and evaluation of products. It describes seven categories of experiences: (1) pleasure stimulation, (2) relatedness—belongingness, (3) security control, (4) effectiveness, (5) autonomy, (6) influence—popularity, (7) self-actualizing—meaning UX practitioners should seek to design or evaluate design products or systems. In the architectural field, it is necessarily important to make a relation with the environmental psychology science, and environmental perception that users naturally have about living/working spaces, along a period of time or use frequency, and how they feel themselves among other people sharing the environment.

Vischer (2008) pointed that a way to collect consistent information about user experience is to focus on one type of built environment, by considering who the users are, how time is defined and what is meant by the users' experience in that specific environment. In this way, for a detailed result, each user experience analysis should be focused only on few rooms in use observation, based on wayfinding data collecting, or on task analysis flowchart. Even if the building or urban space is bigger, users may expose less detailed perception information.

In urban spaces, Gehl (2010) explores cities' quality criteria that seem to be related to human factors satisfaction. It is based on three main categories: protection (against physical and sensory influence), comfort (for walking, seating or being on stand) and finally pleasure (human scale, positive climate and sensory aspects).

Cozza et al. (2018) applied a user-centered approach to evaluate building that embodies three main principles of design:

a. Early focus on users and tasks;
b. Empirical measurement; and
c. Iterative design (Gould et al., 1985).

## 11.4 COMBINING UX AND SUSTAINABLE CONCEPTS AS A 21ST-CENTURY DESIGN STRATEGY

In terms of usability of the built environment, sustainable buildings must be related to the safeguarding and maximizing of their functionality and serviceability as well as aesthetic quality. A useful building and/or city space must be designed to protect health, offering comfort and safety for workers (during construction process), occupants, users, visitors and neighbors. Despite advances in researches about social sustainability and human factors led by Attaianese (2012, 2016, 2018), Attaianese and Acierno (2018), Peffer et al. (2013) and Berardi (2015), Fischer (2011), Hedge (2008) and Charytonowicz (2007), social aspects around sustainable paradigm still have few impacts on built environment, except by United Nations (UN) reports and international political boards.

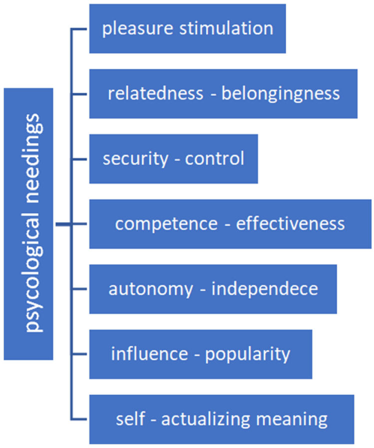
Few design decisions tend to be made favoring user experiences and this challenge might be consequent to the discrepancies between prescribed building codes and user perception (Noguchi et al., 2018), although socially sustainable design for buildings is a hard challenge that involves a range of parameters, considering cultural, economic and political different contexts, around countries, cities and people diversity.

The connection between sustainability and human factors studies is an issue addressed only in the 21st century, with studies from Martin et al. (2013), Zink and Fisher (2013), Attaianese (2016, 2018) and Attaianese and Acierno (2018), as they demonstrated the relations between these two scientific fields. In most cases, it was not considered that sustainable buildings and cities should be first designed to accommodate, safe, protect, promote functionality and accessibility to human beings and then, but not secondarily, offer best conditions to answer environmental questions such as climate adequacy or minimizing energy consumption.

Currently, in this field, the challenge is to establish connections between the concepts of usability and UX and the objectives of international boards in terms of social sustainability conditions. From a human factors perspective (Attaianese, 2018), no protocol areas of assessment are "person-centered," while all show limited credits about human-related factors, including into different thematic areas, such as health, safety and well-being, accessibility and adaptability, actors' involvement in design process (Attaianese & Acierno, 2018).

A theoretical approach that combines usability, UX and social sustainability may be synthesized, going back to some other theories and approaches that make an impact on this proposition:

- Returning to Naumann et al. (2009), their studies demonstrated that experts' interest in usability is focused mainly on designing better products, while UX concept is often associated with the interest of making make people more satisfied, and it is generally more linked with emotional content (e.g. fun and joy) and hedonic qualities. Overall, results indicate that usability/UX-research and practice are well connected.
- Considering Table 11.2, in a way to evaluate the usability of the built environment, researchers elaborated categories of analyses that involve such physical, technical and psychosocial elements (Warell, 2001; Voordt and Wegen, 2005; Voordt, 2009; Preiser et al., 1988) and the AEDET method.
- Regarding Afacan and Erbug (2009), universal usability in architectural design may include four main scenarios: circulation system, entering and exiting, wayfinding, obtaining products and services, public amenities, in order to support seven universal design principles: equitable use, flexibility, simple and intuitive use, perceptive information, tolerance for error, low physical effort, size and space for approach and use.
- Regarding Lallemand (2015), UX evaluation methods may be done as a combination of 1–3 psychological needing and competences related to 12 UX categories (see Figure 11.1). He suggests that alone or as a team, select 1–3 relevant cards and think freely about as many design ideas as possible related to each need. Ask yourself this question: How could we design our system/product/service in order to shape an experience of (UX need, for instance, competence)?




| **UX categories** |
|---|
| Features |
| Visual design |
| Interface design |
| Technical support |
| Content |
| Service experience |
| Accessibility |
| Marketing |
| Information design |
| Usability |
| Operability |
| Interaction design |

**FIGURE 11.1** Lallemand psychological card-set technique to evaluate UX design products.
*Source:* Based on Lallemand (2015).

Combining literature information, psychological needs involving environment behavior can be synthesized into seven categories (see Table 11.5).

Voordt and Wegen (2005) and Voordt (2009) agree with Hillier and Leaman (1976) about distinguished four main functions of a building:

a) *Spatial organization of activities:* A building needs to provide optimum support for the activities desired by properly arranging the available space.
b) *Climate regulation:* A building must provide an optimum interior climate for the user, his activities and his property.
c) *Symbolic function:* A building can be seen as the material embodiment of the specific ideas and expectations not just of its designer but also of the client and the users. This makes it a cultural object, an object with social and symbolic significance.
d) *Economic function:* A building requires investment and maintenance.

These categories implicate the sense of global architectural quality design, including four subquality groups: functional (how suitable for activities the building is), aesthetic (the perception of beauty of the building), technical (involving structure, material and services) and physical quality (how capable it is of achieving an attractive, safe and healthy interior climate, measured in terms of temperature, humidity, illumination, natural lighting and acoustics, in an environment-friendly and energy-saving way).

Physical needs involving environmental behavior (see Table 11.6) are also related to sustainable principles and building design for all. Attaianese (2016) defined six categories of sustainable principles that are the bases of a theoretical approach developed in this chapter: energy efficiency (1), functionality and serviceability (2), operation and maintenance (3), occupants comfort (4), accessibility and inclusivity (5), and health and safety of construction workers (6).

**TABLE 11.5**
**Psychological Needs Involving Environment Behavior**

| | |
|---|---|
| **Pleasure stimulation** | Perception of aesthetic aspects such as colors, forms, human scale, shapes influence, positive landscape, comfort conditions and nature interactions that stimulate enjoyment feeling, performing a leisure or playful activity, having fun on experiencing new sensations and activities |
| **Relatedness/ belongingness** | To a place, neighborhood or city by putting participant of a group or community, being aware of others' emotions, activities or mood, expressing feelings or emotions in a wide variety of ways, having a sense of physical intimacy and caring about others |
| **Security—control** | Of a built environment physical condition, against adverse climate or violence, and in social interactions, having a comfortable set of routines and habits, being safe from threats and uncertainty, being in control of events and personal movements, understanding how things work and interacting with transparent and clear systems and equipment |
| **Competence—effectiveness** | For using/managing environment elements and equipment correctly, usability attributes to complete difficult tasks, affordance conditions, learning how to do things or walk self-secure, interact effectively with the environment and people |
| **Autonomy—independence** | To move him/herself alone in architectural spaces, going toward desired points in urban spaces, to use public transport and access public information, feeling that activities are self-chosen and self-endorsed, having meaningful choices, personalizing one's environment and not being overly pressed or influenced to do something |
| **Influence—popularity** | As a person among a community, feels that your opinion is important, being recognized as valuable person, making friends |
| **Self-actualizing** | By attaining a deeper understanding of oneself, becoming who one really is and developing creativity and spontaneity |

*Source:* Adapted from Attaianese (2016), Gehl (2010) and Lallemand (2015).

The proposed theoretical model was designed to promote a qualitative comprehension about the relation between UX elements, sustainability and design for all criteria about the building/urban space they use, live or work (see Figure 11.2). In practical terms, the approach can be used by designers and architects along ideation design process to develop an usability thinking environment design, as asking him/herself this question: *How could we design our environment in order to shape an experience of UX for support psychological and physical needs?* Results can be written, sketched and/or spoken in a way to combine solutions, ideas and restrictions to improve design process.

Figure11.2 shows the relation between sustainable principles for building design and how these principles may be related to human basic needs about the environment, considering physical and psychological aspects. Energy efficiency, operation and maintenance and functionality and serviceability categories seem to be more related to physical human needs; so, accessibility and inclusivity, occupants'

**TABLE 11.6**
**Physical Needs Involving Environment Behavior**

| | |
|---|---|
| **Reachability and parking facilities** | The facility to reach the place or building in a city space by car, bus, bicycle or other way of transport |
| **Efficiency** | The facility that allows an easy performance inside building with little use of resources |
| **Accessibility** | The facility of access and use of environments, products and services by any person and in different contexts, when people in normal physical condition or with varying limitations can experience the built environment so full and complete (Guimarães, 1999) |
| **Spatial orientation** | Facility that allow users how to recognize the identity and functions of spaces, and the way to move and use it (Dischinger, 2001) |
| **Flexibility** | Easily adjustable condition to suit changing circumstances (Voordt, 2009) |
| **Safety** | The capacity to feel yourself physically safe when using and moving inside the building |
| **Environmental comfort** | The conditions of habitability, respecting thermal conditions, ventilation, insulation, acoustic and visual and others able to change the performance of the building in its context, and the rational use of available resource |
| **Readability** | The possibility of organizing the environment within a pattern of consistent image generation (Lynch, 1960), which directly depends on the legibility of space |

*Source:* Based on Bittencourt et al. (2015), Voordt and Wegen (2005), Voordt (2009), Lynch (1960), Dischinger (2001) and Guimarães (1999).

comfort, health and safety of workers categories are both related to physical and psychological human needs.

In this way, this model needs to be detailed and tested using case studies and suitable tools applied to users and experts, a similar strategy used by Afacan and Erbug (2009) to develop universal design heuristics for usability tests. That step will be shown in future results.

It is important to improve studies about usability and UX approaches to the building design by developing new methods and tools that are mainly based on users' experience, as well as by introduction of new technology resources in usability and UX methods, and/or by using virtual reality as tool to obtain users' and experts' perception about built environment. Such trends are also mentioned by Emo et al. (2016), Afacan and Erbug (2009), Becker-Asano, Ruzzoli, Hölscher and Nebel (2014), Turner and Penn (2002) and Lehman (2011).

## 11.5 FUTURE RESEARCHES

Emo et al. (2016) affirm that in a contemporary architectural scene, innovation in the design of the built environment can be supported with technical tools, analyses and empirical models, but not alienated from users' experiences that are essential for

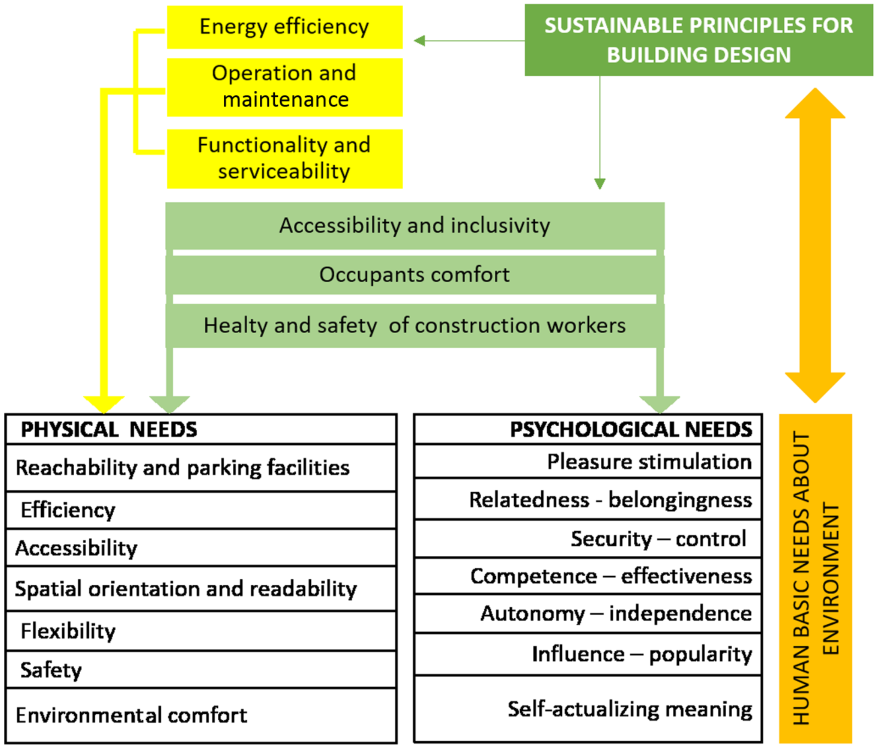



**FIGURE 11.2** Theoretical model for sustainable and usability design thinking based on users' needs. *Source*: The authors.

any modeling or design approach. It is powerful to transform research findings into design interventions for a better city/building. In this way, developing and testing new forms of combining theories may be a suitable strategy to obtain a more sustainable architectural design by addition usability and UX approaches to design process.

An evolution of observation researches with new mobile technologies (such as eye tracking, recording of biometric data) allows for the accurate first-person recording of a user's experience. This has the potential to revolutionize the nature of post-occupancy evaluation studies, an area where research and practice converge (Emo et al., 2016). In this direction, an interesting study was done by Paiva (2018) to evaluate elderly people's perception about built environment using neuroscience technologies. Paiva's (2018) aim was to understand the importance of space, its functions and its characteristics focused on ergonomics studies for human aging, considering cognitive processes and elderly physical and mental limitations.

Virtual world modeling throughout usability and UX studies make it possible to test design interventions in a controlled setup. An area that still has scope for development is the use of cognitively infused agents in virtual models, as a means of analyzing how people might move around such a space in the real world. The level and nature of the cognitive input that such agents might have are still a matter of debate (Becker-Asano, Ruzzoli, Hölscher & Nebel, 2014; Turner & Penn, 2002; Sanders, 2013).

Sensory stimuli applied to building design should not be used only for aesthetic reasons, but also to unite function with form in such a way that occupants engage with their buildings on cognitive, behavioral, emotional, physiological and even spiritual levels. Sensory design is useful to architects as project advantages, so they can use stimuli to evoke a range of human processes in their occupants (Lehman, 2011), helping on users' environment perception and including clues to improve accessibility conditions.

These strategies can be ways to apply UX techniques to train architects and urban planners to connect usability concepts of the built environment to people's actual needs and diversity, making places supportive for human activities and tasks. There are contemporary potentialities in architectural user-centered design, as an indefinite number of fields need to be explored, in order to have housing, working places and urban spaces more sustainable for diverse people.

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# 12 A Human-Centered Architecture

## *Considering Usability and User Experience in Architectural Design*

*Elisângela Vilar, Francisco Rebelo, Paulo Noriega and Ernesto Filgueiras*

**CONTENTS**



## 12.1 INTRODUCTION

At the beginning of the 21st century, according to a research sponsored by the U.S. Environmental Protection Agency and carried out by Klepeis and colleagues (2001), about 87% of peoples' daily time is spent indoors. This data is overwhelming and clearly shows the importance of built space in human lives. In fact, as stated by Winston Churchill when debating the project of Giles Gilbert Scott for the reconstruction of the British Commons Chambers, "we shape our buildings, and afterwards our buildings shape us" (Brand 1994).

Considering the effect that the built environment has on world development, it was on the agenda of the World Economic Forum (WEF) Annual Meeting 2017 in Davos-Klosters, and the initiatives such as the "Future of Construction" were discussed. According to the report of the WEF (World Economic Forum 2017), this initiative, started in 2015, aims to analyze the implications of change in architecture, engineering and construction (AEC) through technology on business strategy,

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skills and organizational design, financing and risk allocation and other fundamental areas. Among others, the WEF established as fundamental area, flexibility, livability and well-being, which is related to creating infrastructure and buildings that improve the well-being of end users. Additionally, the report from WEF also presents and discusses ten innovative initiatives in the AEC area, from buildings to start-ups, that adopt technology-based solutions, mainly related to the use of building information modeling (BIM), 3D printing, wireless sensing and autonomous equipment solutions. It also points that over the past 50 years, no fundamental change occurred in the AEC industry and that new technologies have been slowly adopted.

With the new global challenges, such as climate change, resource shortage and rapid demographic shifts in emerging and developed countries alike, thinking about how the built environment can evolve as an affordable, sustainable and happy place, promoting well-being, for many people is of paramount importance, and new technologies could be of great value for tackling these challenges.

Technological advances already affected the way people plan and use the built environment, so considering technology as a motor for change is not a recent fact. The evolution of a new thought, the intensification in production and massification of some materials, such as iron, coal and cotton, contributed, in the 19th century, to the massive changes in infrastructure and architecture of the cities. For example, with new supporting technologies, such as the steel skeletal structure, new building designs emerged (Moon 2005), together with a new way to interact with the built environments; the small buildings were gradually replaced by increasingly tall skyscrapers, while the pedestrians and horses gave their space to the cars, also changing the way people interact with the urban space.

In 2020, a new challenge was faced with the new coronavirus SARS-CoV-2 causing a pandemic due to its rapid global spread, and its impact on our buildings and cities is still unknown. With lack of knowledge about this new virus and with the necessity of social distancing, massively adopted as the main strategy to diminish the virus spread, telework and the reduction of mobility were encouraged. So, the changes in the daily dynamic made people to spend more and more time in their houses, and to prefer open to closed urban spaces, boosting the adoption of strategies that reduce the chances of the contagion. Thus, what has been seen nowadays is a huge amount of people who used to leave their homes during most part of the day for doing several types of activities, from going to work to having dinner with friends, adopting a more homely behavior supported by an increase of digital habits. For example, physically going to the supermarket was replaced by shopping through the Internet, as well as physical meetings were replaced by online ones. Additionally, bicycles have been even more recognized as an efficient transportation method as they promote mobility through the city while also increasing social distance. In this way, the house has integrated new functions, such as supporting teleworking and distance learning, as well as the urban space, that need to be adapted to support social distance and outdoor activities.

The use of technology was already considered by Groat and Wang (2002) when examining research in architecture. According to the authors, the global economic trends are influencing many professions, including architecture, and research on the scope of architectural practice, in the light of new technological advances, needs special urgency.

Besides, some authors (e.g., Noguchi, Ma, Woo, Chau, & Zhou, 2018) argue that design decisions are misaligned with the users' needs, expectations and experiences, mainly due to overvaluation of the prescribed building codes. And that considering users in the center of the architectural design process should decrease the discrepancies between users' needs and built environment opportunities (Verma, Alavi, and Lalanne 2017).

In this context, this chapter will discuss people's interactions with built environments, and how the new technologies are changing this interaction and also changing the architecture. In the light of user experience (UX) and usability concepts, and considering the experience already accumulated in the human factors and ergonomics area and its relation with architecture, the human-building interaction (HBI) is analyzed and some examples of human-centered architecture are given.

## 12.2 UX AND USABILITY AND HUMAN-CENTERED DESIGN CONCEPTS

Much has been said about UX and usability in the built environment. However, usability and UX concepts were first basically related to ergonomics and human–computer interaction (HCI), mainly considering the relationship between users and software or technological products.

According to Schackel (2009), with the widespread use of microcomputers from 1980 and portable computers from 1990 by all types of users and for many different purposes, the usability problems when interacting with those devices became more evident. Also, users become more aware and much more selective, partly due to experiences of poor usability.

Thus, in 1998, usability was incorporated in a standard and the International Organization for Standardization (ISO) defined it as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (International Organization for Standardization 1998).

As usability was more correlated with performance aspects, with authors linking the failure in usability with monetary loss, low productivity and time wastage (Madan and Dubey 2012), the term user experience evolved into a more emotion-related aspect of the products.

In 2010, ISO 9241-210 (International Organization for Standardization 2010) was revised and the UX definition was included, considering it as "user's perception and responses that result from the use and/or anticipated use of a system, product or service." The same ISO also refers that the perceptions and responses are related to users' emotions, beliefs and preferences.

While usability is considered a product-related aspect, UX is an interaction-related feature. The revision of the ISO 9241-11 (International Organization for Standardization 2018), in 2018, incorporated the built environment in its scope, in a way that the concepts of UX and usability should also be applied to situations where people use the built environment.

Together with the new demand that arose from the heterogeneity of the new users—with different levels of knowledge, expertise and expectations—and the development and dissemination of new technological products, namely, personal computers, a new paradigm for design based on human, called human-centered design (HCD) arose and led to notable differences in the resulting product, system or service.

In their edited volume, Norman and Draper (1986) recommend considering the user at the center of a design process. In this book, the authors directly put the emphasis on people, not on technology, through a set of chapters in which the invited authors write around this central point, setting the base for the human-centered design methodology.

This new paradigm for interactive systems' design was later systematized in an ISO standard (International Organization for Standardization 2019), and the HCD definition was set as an approach focused on users, considering their needs and requirements, to develop usable and useful interactive systems by applying ergonomics and usability knowledge and techniques.

Despite the fact that the HCD is still directed to the computer-based interactive systems (International Organization for Standardization 2019), it can be applied to a broad range of systems with which humans can interact. According to ISO 9241-11 (2018), HCD is "an approach to system design and development that aims to improve usability, accessibility and user experience and avoid harm from use, by focusing on the use of the system."

HCD is described as an iterative development cycle in which people and their relations are considered in the center of the design process according to some key principles (International Organization for Standardization 2010):

- Increasing the productivity of users and the operational efficiency of organizations;
- Being easier to understand and use;
- Increasing usability for people with a wider range of capabilities and thus increasing accessibility;
- Improving user experience;
- Reducing discomfort and stress;
- Providing a competitive advantage;
- Contributing toward sustainability objectives.

In fact, this new paradigm was highly influenced by the ergonomics field of study. According to Dul and Weedmeester (2008), the International Ergonomics Association defines ergonomics as

> the scientific discipline concerned with understanding of the interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance.

It focuses on optimizing the interaction system in a way to meet health, safety and performance criteria. Ergonomics has a multidisciplinary human-centric approach

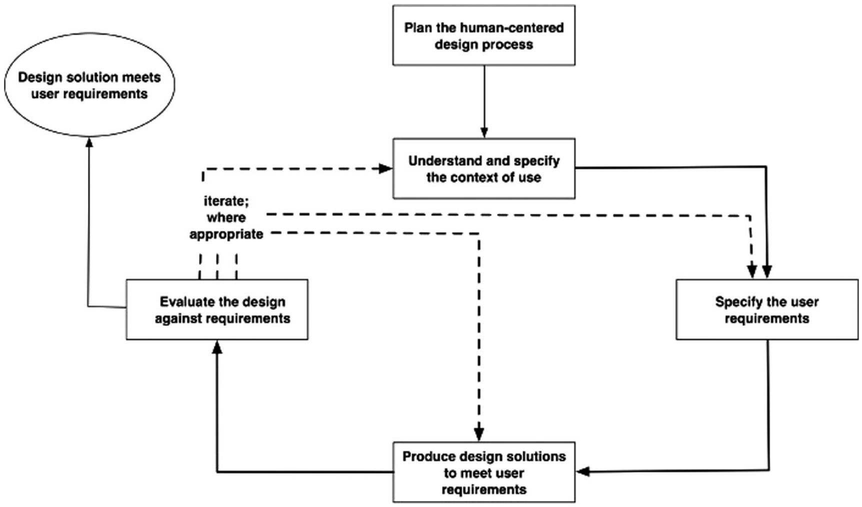


**FIGURE 12.1** Interdependence of HCD activities.

and does not have a specific domain. Thus, it considers cognitive, environmental, organizational, physical and all other relevant aspects of the interactions between the human and other elements of the system (e.g., other humans, tools, technology and environment).

In this way, the human-centered design methodology, considering the ergonomics' systemic approach, is an iterative process that comprises six main phases. This process starts with a planning phase, followed by a set of interdependent activities that occur in an iterative cycle (International Organization for Standardization 2010), as can be seen in Figure 12.1.

When considering architecture, all goals established for HCD are also the focus of the architectural process. However, while HCD puts humans and all their contextual interactions at the center of the process, architecture has its basis in facility programming—that is, a set of functional areas and patterns of use of space—and since the 1980s, some architectural schools have changed its focus from form-making to buildings shape (Cherry and Petronis 2016). Thus, architecture still overvalues facility programming and regulation codes (Noguchi, Ma, Woo, Chau, & Zhou, 2018), and the human factor is considered only in terms of functional needs.

## 12.3 BUILT ENVIRONMENT AND HUMAN BEHAVIOR

The built environment can be understood as a manmade surrounding in which activities can be performed, from large-scale public areas to personal spaces. According to Moffat and Kohler (2008), conventionally, the built environment is usually analyzed as a piece of private property (the parcel), or as a collection of properties with their buildings infrastructure and constructed open spaces. Handy and colleagues (2002) also state that the built environment is a changeable system that can be defined in terms of their subsystems: urban design, land use and transportation system, including records of human activity within the physical environment.

The built environment comprises three interconnected aspects: physical, spatial and social. Thus, the physical elements of a building (physical aspect such as walls) create the space (the spatial element in which human activity occurs), and each of them has a social value (social element) (Hillier 1996). These social values are in the physical aspect, for example, in the shaping and decoration elements with their functional and/or cultural significance; and in the spatial aspect, by providing spatial patterns of activities and relationships (Alavi et al. 2016).

A central point in the built environment definition is human activity, as it could be influenced by the built environment, but it should also shape the way the built environment is planned and used. Thus, understanding this mutual relationship between human activity and the built environment could be crucial to improve mutual interaction.

For this, knowledge of the needs of the built environment users should be the central point of the architectural process. John Zeisel, in 1975 (Zeisel 1975), had already pointed out that, since the Industrial Revolution, knowing users' real needs while interacting with new large buildings daily used by a diverse type of visitors (such as universities, office buildings, hotels, hospitals, factories, apartment buildings) become more difficult to the architects. It happens because, with the new buildings' demand that arose with the new industrialized city, there was a change in the architect's client, with the emergence of a new relationship, turning it from an architect–user/owner relationship into an architect–owner/paying client–user client relationship. Architects have now two main clients, the one who pays for and the others who use the product of their design. Thus, in this situation, architects are familiar only in a general sense with the type of people who will use their buildings, relying on a dialogue with the paying client. Zeisel also argues that it may create a large communication gap, which the architects try to minimize by designing buildings according to their concept of function. According to the author, it could be better solved if social research would be more integrated with architectural design, in a way that the human activity could be better investigated and understood in order to be applied to the architectural project.

Some authors (e.g., Appleyard, 1980; Whyte, 1980) have already focused their research on human behavior to understand how the built environment can influence users' satisfaction, performance and even health in urban areas.

In 1980, Whyte (1980) wrote a seminal book which is a manual about why some urban areas work and others don't. Using direct observation techniques (very little used at this time to study the dynamics of an urban area), he started studying parks and playgrounds in New York City motivated by an emerging concern over urban crowding. However, the main findings from direct observation suggested a lack of crowding in many of these areas, even in neighborhoods with a very high density of people, while some streets were full of children playing, contradicting the assumption that children play on the streets because they lack playground spaces. The authors expand their research to the plazas built in the light of an incentive bonus given to builders by New York City since 1961. So, builders could add 10 square feet of commercial floor space for each square foot of plaza they provided. Researchers recorded human activity involving plazas in order to acquire daily patterns of use and inquired users about the frequency they used the plaza, what they thought of it, where they worked and where they came from. The findings suggest that most users were young office workers and that most of them were not workers from the plaza's building. The reason for this dynamic is that workers want to keep some distance from their work, creating an interesting movement of people. According to Whyte (1980), this dynamic highlights a key factor: supply creates demand.

Whyte's studies about the way human activity can shape urban space, and how urban space can influence human behavior were of paramount importance for architectural thinking mainly regarding putting the users at the center of the architectural design process.

Unfortunately, according to Handy and colleagues (2002), when discussing about urban planning, the direct assessment of the relationship between human activity and the built environment and its influence on the individuals is still rare. Noguchi and colleagues (2018) also argued that, despite the high impact that the architectural design has on users' physical and perceived comfort levels in the built environment, the notion of such influence and the design of this experience is barely applied to the practices of architecture today.

However, with the increased incorporation of technology-produced materials, and also the concepts of UX, usability and human-centered design in the architecture project, architectural thinking is also evolving in a more human-centered experience.

Nowadays, architecture evolved in a way that the idea of an adaptative architecture, as proposed by Cedric Prize in his Fun Palace (Mathews Hobart and Smith Colleges 2005), could be considered plausible, thanks to the use of new technological systems and to the growing awareness by the architects that the user is now not seen as a spectator. In this sense, some architects have already recognized that the human factors/ergonomics field, with its research and design methodologies, mainly those related to the human–computer interaction, could be a helpful ally to architectural design. In the same way, the human–computer interaction field evolved and its research challenges have also changed, from a restricted focus on technological systems to the recognition of its relevance to other disciplines, incorporating other knowledge and expanding the human–computer interaction approach.

With the spread of ubiquitous computing, turning the built environment into a large-scale technological product, as well as the increasing consciousness of users about the quality of a product/built environment, the HCD approach has been adapted for a broad range of applications, including architecture. Incorporating these concepts could be an influential support for architectural practice, providing professionals with beneficial tools and methods to achieve a better communication and understanding of the needs and requirements of architectural product users.

### 12.3.1 UX, Usability, HCD and Architecture

Architecture has increasingly incorporated concepts from areas such as ergonomics, environmental psychology and information technology, moving closer to the UX and usability concepts and fostering the emergence of new approaches to planning the built environment. From the developmental phase, with the introduction of a building information model (BIM) and computer-aided design (CAD), modeling, visualization, presentation—with virtual reality (VR), augmented reality (AR) and 3D printing—and approval of new materials and functions, such as the introduction of sensors/actuators systems or monitoring visitors and adapting buildings to their needs, to the construction phase—with using new techniques and process—new technologies are being incorporated in the AEC industry. In this context, it is interesting to look at the built environment as a place for interaction frameworks that are planned and designed considering the users' needs and motivations.

Dade-Robertson (2013) argues that the built environment is being conceived more and more as a user interface. The users of the space—visitors of a building, consumers in a mall, workers at an industry, and many others—are now considered as a major part of a project model, in which their interactions with the built environment, mediated and/or optimized by technology, are key factors for the architectural design process. Thus, there is a need for closely knowing users' needs, capacities and expectations to promote their effectiveness, efficiency and satisfaction and, as an ultimate goal, to enhance UX with and within the built environment (where the human behavior can be mediated and/or optimized by technology).

Even with a still ambiguous attitude of the architects toward the participation of users in the architectural planning activities because of the dual nature (i.e., artistic dimension and social dimension) of architectural design, the participation of users has increased in the last decades (Attaianese and Duca 2012). The social dimension of architecture, in which the product of an architect's work is the stage for social activities and sharing experiences, encourages these professionals to involve users in the architectural process from the beginning, even with the pressure of the artistic dimension that is many times considered as an activity of individual inspiration.

According to Zeisel (2006), the control of the effects that design decisions can make on user's behavior should be the architect's ultimate desire, despite that the main objective of their work is to change physical settings through the architectural design. So, the product of their work should meet its users' social, psychological and developmental needs. Additionally, with the introduction of technological features into the architectural design, it is crucial for the architects to understand the new interactions that these new technological environments can allow. The development and introduction of technology into the built environment can radically change the architecture project, changing also the way architects deal with the design process.

In fact, buildings were always a large-scale scenario for interaction, in which human activity and building's physical, spatial and/or social aspects can mutually affect each other. For example, opening a window can affect the temperature and light of a room, changing the physical aspect can influence user's comfort and well-being, as well as rearranging the furniture to reconfigure the space for a meeting promotes change in the spatial aspect, which also promotes new social interactions. Even when designed to be unchangeable, buildings are adapted constantly by their usages that are also constantly changing (Brand 1994). Contradicting the idea that architecture is permanent is the main focus of debate in Brand's book *How Buildings*

*Learn*. This book starts with a cover history about two neighboring buildings which had an identical design when they were built in the 19th century, but they are completely different (even in their use) in the 20th century. With this, the author argues that considering a building only as a matter of space, forgetting the temporal dimension and all changes that this dimension brings (such as cultural and usage changes), is inviable and even impossible, as building always will be adapted and changed, physically, spatially and socially.

Nowadays, with the advance of new technologies, such as Internet of Things (IoT) and sensing, some simple interactions are also changing. For example, the development and improvement of voice interaction and personal assistants—such as Alexa from Amazon, Google Assistant from Google and Siri from Apple—have enabled their users to change room temperature and lighting, call friends, change the channel of television, change music and so on only through voice commands. And, with more sophisticated systems, based on sensors and actuators, the environment can adapt itself to the user only by sensing their physiological data or by learning with their patterns of behavior.

The smart environment concept, such as smart cities, smart homes and smart buildings, although more focused on sustainability, effectiveness or cost (Alavi et al. 2019), has also enabled its users to effectively use the space and socially interact within the space. An example is the new dynamic created in space use by the employees of Deloitte's headquarters at Amsterdam. With the use of sensors that inform employees about empty desks or other places (like tables and sofas in the cafeteria or library areas) and the policy of "take a free place and work where you want" adopted by the company, a new pattern of use was set. Despite the fact that the building has areas planned for office work and others planned for meetings, employees prefer to use the area of the cafeteria and open spaces in the halls to work or have informal meetings. Additionally, as they can be informed by an app about the location of colleagues, they also start to work at the same place as their working group, enhancing the creation of work teams (World Economic Forum 2017).

Thus, with the increasing incorporation of new technologies that promote interactivity with and/or within the built environment, new outlines and demands have emerged when considering UX in architecture (Verma, Alavi, and Lalanne 2017). HCI research and design can effectively contribute to architecture to understand these new spatial-temporal dynamics and user's demands that arise with those new opportunities and interactions, in a way to chase the utopic dream of a user's adaptable building.

The main questions that arise are those related to humans and their experience with the built environment, mainly considering human values, needs and priorities to reflect, according to Alavi and colleagues (2019), the complexity of human interaction and social experiences with and within built environments. With this in mind, a new area has been developed, the human-building interaction.

### 12.3.2 The Human-Building Interaction Concept

According to Alavi and colleagues (2019), HBI is an emergent area that seeks to examine the involvement of HCI in studying the evolution and shaping of built environments. It emerges with the increasing incorporation of technology in the built environment, allowing several new forms to interact with it. In this way, a definition of HBI could derive from the HCI's concept and could be set as the study of the human part of the interaction between the individuals and the built environment in order to understand their needs and expectations, orienting all project phases, from designing to construction and maintenance, promoting and optimizing human interaction with and within the built environment in a way that it can be achieved with effectiveness, efficiency and satisfaction, and ultimately enhancing UX.

Thus, designing for HBI should provide interactive opportunities for the occupants to shape the physical, spatial and social impacts of their built environments (Alavi et al. 2016). For this, HBI also considers a multidisciplinary approach, adding knowledge from several fields, to map user's requirements and expectations, and design solutions that meet these requirements, always aiming to enhance UX. Dade-Robertson (2013) made a parallel between HCI and architecture considering that both are supported by technical rigor and artful practice with the main objective of solving diffuse and complex problems.

So, according to Alavi and colleagues (2017), HBI is an intersection of three main domains, architecture and urban planning, HCI and new technologies (mainly ubiquitous computing), to promote usability and UX in built environments and to anticipate the questions that may arise with the new complexity of our interactive experiences with the built space (Figure 12.2).

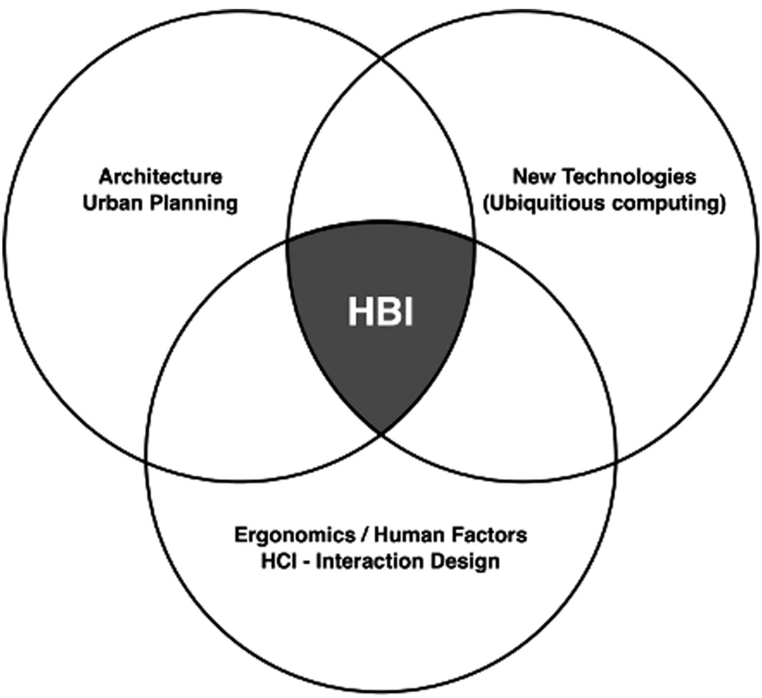


**FIGURE 12.2** Human-building interaction as an intersection of three main areas.

From the beginning, studies in the HBI area were mainly in building performance research, considering resources management and energy saving, in a way that the building could adapt itself to user's needs in order to manage the use of energy resources, increasing building performance (e.g., Hsu et al., 2010; Jazizadeh et al., 2012; Malkawi & Choudhary, 1999; Malkawi & Srinivasan, 2005). However, we agree with Alavi and colleagues (2016) in considering a broader and human-oriented perspective.

This perspective also defines the extent of this human-building interaction, in order to prevent users from inconvenience that may arise from considering all data that can be acquired and used. An interesting approach to this issue was carried out by Urquhart and colleagues (Urquhart, Schnädelbach, and Jäger 2019). In their work three adaptive architecture applications based on IoT were considered in the light of emerging information privacy and security regulations. Although regulatory concerns are not the focus of this chapter, it is important to reflect on some implications of creating smart environments.

Additionally, technology can allow changing the state of the environment, as the potentially harmful situations could be created with the poor design of this new interaction, affecting the safety of built environments' users (Dasgupta et al. 2019). Consider, for example, a smart building in an emergency situation like a fire. Previous studies (e.g., Vilar, Rebelo, Noriega, Duarte, & Mayhorn, 2014; Vilar, Rebelo, Noriega, Teles, & Mayhorn, 2013) have already shown that often people rely more on architectural features than on emergency signage systems. What smart solutions could be considered to enhance compliance rates with the emergency signage system? Should the emergency signage paradigm change? What's the good of a smart alarm system if people do not trust the alarm or take longer than necessary to start the emergency evacuation process? So, it is not about technology-based environments, but it is about understanding users while planning the whole system.

Predictions of new interactive experiences with and within the built environment are growing, and the smart agenda is really evolving with projects in many countries. However, in a recent study about Rio de Janeiro's Smart City project, it was concluded that applying the smart city paradigm itself is not enough without considering the real context. In fact, it could potentialize socioeconomic and political divides (Gaffney and Robertson 2018).

Some research has been done with the aim of understanding human behavior (e.g., Vilar et al., 2020, 2014) and emotions (e.g., Dias, Eloy, Carreiro, Proença, et al., 2014; Dias, Eloy, Carreiro, Vilar, et al., 2014; S. Dinis et al., 2013) within the built environment, space use (e.g., Verma et al., 2017), universal design (e.g., Noguchi et al., 2018) and building performance (e.g., Hsu et al., 2010), adding knowledge to the HBI area. However, there is a lack in clarifying and unifying concepts to strengthen HBI as a field of research. It could be one of the reasons why much of the work that has been done in this area involves many other fields of knowledge.

In this way, efforts can be made to envision possible scenarios and plan for them, and according to Alavi and colleagues (2016), it is important to understand and reflect about HBI contributing to the generalized understanding of human interaction with the building environment. For this, the authors suggest the necessity of developing more innovative design instances and improving the knowledge in the area, by, for example, design heuristics and strong conceptualizations. The development of cumulative understanding of evolving human living and working behaviors in a new scenario of interactions that the introduction of new technologies can promote would be possible with the incorporation and assimilation of knowledge and methodologies from the three main domains in the HBI field of study (D'oca et al. 2019), as shown in Figure 12.2.

### 12.3.3 The Human-Centered Architecture

With the increasing incorporation of new technologies in the buildings, allowing a myriad of new interactions between users' and the built space, the need for knowing users and filling the communication gap is obvious, as illustrated in Figure 12.1. Adopting an HCD paradigm could be an interesting approach to make it possible. As a problem-solving approach focused on the human perspective during all problem-solving processes, HCD uses methods and techniques imported from a broad range of social sciences, such as observation, interviews, focus groups, questionnaires and others, to understand users' needs, defining requirements and testing solutions against these requirements.

According to Schulzová and Bošová (2019), the main components of indoor environments are mainly related to physical aspects (i.e., thermal and humidity microclimate, lighting, acoustics, indoor air quality, electromagnetic, electroionic, electrostatic and ionization microclimate) and psychological aspects (i.e., users' well-being). However, even if all physical aspects are controlled and attended to in the architectural project, there is no guarantee that the psychological well-being of the user will be achieved. Promoting good user experience could be a key factor for achieving well-being. In this way, adopting a methodology that allows knowing users and putting them at the center of the architectural process can contribute to the architects' work, allowing them to design the built environment not only in terms of functionality, but also as a place that promotes good UX, and thus promoting well-being.

In this sense, works related to the built environment with the concepts of UX, usability and HCD can be found in literature, and the following are some examples.

In a recent study carried out by Van der Linden and colleagues (2019), the UX methods and the HCD process were used to make the people's spatial experience part of the architects' design process. Thus, elements like persona[1] and scenarios[2] were considered and adapted to the particularities of architectural design to have a new integrated approach to support professionals in designing human-centered environments. This new approach suggested by Van der Linden and colleagues (2019) is in line with the new perspectives that arose with the evolution of the HBI concept.

Although project promoters are still disconnected from real end users, tackling with some difficulty in acquiring and understanding their needs, there are some successful examples of user-oriented projects for new buildings. A good example is The Edge, designed for Deloitte, a global financial firm. This new building aimed to accommodate the company's employees spread across multiple buildings in the city.

An HCD approach was considered and interviews with the employees about their preferences and needs, as well as observation of their work at their previous workplaces, were carried out. According to the WEF report (World Economic Forum 2017), this HCD orientation was maintained during all project phases with a constant focus on enhancing employees' UX. Planned to be a smart building, the project was developed considering a set of sensors/actuators. Additionally, an application was developed and the building's users could interact with it through a smartphone or a tablet to, for example, personalize temperature or lighting levels, book a room for a meeting or find a free desk to work. Through the app, users can also find a parking lot, navigate into the building, manage work schedules, find others, report problems and so on. This building is also considered the greenest until the date, according to the BREEAM green building certification scheme (Fytrou-Moschopoulou 2017).

An example of how new interactions can shape the built environment is the "ExoPranayama" (Moran et al. 2016). In this project, biofeedback of yoga practitioners was used to develop an environment that, according to the authors, physically manifests users' breathing in yoga. The "ExoPranayama" was developed considering direct observations of yoga class and an HCD approach. The tests with the environment revealed an improvement in self-awareness and allowed teachers to better know their students and help with the new class. However, the authors point as a drawback the social concerns related to exposure of what they called "invisible inner-self" that they related with competitiveness and deviation from the spiritual aspect of the practice.

Conceptual frameworks to answer the demand created with the HCI research and design in architecture were also proposed. An example is the human–environment approach developed by Ma and colleagues (2017) called Environmental Experience Design (EXD). It was designed to identify the main objectives of the project, analyze user perception, propose design strategies and solutions (Noguchi et al. 2018) and encompass objective physical parameters, such as environmental quality data and subjective user perception, for example, the human emotions. An aged care facility was chosen as a case study to apply the EXD, and, based on it, physical (indoors environmental quality data) and psychological parameters such as freedom, connection to the natural environment, belongingness and individual dignity were considered. These parameters feed the methodology of the function analysis system. This methodology aims to identify the performance of a user function and to refine design as a function of the users' requirements by asking what functions users need and how design can achieve these. The methodology's result is a diagram (FAST—Function Analysis System Technique) that helps to explore users' physical and psychological needs and demands. The EXD framework derives from the FAST diagram and encompasses related design criteria, design settings, objectives, design elements, opportunities and design solutions.

Sandman and colleagues (2018) proposed the incorporation of HCD methods in two sustainability models. They also applied these models in two case studies; they proposed a new one in which the four dimensions of sustainability (i.e., environmental, economic, social and cultural) have an equal balance, highlighting the aspects that need the inhabitant's engagement. According to them, to reach this balance, architects need to understand people in depth, by having an empathic involvement with the users.

HBI being a recent area, studies that encompass this field are still sparse and are usually found in correlated areas, such as publications on HCI, building automation, building engineering, sustainability and energy research. Despite HBI being an emergent field, with a lot of new research being produced, there is still much work to do in the direction of incorporating more human-oriented processes into architecture.

## 12.4 CONCLUSIONS

New opportunities also bring new problems and new challenges. What is going to happen when full building automation occurs? Could people live in a place where technology decides for us if our window should be open or closed? Will we rely on a safety information that changes according to the circumstances of an emergency? And what about our privacy when the built environment, being urban spaces or indoors, is able to store all information about our physiological data, patterns of behavior and also emotions? How a new built environment should be designed considering all the adaptive opportunities that new technology could allow? There are many questions that could arise from a reflection on the subject of smart environments and all new demands that they could allow.

Nowadays, with the evolution of sensing technologies, both human and environment can be monitored and communicate with each other allowing the optimization of their interaction. These new technology-produced products can also affect architectural thinking and promote changes in the design process. According to Lester and colleagues (2008), sensing platforms are being increasingly used and the number of potential users and applications being developed continue to expand. With this, a number of data—some collected by environmental sensors considering more traditional aspects such as air quality and temperature and others collected through users' devices such as mobile phones, considering, for example, users' activities and locations—can be related with each other to inform and optimize the interactions between the users and the built environment.

From the architecture point of view, considering the new interactions and all opportunities and disadvantages that could arise is a new demand that professionals from this area need to deal with. And with new demands, also new ways of thinking about problems and solving them are also necessary.

Some authors (i.e., Ma et al., 2017) agree that architecture requires interdisciplinarity and a human-centered process, but, unfortunately, thinking about the user experience while interacting with or within the built environment has barely been applied to architectural practice.

This chapter deals with these new demands and presents some concepts that are helping architects to change the architectural process to incorporate more human-oriented strategies to solve complex problems in architectural design.

Interaction design and architecture are increasingly interconnected, from the mid-1980s, with the first attempts to design computer-aided design (CAD) tools, to the incorporation of technologies that are designed to be part of the built environment, using the architecture as support for new digital technologies (Wiberg, 2017). Thus, new technologies can allow new interactions with the built environment, such as temperature controllers, aperture controllers and presence sensors, that can change space use, and also ultimately alter the architectural design.

McCullough (2004) argues that the digital world is mixing with the real world as ubiquitous computing has to be inscribed into the social and environmental complexity of the physical built environment. This makes digital networks bonded with architecture and opens a new paradigm for architectural design. However, with new grounds, new ways of thinking about problems also emerge, and new theories tend to unify perspectives among disparate groups, generally introducing a few widely applicable problem-solving strategies. All these exchanges and intercommunications among disciplines and fields of knowledge allow generating shared assumptions and concepts underlying a common frame, also producing a more consistent and coherent set of models and techniques (Moffatt and Kohler 2008).

In this way, contributions from HCI to HBI field are mainly related to research and design methodologies that are aimed at understanding user's needs, requirements and expectations, focusing on enhancing UX and usability. For this, it is important to identify, to understand and to organize in a framework the converging aspects of HCI and architecture to establish new knowledge on the HBI area allowing all interested in this area to predict and shape the future of living.

## NOTES

1. "Personas, are detailed, composite user archetypes that represent distinct groupings of behaviors, attitudes, aptitudes, goals, and motivations observed and identified during the research phase" (Cooper et al. 2014).
2. A scenario is a concise description of a persona using a product to achieve a goal (Cooper 2004).

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# Section 4

## *Usability and UX in the Digital World*

# 13 Digital Human Modeling in Usability

*Gunther Paul*

## CONTENTS



## 13.1 INTRODUCTION TO DHM AND USABILITY

Usability has been widely accepted as an aspect of human-centered design, and thus in a close relationship with human factors and ergonomics (HFE). Historically, however, usability was often associated with software or Web site design and therefore a psychological property, versus an understanding of HFE rather relating to physical properties and functionalities of a product, user interface or work system. There is also some form of agreement that usability cannot be directly measured as an objective and quantifiable property. Usability is connected with "learnability"—how easy a product function can be learned and understood initially; "efficiency"—how well the product function performs once fully learned; "memorability"—how easy it is to memorize a product function and use it again when returning to the product after absence; "reliability"—the amount of errors generated by the product function, their severity and easiness of recovery from those errors; and "satisfaction"—how pleasant it is to use a product function.

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Given that our modern understanding of HFE includes cognitive ergonomics, usability may now be seen as a discipline within HFE. For this reason, usability is now also standardized through ISO rather than IEEE, and falls under the authority of the ISO technical group 159 "Ergonomics" (ISO TC 159 / SC4). Specifically, ISO/TR 16982:2002—Ergonomics of Human-System Interaction—Usability Methods Supporting Human-Centered Design; and ISO/FDIS 9241–210:2019—Ergonomics of Human-System Interaction—Part 210: Human-Centered Design for Interactive Systems—provide guidance and a defined framework for using ergonomic methods in the context of usability.

Digital Human Models (DHM) in HFE can be seen as a virtual tool to accomplish a design target that is explicit in its representation of users, tasks and environments. DHM as digital and often fully integrated systems support fast iterations in a human-centered, or even human-in-the-loop (HITL), design process. Thus, they accelerate the design process, make it reproducible and support quality management and reporting requirements. As systems representing humans in a digital world, DHM particularly lend themselves to interactive, human-centered system development. In particular "accessibility"—the "extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use" (ISO/FDIS 9241-210, p.2)—has become an aspect of usability that is preferably studied and designed using DHM. DHM usage in the user-centered design process has been previously described by Summerskill and Marshall (2011) and del Rio Vilas, Longo and Rego Monteil (2013). In their respective digital worlds, which may be stand-alone or integrated, and based on a variety of data modeling techniques, DHM avail themselves to interact with digital prototypes. Such digital prototypes are slowly replacing physical prototypes which once formed the workhorse of usability testing. An example of this approach is the digital factory (e.g., da Silva & Kaminski, 2015).

While DHM can be seen as an active tool in human-centered design, they may as well be regarded as the passive object of usability investigations, for the tools themselves form a human-centered system, involving the DHM software and its user or operator (Perez & Neumann, 2015); and they must therefore comply with usability requirements. As a consequence, usability of DHM tools in use becomes a paramount aspect in achieving product design targets, for the usability performance of the tools directly impacts on the usability performance of the product. The same however could be argued for almost every tool, whether physical or virtual.

Overall DHM-designed physical systems or products are expected to provide superior productivity and operational efficiency (e.g., Greig et al., 2018), they are easier to understand and use and they have better usability, accessibility and an improved user experience (UX). Equally these qualities will apply to mature DHM products. Parallel to the physical world, many systems and products now exist in a virtual world (e.g., Manns et al., 2018). This also applies to DHM, for example. DHM can help specify user requirements in the physical or virtual world (belonging to this world themselves) (as exemplified by Sun et al., 2019, p. 4969), or evaluating designs against their requirements (Ribeiro Okimoto, 2011). Even more than in physical items, DHM help to understand and specify a context of use in a virtual world (e.g., Sanjog et al., 2015; Fan et al., 2017). For

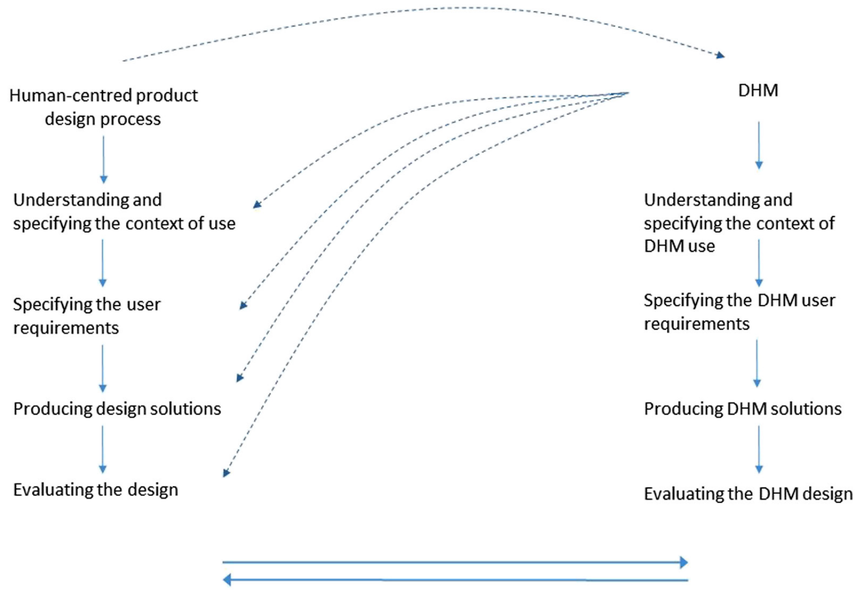


**FIGURE 13.1** DHM in usability.

example, a virtual DHM fastening a virtual bolt in a virtual engine assembly can receive feedback about the level of torque applied to the bolt. This feedback may be very useful in a training context. How the feedback is transformed and messaged to the DHM user, however, is again a matter of usability (Figure 13.1).

## 13.2 DHM REPRESENTATION OF THE USER

In such a user-centered design framework, products, systems and even services are designed with consideration of the people who will use them—the "user." Different assumptions will apply to a different "context of use," i.e., users behave differently and have different expectations (e.g., professional vs. leisure), different characteristics and different proportions (e.g., in a very cold vs. very hot atmosphere) in different environments. In scientific DHM, typically anthropometric, biomechanical and cognitive modeling (Scataglini & Paul, 2019) are used to represent the user. In the context of usability, this taxonomy is being expanded by persona, which represents a user's character, behaviors and expectations, rather than a physical or cognitive property or ability (Mueller et al., 2020). When developing a system, product or service, the first design step involves understanding and specifying the context of use. This includes the user groups (e.g., different nationalities), the characteristics of the users (e.g., different anthropometry), the goals and tasks of users (e.g., frequency of tasks; quality vs. quantity focus) and the environment (e.g., physical attributes). Much of this step can be modeled in DHM. From then onward, for specifying user requirements (Avsar, Fischer & Rodden, 2016), producing design solutions and evaluating the design mostly of user interfaces, DHM are particularly helpful. They inform on accessibility (Maruyama et al., 2016; Marshall et al., 2016), effectiveness, efficiency and maintainability of a system (Schulze, 2011; Bernard et al., 2019), product or service (Bernard et al., 2020). Moreover, they allow for variation of the task, user or other elements of context of use. While DHM can contribute significantly to validation and verification (Aromaa et al., 2018), issues remain even in predicting physical experiments (Delangle, Petiot & Poirson, 2017). Tools have not yet reached a state where a DHM could reliably predict user satisfaction or UX (Johnson & Fletcher, 2015), although comfort models have been included in DHM (Paul, 2019) and the use of artificial neural networks has proven promising in predicting ride comfort, for example (Cieslak et al., 2019). Obviously, modeling of UX would require a significant level of integration for cognitive and physical DHM, which will necessitate an understanding of physical-cognitive interaction beyond today's level of knowledge. Such has been shown by Califano et al. (2019) for the impact of expectations on comfort perception and modeling. Compared to the early crude DHM systems, nowadays systems are highly interactive, versatile, articulated, deformable, realistic and computationally efficient. They also interface with various types of sensors, such as motion capture systems (Badler et al., 2005). Nevertheless, more and more usability of complex DHM systems themselves becomes an issue, and interactive virtual reality (VR) interfaces, for example, have been suggested as an interface to instruct DHM (Geiger et al., 2018). Even though scripting of high-level commands, which are typically used for the definition of tasks (e.g., grasp *Object*; walk from *A* to *B*; carry *Object* from *A* to *B*), is a very efficient way to improve usability and interact with a DHM, it has become evident that mouse and keyboard are generally rather insufficient input devices to control a complex DHM.

## 13.3 DHM IN PRODUCT DESIGN

While DHM have become common product design tools for well over a decade and are well advanced in automotive (Högberg, 2009; Andreoni & Paul, 2019; Happee et al., 2019; Reynolds, 2019), aerospace (Rueckert, Rohmert & Pressel, 1992; Green et al., 2019; Hiemstra-van Mastrigt et al., 2019), military (e.g., Chatterjee et al., 2019; Bhatt et al., 2019) and manufacturing (Ma et al., 2010; Chen & Liu, 2014; Naddeo et al., 2013; Maurice et al., 2019; Jadhav, Arunachalam & Salve, 2019), their use in other areas such as apparel design (Shah & Luximon, 2019; Dove, 2019; McGhee & Steele, 2019; Durá-Gil et al., 2019), healthcare (Samson et al., 2009; Cao, 2011; Quintero Duran & Paul, 2018), Assistive Technologies (Suteu & Bazatu, 2015) and medical device design (Forzoni et al., 2019; Regazzoni et al., 2019; Little, 2019) is still emerging. They have been mostly applied to concept development and (rapid) prototyping though, and thus the early phases of product development, where a number of applications implemented motion simulation in virtual environments (e.g., Kuo & Wang, 2012; Qiu et al., 2014), their use in final usability testing, however, remains limited. Usability testing, for example, in household appliances or in common handheld tools and devices must also consider behavioral user characteristics, such as a naïve user vs. a professional expert, in order to identify the likelihood of usability issues. This may be one of the reasons why designers are still hesitant in their use of DHM (see also Ranger, Vezeau & Lortie, 2018).

## 13.4 DHM IN TESTING AND PREDICTING USABILITY

DHM lend themselves to an objective evaluation of designs, as far as they can represent typical users and personas, a realistic environment and common use cases. They support a cognitive walk-through and component-based usability testing, with clear usability metrics, such as task completion time, hand or finger forces, accessibility, etc. Moreover, they can be used as predictive tools, for example, in task analysis. Traditional observational usability testing is mostly based on video recording and subjective user satisfaction surveys, which can be error prone and misleading. A range of elements of usability, however—for example, behavior, emotions, perception, difficulties of understanding, higher level opinion expressed in comments—are not suited for DHM evaluation and are still best tested using ethnography, needs analysis, focus groups or questionnaire methods (see, for example, van den Broek & Westerink, 2009).

## 13.5 COMMON DHM TOOLS IN USABILITY

A complete overview and introduction to the most commonly used DHM tools in usability can be found in Scataglini and Paul (2019).

### 13.5.1 SIEMENS JACK

SIEMENS JACK (Raschke & Cort, 2019) has been used in a wide array of applications, and is well integrated into the SIEMENS product life cycle management (PLM) product suite, a comprehensive product design and simulation environment. While it is integrated with the SIEMENS NX CAD software for product design, it also sits in SIEMENS Teamcenter where a large amount of data can be visualized in a tessellated format to represent complete systems, such as a complete vehicle including the driver. JACK is also integrated into SIEMENS Process Simulate, where task sequencing, assembly operations, automation or robotic interaction are simulated. In its stand-alone version (Figure 13.2), JACK has a task simulation builder module which allows the software to automatically animate the DHM based on high-level task descriptions and environmental constraints. The task simulator then independently produces a report on a range of ergonomic factors, such as strength requirements, postural loading, times or distances. JACK integrates with VR and motion capture systems to position and control the DHM.

### 13.5.2 Human Solutions RAMSIS

The RAMSIS DHM (Wirsching, 2019) was developed in the late 1980s for the German automotive industry to design and test vehicle packages. Given its intended use, it started to be modeled around a "most likely" posture model for the then most common type of sedan passenger vehicles; and later when the DHM had effectively become a standard for package engineering in the global automotive industry, further posture models were added to account for other vehicle types which were either emerging (e.g., the "H30

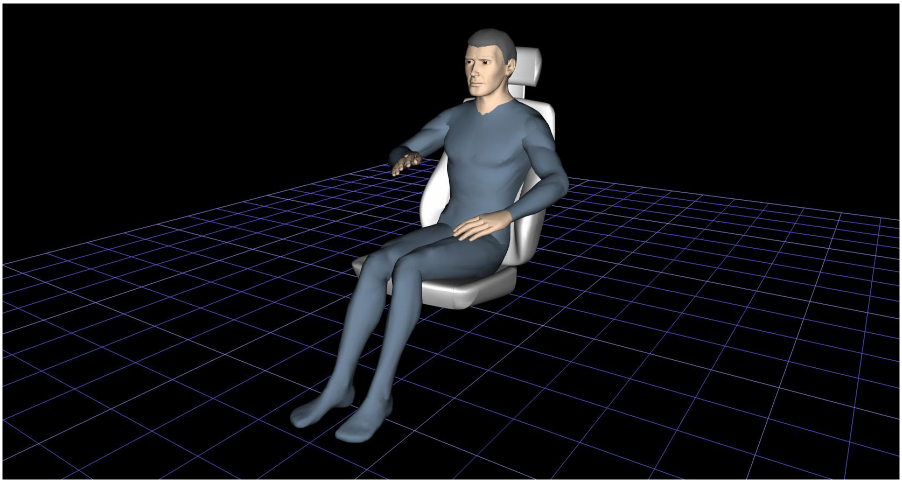

**FIGURE 13.2** DHM SIEMENS JACK.

model" for SUV) or had been more common in other markets (e.g., the "truck model" for pick-up and commercial trucks). The early RAMSIS DHM focused on automotive applications, such as optimizing accessibility, visibility, reachability, posture, seatbelt fit, safety and discomfort. Eventually further postural models were added, such as an aircraft, motorbike and free-standing model (Figure 13.3). The DHM was also expanded to include some biomechanical and cognitive functions. While initially stand-alone and thus limited in its usage in integrated engineering processes, RAMSIS later became available as plug-in for the most common C3P packages CATIA and NX. Nowadays RAMSIS is also used in industrial applications.

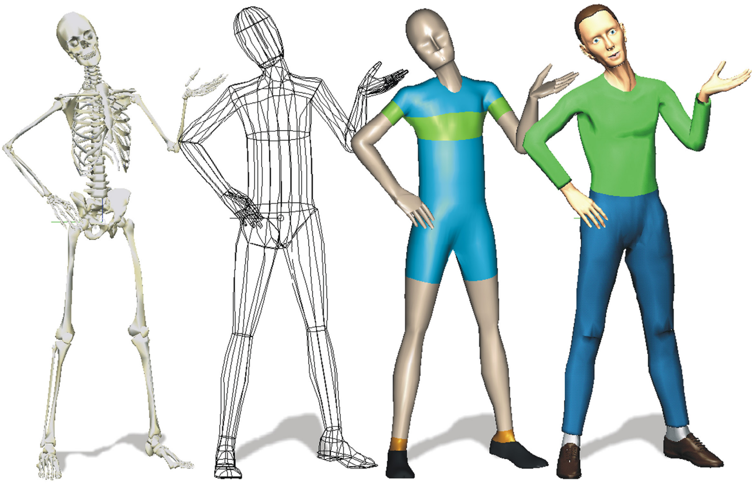

**FIGURE 13.3** DHM Human Solutions RAMSIS.

### 13.5.3 Dassault Systèmes 3DS Virtual Ergonomics

Today's 3DS Virtual Ergonomics DHM tool was initially created as a generic standalone DHM called SAFEWORK in the early 1990s, and its first customer was Boeing where the tool was used in virtual manufacturing (Charland, 2019). Nowadays part of the Dassault Systèmes extensive suite of engineering software, Virtual Ergonomics was first integrated into the CATIA and DELMIA C3P systems and is currently part of their 3DExperience platform. The DHM is used broadly in a wide range of industries (e.g., Sanjog et al., 2012; design of a shoe rack). The Virtual Ergonomic tool focuses on ergonomic analyses and integrates several ergonomic methods (e.g., RULA, NIOSH, Snook & Ciriello, energy expenditure, etc.) for this purpose. Fields covered are reach, clearance, vision, forces in lifting, carrying, pushing and pulling, fatigue and postural comfort or safety. Given the complexity of the DHM tool, its associated analyses and integration of the method into a complex industrial design process, Dassault Systèmes and Boeing have recently focused on usability of the DHM and its application in industrial practice. At the end of this development, the DHM will be an integral part of the product design process, and DHM simulation outcomes will be tracked in-the-loop through the Dassault Systèmes ENOVIA product data management system (Figure 13.4).

### 13.5.4 NexGen Ergonomics HumanCAD

HumanCAD is based on an early DHM from 1990, which was initially a 2D tool called ManneQuin. HumanCAD is now a fully animated DHM with forward and inverse kinematics, collision detection and various analytic functions for reach,

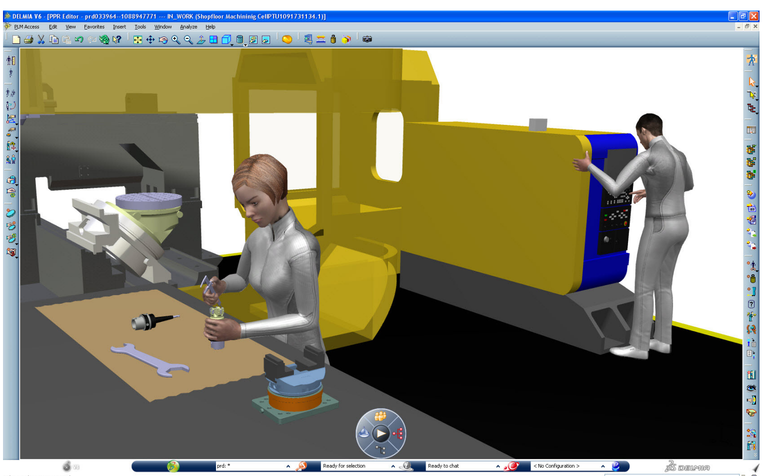

**FIGURE 13.4** DHM 3DS Virtual Ergonomics "Teo" and "Sia" operating in a CNC machining center.

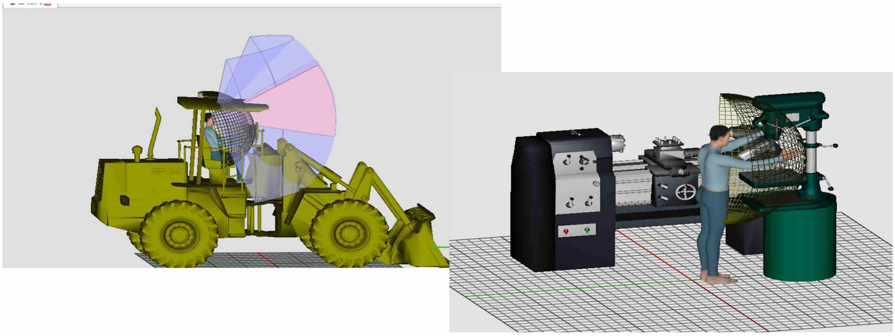

**FIGURE 13.5** DHM HumanCAD.

vision and ergonomic analysis (Pinchefsky, 2019). It incorporates two biomechanical models and thus allows use of the NIOSH, RULA, OWAS, Snook & Mital or energy expenditure methods. Moreover, the biomechanical core allows the DHM to predict joint discomfort, such as shoulder comfort zones, joint amplitude discomfort (JAD) and joint positions discomfort (JPD). While HumanCAD is still available stand-alone, HumanCAD-MQSW is a fully integrated low-cost plug-in within the Dassault Systèmes SOLIDWORKS CAD software system, which is used in many academic teaching environments (Figure 13.5).

### 13.5.5 SANTOS

The SANTOS DHM was initially developed as part of the US Virtual Soldier Research program. It follows a strictly physics-based approach called human predictive dynamics (Abdel-Malek et al., 2019). The 215-degree-of-freedom model allows for the analysis of dynamic tasks, which particularly lends itself to the study of interaction between a human and objects. An example of this ability is a SANTOS study on a soldier's ability to jump when wearing a back pack, where both the geometric interface between the soldier and the back pack, and the dynamic interaction between the human body in motion and the back pack in motion are to be considered. The SANTOS model (Figure 13.6) includes physiological parameters of strength, fatigue and cardiovascular factors, as well as a complete musculoskeletal model. It is therefore suited for predicting injuries from overload conditions; a functionality which has been used in athletics and the military. The aims of the SANTOS DHM project are aspirational: in-line with virtual mock-ups, digital twins or the digital factory used in industry for mechanical systems, SANTOS aims at providing a human digital twin. This digital twin DHM is planned to include cognitive abilities, which will enable SANTOS to perform in usability testing of equipment, and provide human-like feedback. SANTOS software includes a rules-based artificial intelligence (AI) controller which allows the DHM system to plan and sequence tasks, and generate DHM motion paths based on a library of tasks for walking, climbing, kneeling, etc., which is based on behavioral studies. SANTOS predictive physiology considers

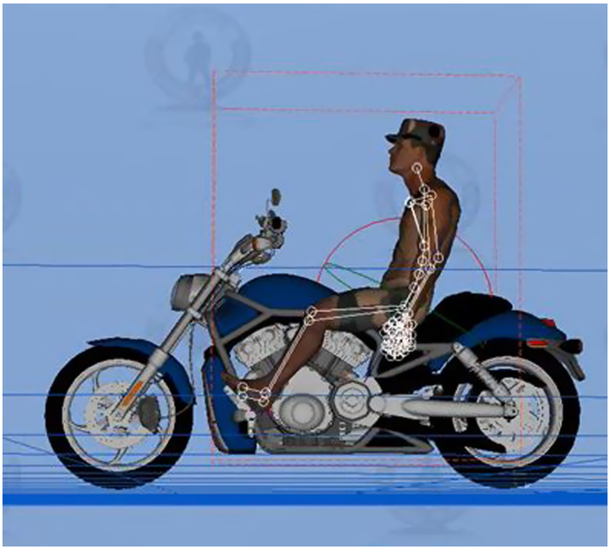

**FIGURE 13.6** DHM SANTOS.

environmental factors such as air temperature and humidity and predicts body temperature, heart rate, respiratory rate, oxygen consumption, energy consumption and an overall physiological strain index. Among other developments, SANTOS is further improved in the areas of cognitive abilities, realistic behavior, AI and the human-to-DHM interface; all of which will substantially expand the capability of SANTOS to perform in usability testing.

### 13.5.6 IMK EMA

This recent DHM system is a product of digital factory developments in the automotive industry in Germany, where it was found that manual production processes, human-machine and human-robot collaboration required a DHM representation that was capable of interacting in a complex, process-driven industrial simulation environment. Thus, the computationally efficient DHM tool EMA (Figure 13.7) was launched in 2012 (Bauer et al., 2019). EMA has a clear focus on planning, simulation, visualization and evaluation of manual production tasks. For this purpose, the system uses industry standards methods time measurement (MTM) and ergonomic assessment worksheet (EAWS) to generate, aggregate and evaluate motion elements, postures, forces and eventually tasks. While limited in its ability to represent user details, such as a larger range of anthropometry, it was designed to support complex simulations in representative simulated work environments. In product development, EMA is useful in concept evaluation, production planning, virtual prototype build, human-robot collaboration planning and continuous improvement. Recent developments added a manikin configurator, including gender, age, stature, corpulence, range of motion and various work-related restrictions, such as vision,

FIGURE 13.7 DHM EMA.

hearing or body forces. EMA interfaces with motion capture data to drive motion of the DHM.

## 13.6 USABILITY AND UX OF DHM TOOLS

Despite a large amount of non-academic, user internal studies about DHM usability and UX, published studies on the topic are surprisingly scarce. Perez and Neumann (2015) and Quintero-Duran and Paul (2018) have studied aspects of usability of DHM tools; other facets of usability have been discussed in Shah and Luximon (2019) and Peters, Wischniewski and Paul (2019). Usability and UX of DHM tools can be categorized into three areas:

1. UX of the DHM software tool in its own

   This category considers whether the tool is focused on its user group. It reflects learnability, accessibility, visual design, functional content, efficiency, information architecture, memorability and how pleasant and intuitive it is to use the DHM tool. Overall, the tool must be relevant and meaningful. While DHM tools have been mostly used by well-trained experts in the past, both industrial customers and DHM developers are now interested in broader access to DHM tools. To support this expansion, DHM tools will need to acknowledge different user types and provide adequate user-level customization, for example, in the form of knowledge-based expert systems.
2. Integration of the DHM software tool

   DHM tools are typically intended to be used as an integral part of a design or engineering process. Such processes will normally involve other software, such as design, CAD or CAE packages. While historically DHM users were DHM or ergonomic experts with a clear focus on the DHM, users now are much more likely to come from a design or engineering background, with little or no expertise in DHM. This leads to two opposite direction integration requirements. The non-expert DHM user who is an expert user of design or engineering software expects the DHM to be embedded into their "world view." The DHM is expected to reside as a tool within these software systems, and the DHM interface must not look or behave differently from the "mother system." For example, if the "mother system" uses a right mouse button to scale a view, and the DHM system uses the same right mouse button to rotate the DHM, then a mismatch occurs, and an *integration usability issue* arises. Similarly, if a CAE system follows a node-based structure, the DHM must comply with same structure to assure usability. From the expert DHM user perspective, outputs which are generated in the DHM tool (e.g., postures, zones, forces) must integrate into the design or engineering system as valid objects. An example of an *integration usability issue* in this case is where a reach zone is exported from the DHM to a CAD system, and the object can be no further modified (e.g., attached to a node) in the CAD system because it is recognized as an external and imported geometry object. Integration of DHM and other design and engineering tools however requires standardization of data formats as a minimum (Paul & Wischniewski, 2012), and a more widespread implementation of such formats in all systems (e.g., COLLADA).

3. Reliability and validity of the DHM software tool

   Reliability concerns occur where DHM systems use optimization algorithms, and boundary conditions are not transparent or controlled. In this case, a repeated use of a function will yield different outcomes (e.g., for predicting a posture). Another example of a *reliability usability issue* is where different DHM are used in a process or collaboration, and the different DHM produce distinct outcomes (e.g., visual cones) because they use nonuniform anthropometric data, postural prediction or underlying methods from disparate sources. Moreover, reliability of DHM tools depends on the amount of errors generated by product functions, their severity and easiness of recovery from those errors. Validity of DHM tools relates to their ability to predict real-world outcomes. A *validity usability issue* ensues where DHM simulations and predictions fail to coincide with real-world (laboratory) experiments or real-world user feedback. An example is driver accommodation in truck cabins, where DHM underestimate driver corpulence for specific body statures, because their underlying databases have not yet been updated to reflect the rapidly changing anthropometry of a population (see also Wu, Tian, & Duffy, 2012).

All three categories of DHM usability and UX impact on user satisfaction with DHM tools and contribute significantly to their success in the market.

## 13.7 CASE STUDIES

### 13.7.1 Hospital Bed Design

Moving patients in hospital beds (Figure 13.8) during care activities is a common task for nurses. Nurses can be considered the normal active user of such beds, rather than the patient who typically remains a passive bed user. The use of hospital beds frequently involves pushing and pulling (Quintero-Duran & Paul, 2018) and particularly for bariatric patients, often multiple nurses jointly move a hospital bed, further complicating usability conditions and UX. Pushing and pulling when moving hospital beds is a dynamic task, as the lower extremities are involved in a walking movement and arms are steering the bed. On the other hand, the trunk remains static with isometric muscular force exerted while controlling and steering the moving bed. Static load and effort are known to cause user strain which will normally have a negative impact on user satisfaction with the bed. Frame geometric design, frame proportions, handle design, bed weight, wheel design, roll resistance and interface design of powered beds contribute to hospital bed usability and UX.

The use of virtual environments and DHM tools is very useful for evaluating a usability scenario such as bed moving in hospital. When usability is studied with real humans, ergonomic assessments may be costly, time-consuming, tedious and require

**FIGURE 13.8** Hospital bed in CAD.

an uncommon and specific laboratory setup. If studied in a real-world situation, the study may interfere with normal workplace activities which is critical in hospitals. Application of a DHM tool to analyze usability of a hospital bed, and specifically the task of bed moving, overcomes these limitations.

DHM tools in design and testing for the healthcare industry are particularly valuable because generally tasks in healthcare involve postures, movements and activities that are complex to simulate in experiments using real humans and environments. Thus, the use of analytic tool studies represents a significant advantage when evaluating designs and use case scenarios in the healthcare industry. DHM have been applied to the ergonomic assessment of patient lifting, where chair, hoist, bed, additional tools and process all contribute to the outcome of the task. This is one task where hospital bed design features and usability impact on work practice.

Typical hospital beds (e.g., Hill-Rom 900) weigh 100–120 kg unoccupied and have a safe working load of 200–300 kg, and therefore require superior usability to avoid ergonomic hazards.

This case study looks at the usability assessment of hospital bed moving using the DHM tool imk EMA (imk automotive GmbH, Chemnitz), and provides the results from simulations in the DHM tool. The usability assessment performed in a virtual environment allows the variation of body proportions in order to represent typical anthropometric conditions, the variation of handle-coupling conditions, the variation of mobility pathways in hospital and the variation of rolling resistance. Common ergonomic methods used in the case study are integrated in the Ergonomic Assessment Worksheet (EAWS) and are therefore quasi-static. EAWS calculates and assesses a workload from posture, interface condition, action forces and repetition. Posture evaluation in EAWS considers traditional ergonomic evaluation methods such as EN 1005-4:2005+A1:2008, ISO 11226-2000, Toyota, OWAS and RULA. This workload is, among other factors, a function of the bed's usability. If the other factors are kept constant, then the EAWS score can be used to assess usability of the bed.

The simulation process in this case study is divided into three areas: environment, manikins and the actual usability analysis. In addition to these sections, tasks, postures and bed positions are defined to inform the analysis phase. For the digital environment design, only physical elements of the usability case are considered, while cognitive and psychological factors cannot yet be studied in the simulation. At this stage, input parameters such as loads and distances were established.

The usability assessment performed in a virtual environment allows for variation of body proportions in order to represent typical anthropometric conditions. In EMA, human models are predetermined on a German DIN-defined population and at the time of the study, it was not possible to scale the models. The German 5th percentile stature female was selected for the study, which in EMA presents with 52 kg of weight and is 40 years old. Even though it is possible to select gender and percentiles (5th, 50th, 95th) of the human models, other parameters such as nationality, age, weight and somatotype were predetermined in EMA (V.1.5.1.0) and could not be modified. Anthropometric data was also not extrapolated for the study year to reflect secular growth and up-to-date anthropometry. Additional manikins could be imported into the simulation (Figure 13.9), however without the option to adjust

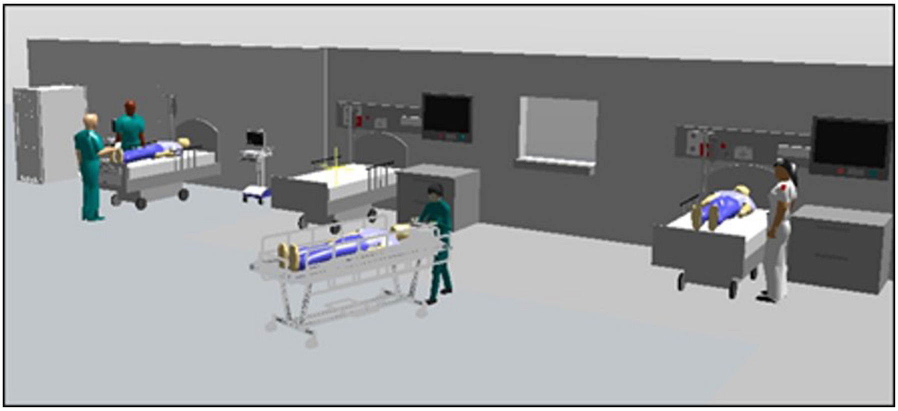

**FIGURE 13.9** EMA representation of a hospital ward.

their anthropometry measures or include them in the analysis. Consequently, those human models were used only for the purpose of creating a representative visual virtual hospital environment.

A grand score of 78 was obtained for the simulation of moving a hospital bed, which according to the EAWS overall evaluation scheme with a three-zone rating system falls into the red zone (>50 points) and represents a high risk for the development of MSD, requiring the task to be avoided or modified.

For the evaluation, EMA considers posture duration and frequency, however as a sequence is not considered, recovery aspects are not accounted for. For the assessment of hospital bed moving, a posture summary score of 2 was obtained. For action forces, a total score of 55 was obtained for the simulation, corresponding entirely with whole body forces and not reflecting forces of the hand-finger system. Parameters such as muscular force, force type (arm/body force or finger force) and wrist joint/kickback level (light, heavy, very heavy) are adjustable in EMA for each task. Duration and frequency are calculated by EMA according to the complete simulation setup, the specified shift time and number of cycles per shift (with an assumption of 10 chosen for the case study). The magnitude of force exertion was assumed as 350 N in correspondence with literature. For manual materials handling, a total score of 20.5 points was obtained entirely representing the push/pull task. In the EAWS evaluation system's load section, the weight of loads, the corresponding posture according to the task, frequency and duration of the task and the working conditions are considered. The weight of the hospital bed was 250 kg.

In order to establish the transport route for the hospital bed in the simulation, a realistic hospital environment was replicated. Movements and variables such as straight walking along corridors, 90° turns when transporting the bed around corners and 90° turns to enter/exit lifts were included in the simulation. EMA incorporates some dynamic methods, enabling the software to consider external factors such as floor friction. This functionality however was not well documented and didn't accept physical parameter input, working instead with unspecified categories. Asymmetric effects such as trunk rotation, lateral bending and far reach (twist, bend and reach scores) were not realistically considered. During bed rotation movements (e.g., pushing around corners, sideways or in a confined space), lateral bending or trunk rotation can be expected. Such events are reported as common issues in real workplace scenarios; however, they were reported with a "0" score in the simulation results. This discrepancy could be attributed to the oversimplification of complex operations and movements performed by the digital model, where the software automatically determines the shortest walkway and the best boundary conditions of the work task, which may not always correspond to real movements and conditions in the workplace. From spine values reported in EMA for the simulation, it was shown that only variability in thoracic, lumbar and pelvis flexion angles was reported, while thoracic and lumbar rotation angles were reported as "0." Obviously, the DHM tool did not realistically represent the actual complex worker movements.

At the time of the study, it was not possible to analyze how anthropometric conditions influence usability outcomes, because it was not possible to generate custom mannequins for the simulation in EMA. Ergonomic methods integrated in EAWS pose the risk of misinterpretation of results as the methods integrated were not originally developed to be used in conjunction with DHM.

EMA is well suited for ergonomic analysis through parameter variation in a simulated environment. Nevertheless, this analysis in a DHM tool has limitations that need to be considered when interpreting the results. Complex interface conditions such as the influence of handle design, floor materials, front caster locks, effects of wheel size and wheel rolling resistance cannot be simulated in EMA.

Given the limitations found, a simulated assessment of the biomechanically complex task of pushing a hospital bed remains a challenge in EMA, although the DHM tool can provide valuable direction for further design.

### 13.7.2 Vehicle Ingress-Egress

This usability study aimed to identify and optimize the main design parameters of ingress-egress, as well as understand the preferences and factors of influence for comfort perception in a selected Chinese population. Research data was captured from 22 healthy participants in several ways:

- Anthropometric data measured by the researcher;
- Motion capture data using VICON MX 20 and Optitrack motion tracking systems with 12 cameras each;
- Written questionnaires; and
- Videotaping of participants during motion capture trials.

The study was conducted in a controlled realistic laboratory environment in Australia. A China specification Ford Mondeo LHD vehicle was supplied by Ford of Australia, and a Mercedes S-Class RHD vehicle was provided by Mercedes Benz of Australia. Ingress/egress motion was recorded using VICON NEXUS/Optitrack AMASS 12 camera systems and video cameras. All ingress/egress motion was recorded on the right-hand side of the vehicles, i.e., passenger-side Ford Mondeo and driver-side Mercedes S-Class.

Subjects were measured for *stature, weight, sitting height, shoulder width, buttock to knee length* and *hip breadth*. According to the Chinese anthropometrical data standard GB-10000-88 which was corrected for actual anthropometry from data measured in a clinic in China, stature of male participants was chosen to lie within a range of 163.7 cm (5% male)–181.5 cm (95% male), and a weight range of 60 kg (5% male)–94.6 kg (95% male). Similarly, the range of female participants was chosen to lie within 153.7 cm (5% female)–169.6 cm (95% female), and a weight range of 52.5 kg (5% female)–81.3 kg (95% female). The 22 (11 males; 11 females) selected participants (mean stature 1657 ± 99 mm; mean weight 65.3 ± 14 kg; mean age 34 ± 7years) were all of Chinese ethnic background.

Ingress-egress motion of subjects was video recorded, and time synchronized with motion tracking data. Each subject performed ingress/egress three times. A custom marker set (Figure 13.10) was used to track body motion. Mercedes motion data was then processed in a VICON NEXUS pipeline and modeled in Visual3D (Figure 13.11) for further biomechanical investigation, and transfer of trajectories into a DHM (Figure 13.12). While motion tracking can be readily used in biomechanical laboratory studies, the application to usability studies is somehow limited. In the case of this study, markers are occluded over substantial periods in visual tracking

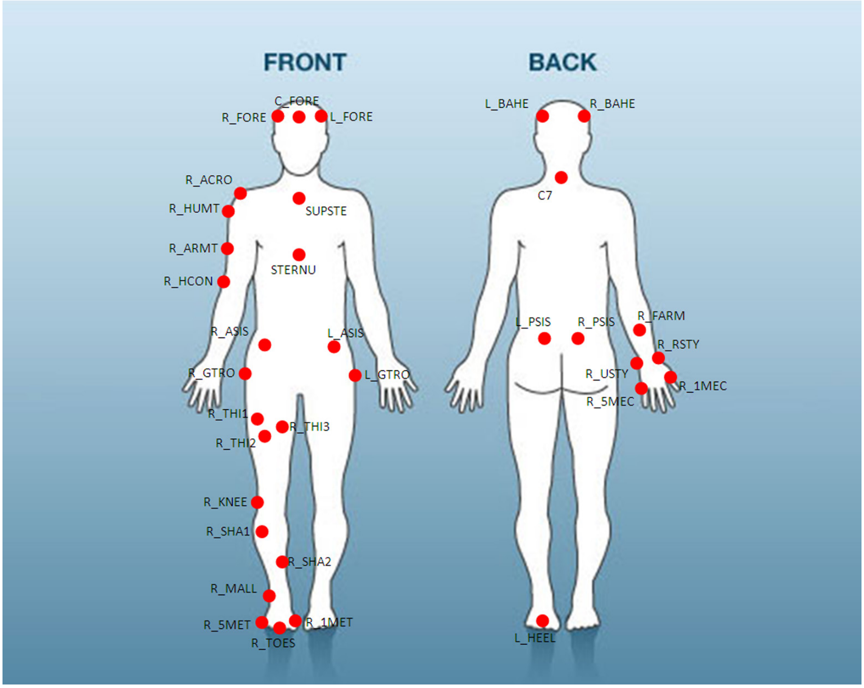


**FIGURE 13.10** Ingress/egress motion capture marker setup.

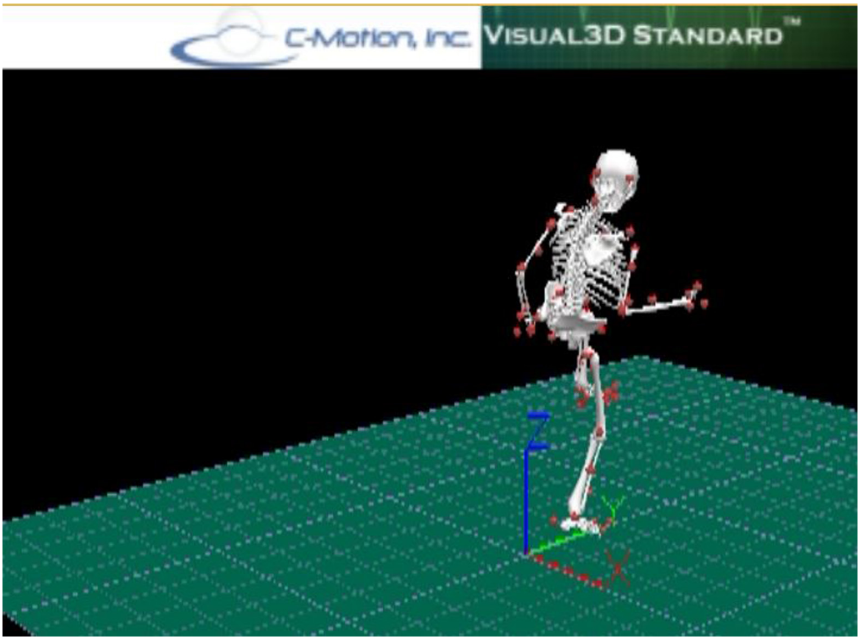


**FIGURE 13.11** Simulated ingress/egress motion (Visual3D).

of the ingress or egress motion, requiring interpolation which becomes more and more cumbersome the longer the period extends. The same issue hampers magnetic marker tracking, where the vehicle environment is not conducive to such a method. Furthermore, markers extend space requirements for the motion and hinder natural motion rhythms. Moreover, when contacting vehicle geometry, markers tend to get displaced or fall off. Hence, traditional motion tracking is not a suitable method for studying usability of a vehicle design for ingress/egress. The method lends itself however to inform a DHM study. In this case, only a limited marker set from motion tracking was used to drive the motion of the DHM, which can then predict motion of those body parts which are not directly tracked. As a result, whole body motion can be analyzed, segmental motion parameters can be calculated and joint dynamics computed to assess motion trajectories and objective biomechanical load.

The importance of ingress/egress in relation to overall rear compartment comfort had been previously determined as high (7.8 VER), and ingress/egress was typically considered as "somewhat important" when purchasing the car. Anticipated ease of ingress with door shut was on average 7.9 VER for Mercedes and 7.3 VER for Ford, and improved when the door was opened to 8.6 VER for Mercedes, while it decreased for Ford to 7.0 VER. Actual perceived ingress was slightly better than anticipated for Mercedes at 8.8 VER, and better for Ford at 7.5 VER. On the other hand, perceived egress was lower than anticipated for Mercedes at 7.9 VER, while it was like anticipated egress for Ford at 7.4 VER. Overall ease of ingress was typically

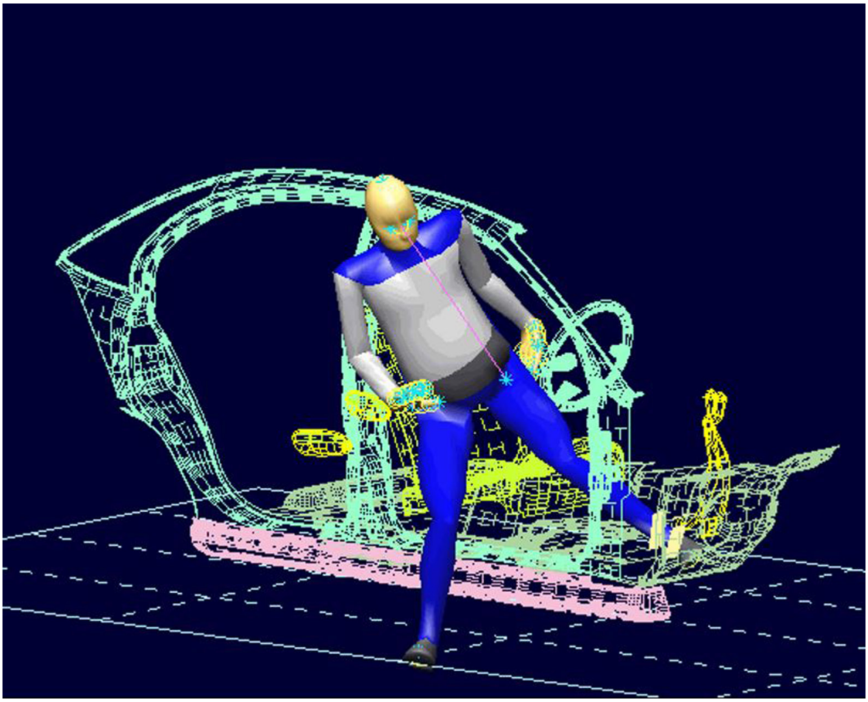

**FIGURE 13.12** DHM RAMSIS ingress/egress simulation.

"very satisfying" for Mercedes and "slightly satisfying" for Ford. Overall ease of egress was typically "slightly satisfying" for Mercedes and Ford.

While the findings were consistent with phenomenological considerations—ingress is normally perceived as easier than egress in lower H30 vehicles, and larger vehicles generally provide more space for ingress/egress—the usability laboratory study failed to inform the designers about specific design targets. Application of the DHM tool to study usability of the vehicle designs however allowed in-depth understanding of the impact of design parameters on usability perception.

### 13.7.3 Welding Station

In this case study, a systematic ergonomic evaluation approach was adopted to the usability analysis, assessment and design of a welding station (Figure 3.13). In the analysis stage, the welding task was examined to obtain the functionality of the welding process, establish the boundaries of the process and understand how the different elements contained within the process interacted. The analysis identified the various constraints and bottlenecks of the process permitting subsequent stages of the study to focus on the problem areas. The principal outcome of this evaluation was to enable the development of solutions to address these problem areas by optimizing human interaction with the other elements of the welding fabrication process.

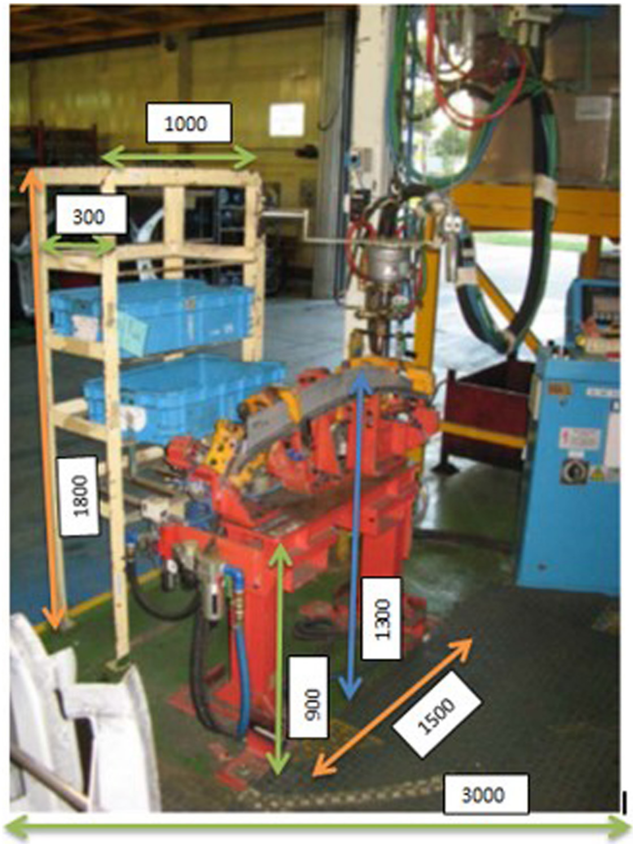


**FIGURE 13.13** Automotive welding station.

Car frames are placed into a holding jig where they are held in place by mechanical clamps. The welding station uses a resistance spot welder to weld parts onto a car frame. The spot welder is suspended on an overhead gantry system to compensate for the weight. The operator moves the spot welder into position above the car frame. Operators consult the weld drawing for part selection and part placement, then select the parts from the blue bins and place the parts to be welded onto the car frame at the required position. They manually move the spot welder to each position for welding the part in place and push a button on the weld head which closes the welding clamps. Once the clamps are closed, the weld starts automatically. The operator then pushes the button a second time to open the clamps and stop welding, and eventually removes the welded frame from the welding jig and places the completed assembly onto a support rack.

Hierarchical task analysis (HTA) identified several problems associated with the various ergonomic domains (Table 13.1). A principal bottleneck identified in the process was the cognitive load placed on the welder to execute approximately 20

**TABLE 13.1**
**Welding Station Aggregated Ergonomic Risks from HTA**

| Condition | Ergonomic domain attribution | Welder implication | Quality/production implication |
|---|---|---|---|
| **Multiple weld variations** | Cognitive | Mental stress<br>Demotivation | Parts missing<br>Poor quality |
| **Reaching forward to retrieve parts from storage*** | Physical<br>Postural load<br>External load | WMSD injury<br>Fatigue | Lost production time<br>Increased errors<br>Poor quality |
| **Prolonged standing posture*** | Physical<br>Postural load | WMSD injury<br>Coronary and circulatory health risks<br>Fatigue | Increased errors<br>Poor quality |
| **Lighting considerations** | Physical | Reduced vision | Incorrect selection or positioning of parts<br>Increased errors |
| **Excessive noise** | Physical | Hearing damage risk<br>Loss of concentration | Poor quality<br>Parts missing |
| **Heat exposure** | Physical | Heat strain | Increased errors |
| **Awkward body postures***<br>**Shoulder position for weld head grip*** | Physical | WMSD injuries<br>Shoulder and upper body injuries from overhead reaching<br>Forearm, wrist and hand overuse injuries<br>Back injuries | Poor quality |

Conditions considered for DHM study are marked with*.

possible variations in the parts to be welded. These multiple variations required the welder to continually refer to the welding task sheet, thus adding process time and distracting attention from the principal process of welding. Beyond the cognitive load, the welder was exposed to a physical workload, including manual materials handling (MMH), postural work and environmental stressors (lighting, noise, thermal). DHM EMA (imk automotive, Chemnitz) was then used to further analyze workflow, MMH and postures to redesign the workstation and improve usability.

EMA simulated the complete working cycle described before, including part retrieval, part transport, welder positioning and welding, so that critical postures and forces could be easily identified (Figure 13.14). The DHM tool was configured to represent the working population between a 5th percentile body stature female and a 95th percentile body stature male. Based on EMA EAWS calculations, overall

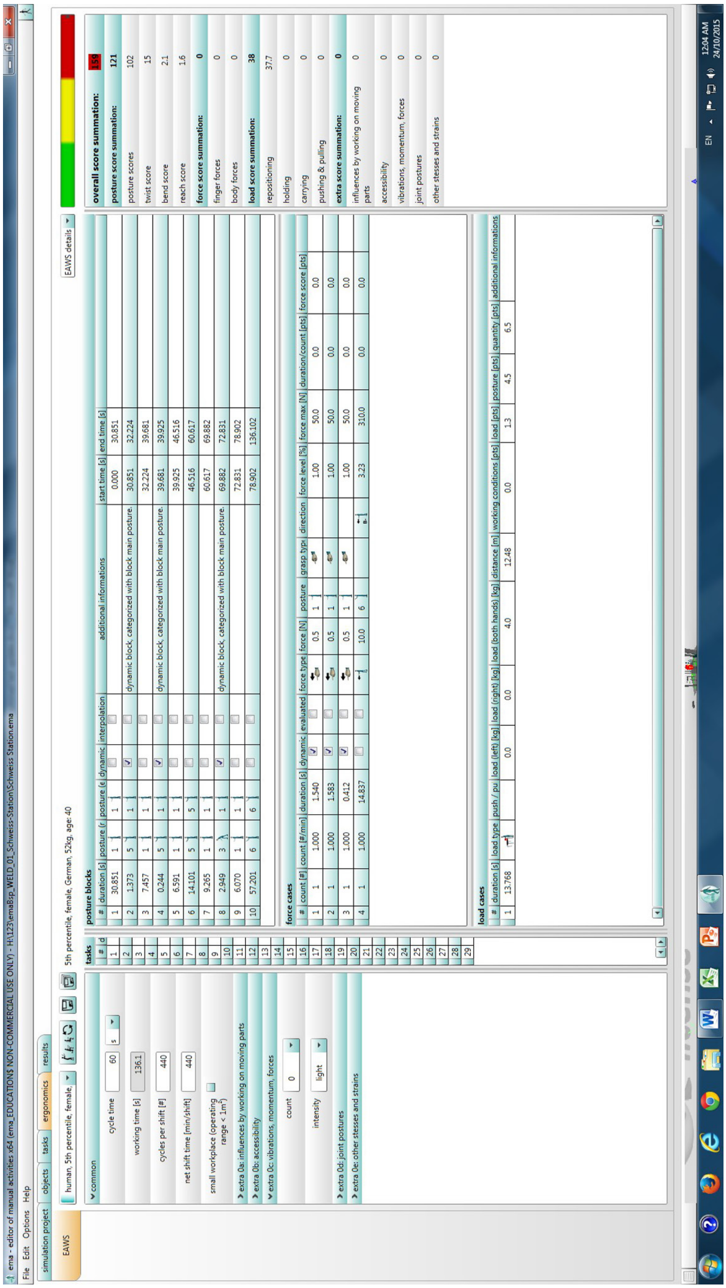


**FIGURE 13.14** Posture and force tracking over time and tasks in EMA.

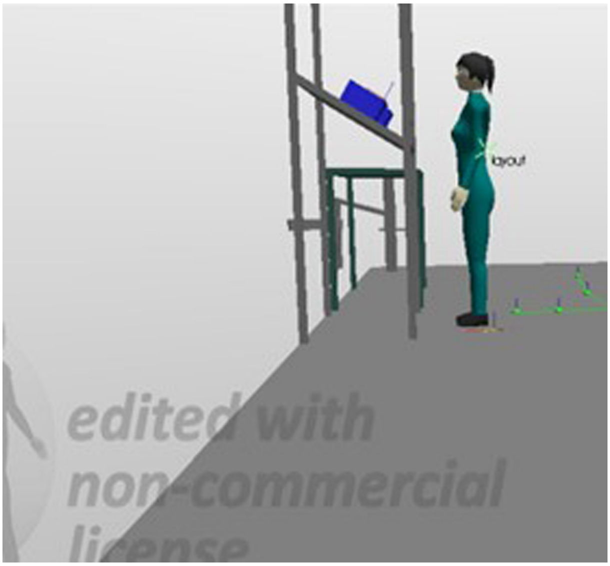


**FIGURE 13.15** Small female worker in EMA retrieving parts from the bin rack.

postural scores for both percentiles were similar and within the red band (high-risk area) as most of the postural loading resulted from prolonged static standing and overhead work. The load score for the short female however was much higher than for the tall male due to an anthropometric mismatch when retrieving parts from the rack (Figure 13.15). Moreover, spine and pelvis angles highlight the inadequate working height for the short female worker at the welding station. The welding table height of 1300 mm is too high for this worker. Therefore, both the bin rack and the height of the welding table were revised.

Objects to be used by standing workers are best placed between hip and shoulder height to minimize postural stress according to generic ergonomic design guidelines. The worker's stature and vertical depth of the work object (jig) are considered to put the hands in a comfortable position. However, at this workplace, hip-to-shoulder distance is the wrong target measure because the work surface would be too low for the tall male and too high for the small female worker (Figure 13.16). Here, the recommended welding table and rack height range is the difference between the elbow height of the tall male and small female workers. To improve usability, the welding station and rack height must be adjustable and lie between 955 and 1192 mm when considering the welded part. For reach into the bin rack, the maximum permitted horizontal distance is defined by the small female arm reach and is 282 mm. Required knee and foot clearances are conforming to the standards and are 80/120/150 mm (knee depth, foot height, foot depth). Maximum holding times should be less than 2.15 min in an 8-min welding cycle, and if longer, adequate supports must be added to the design of the workstation to provide acceptable usability.

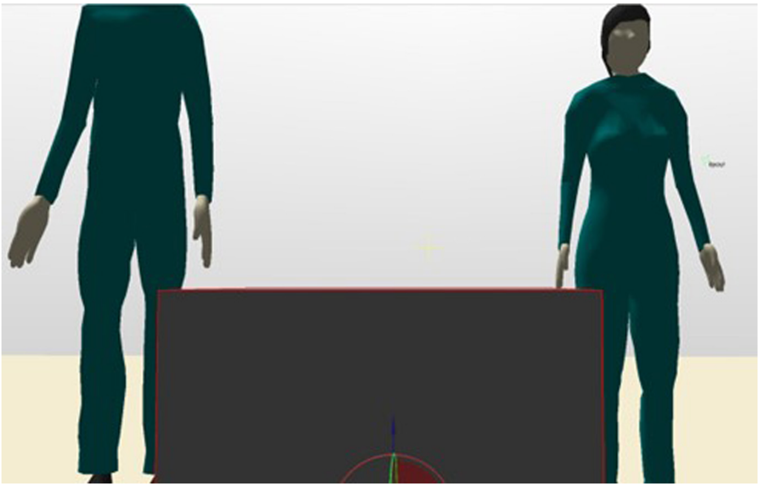

**FIGURE 13.16** Usability mismatch for a tall male and small female worker when using generic ergonomic design criteria.

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# 14 User Experience and Information Architecture

## *Interaction with Recommendation System on a Music Streaming Platform*

*Luiz Agner, Barbara Jane Necyk and Adriano Renzi*

**CONTENTS**



## 14.1 INTRODUCTION

Human-computer interaction has evolved dramatically since the last decade, expanding and revising user experience (UX) concepts. This evolution contributed to shifting trading processes, rethinking companies' culture, changing laws and political scenarios, revisiting privacy concerns and transforming how people interact with each other, with machines in the digital environment. In a world where physical and digital environments merge into one experience involving digital apparatuses, physical ambiences, users, actors, data, algorithms and information in interoperability, information structures are growing dynamically beyond their boundaries. As Pierre

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Levy (1993) said, users embrace editors' and protagonists' roles, gaining an active approach toward media. Furthermore, artificial intelligence (AI) has been rapidly adapting to the new technology era in a background layer, becoming a new and significant change agent.

In this scenario, this text attempts to understand streaming music consumption and human-information interaction based on users' mental models about machine learning (ML) algorithms. Through semistructured interviews with Brazilian undergraduate students regarding their experience with the Spotify platform, our research aimed to identify users' perceptions about how algorithms suggest categories and how users feel its relevance in a context where sometimes transparency and explainability are forgotten requirements. Conflicts in the intersection of artificial intelligence with user experience are discussed, as well as the "black box" feeling and other biased user perceptions about algorithms' functioning.

Regarding Spotify, the following research questions inspired us: What is possible to know about the experience quality based on these interactions? Are users satisfied with custom recommendations? Are users able to formulate a mental model on how recommendation systems work? What is the mental model built by users regarding machine learning algorithms? Do users understand how machine learning operates and can interact with these algorithms to improve their outputs and better match them to their goals? Do users worry about privacy issues?

This research also aims to better understand how the information architecture discipline is evolving toward a broader horizon. From classical authors such as Rosenfeld, Morville, Arango, Lima-Marques, Morrogh, Wurman, Resmini and Rosatti (among others), we propose to discuss how the fundamentals of information architecture are being challenged in the era of machine learning. We intend to highlight contemporary tendencies that may reframe the discipline as the reported changes conducted the goals of overcoming information overload and establishing findability as objectives set beyond. These goals are substituted by technological solutions that systematically collect and analyze massive user interaction data to display relevant information. This work describes interconnections between information architecture and recommendation systems, considering its purpose of creating personalized categories and filtering data to present meaningful content.

## 14.2 INFORMATION ARCHITECTURE: FROM WEB SITES TO ECOLOGIES

If the user experience could be metaphorically compared to a large umbrella, including several correlated disciplines—such as usability, content strategy and user research—as Willis (2020) has done, information architecture would undoubtedly be one of its main strands.

As Rosenfeld, Morville and Arango (2015) have established, information architecture is the discipline for the structural design of digital landscapes, through the synthesis of organization, labeling, navigation and search to build physical, digital and transmedia information ecosystems. Its goal is to develop experiences and products that provide the best usability, findability and comprehensibility.

According to Albuquerque and Lima-Marques, it can also be seen as "a systematic effort to identify standards and create methodologies for defining information spaces" (Oliveira, Vidotti and Bentes, 2015). Its purpose includes the representation and manipulation of information and the generation of relationships between entities to construct information spaces. According to Benyon and Resmini (2017), information architecture relates to structure, access, retrieval and use of the content, focusing on space, navigation and way-finding.

Rosenfeld, Morville and Arango (2015) pointed out that today information has become more abundant than ever before: with the ubiquity of media, a series of devices and objects connected to the Internet for all kinds of daily and routine activities, in homes, offices or urban spaces, have come to configure new and diverse ways of human beings interacting with information. The process has caused the escalation of a problem known as "information overload" (Wurman, 2001; Morrogh, 2003), which we will discuss later.

It is essential to determine priorities to our attention and interest, create hierarchies, information structures, groups, categories and sequential interaction according to people's affinities and expectations. Information architecture is responsible for creating structures to effectively allow users to transform their informational necessities into actions and reach their goals. In this sense, the traditional information architecture's role is to organize and structure the information to help users discover and consume content as well as facilitate their decisions and actions.

Roselfeld, Morville and Arango (2015) believe that information can be comprehended through four interdependent systems:

(i) *Organization system:* This determines how content should be organized, classified and presented.
(ii) *Label system:* This determines verbal and visual signs for each information element and support navigation.
(iii) *Navigation system:* This specifies routes within the informational space.
(iv) *Search system:* In this system, users call upon typing questions to achieve desired information.

For Rosenfeld, Morville and Arango (2015), findability and comprehension are the key objectives when structuring information—emphasized by the multiplicity of channels and diversity and dynamism of technological apparatuses in systems ecology. Nowadays, content is building up dynamically in new connected hyperlinks. As the emerging participative culture grows, users cite, comment, share, reinterpret, edit, mix, create and recreate information through interconnected channels to build their journey. The possibilities of channels involve not only new digital devices but also physical spaces, services and new actors—involving algorithms. Even if the ecosystem is not prepared for bridging channels, users will blend spaces and actions by themselves (Renzi, 2017), finding their paths to a smoother and trustworthy experience.

Since the 1960s, information architecture concepts have evolved as new possibilities of interaction; and although expanding to new visions, its essence remains the same. Our ubiquitous reality with pervasive experiences urged for new information architecture understanding, not restricted to Web sites or apps, as the information flows out artifacts. Resmini and Rosatti (2011) pointed out a list of transformations from the classic information architecture to a new kind of experience:

(i) *Information architecture as an ecosystem:* Different media and different contexts are integrated; therefore, no artifact can be considered an isolated device. Artifacts now belong to a large ecosystem.
(ii) *The users' new role:* Users contribute and actively produce new information or edit/add to something already published, inserting links, comments or critics.
(iii) *Static versus dynamic:* The users' active role makes the structure forever unfinished, permanently in change and open to constant refinement and manipulation.
(iv) *Hybridization:* Boundaries that separated different media, genres, entities and domains are becoming blurred and spanning different environments.
(v) *Horizontality:* The correlation of elements overrules traditional top-down hierarchies. Users push the system to spontaneous, ephemeral or temporary semantic structures.
(vi) *Focus on experience:* Design changes its focus from individual devices to planning and developing experiences and processes.
(vii) *Experiences are now cross-media:* According to Resmini and Rosatti (2011), experiences connect different environments and media in ubiquitous ecologies, a process where all parts contribute to building one whole experience journey.

User interactions in ecosystems are now collected and interpreted by algorithms to respond to desires and train the continuous learning system. Through machine learning, ecosystems can now collect data, classify subjects, cluster related actions, display ads, filter items and recommend personalized content, generating additional complexity to the functioning of information architecture—as we will detail in the next sections.

### 14.2.1 Information Architecture: From Ecologies to Machine Learning

Given the impressive achievements of recent advances in intelligent machines, several platforms somehow incorporate AI, or at least machine learning. These technologies have significantly impacted the user experience and how content is organized, discovered and accessed in places replete with information (Wallach, Flohr and Kaltenhauser, 2020).

Notorious examples of "AI summer" (the ongoing promising period of accelerated development and funding) are content recommendation systems, online marketing and advertising, voice recognition, speech-based systems, face recognition and stand-alone cars, among many other specific applications. This chapter is particularly interested in discussing user interaction with content recommendation systems due to its natural relationship with information architecture, an essential part of our theoretical framework.

ML-based recommendation systems are answers to one of our age's central problems—traditionally addressed by information architecture—the information overload. As we know, information is being produced at a rate that exceeds the human ability to find, review or understand it. In this sense, information management has become one of our main challenges, on both individual and societal levels. It may be the cause of information anxiety (Wurman, 2001). When faced with the extraordinary profusion of online content, traditional information management strategies are no longer useful, Morrogh (2003) warned us. Bawden and Robinson (2020) stated that although the problem has been there for centuries, it has become more urgent since the arrival of ubiquitous digital information. Among the best ways of avoiding information overload and guarantee findability, there are strategies such as filtering or better design of information systems.

Faced with the current profusion of environments and services with vast amounts of content, we must keep in mind one of the central concepts of the discipline of information architecture—the idea of findability. According to the information architect Morville (2005), findability is an essential notion—that connects to the degree to which a specific object can be discovered or located; and alternatively, to the degree to which an environment can support user navigation and item retrieval.

In this context, machine learning opened a new era for information architecture—considering findability in information-rich ambience. Its approaches are widely employed nowadays to analyze large bodies of data in cloud-based computing, extract patterns and support users' decision-making. As examples, we can cite the choice of a movie to watch on Netflix, a product to buy on Amazon or a song to listen to on Spotify. ML-based systems have significantly increased and lead us to question how these new techniques can meet users' information search needs while respecting human-centered design principles. For Wallach, Flohr and Kaltenhauser (2020), the UX discipline's traditional evaluation methods could underpin ML-based products' best development.

### 14.2.2 Discussing AI and ML

Artificial intelligence seeks to study the mathematical principles of learning applied to computers. The European Commission's High-Level Expert Group on Artificial Intelligence stated that AI systems are software or hardware that act by perceiving their environment through data acquisition. These systems interpret the collected data, process the information derived from this data and decide the best action(s) to take to achieve a given goal. AI systems can also "adapt their behaviour by analyzing how the environment is affected by their previous actions."

For Bengio (2019), human learning is not limited to reading books or accumulating facts or data; it adapts to the environment's stimuli. Learning means integrating information that we obtain through experience into abstractions that allow us to make better decisions, understand the connections between the things we see and predict what will happen next. In artificial intelligence, we work with the notion of generalization: the machine can generalize from things it has already seen and learned to new situations, in a slow and gradual process, totally based on experience, through contact with a large volume of data. It is what is called machine learning or statistical learning. Machine learning has emerged as a topic of great interest within the field of artificial intelligence research.

Based on Lovejoy and Holbrook, we can consider machine learning as the technique of making computers unveil patterns and relationships in a set of data, dispensing with their manual programming. Lately, digital product developers have had more access to ML tools and techniques and have been more dedicated to creating better user experiences. These experiences are now more personalized and customized; they are engaging and present in various services, with examples from streaming music to autonomous cars.

Machine learning is the study of algorithms that improve automatically through experience (Hechler, Oberhofer, and Schaeck, 2020). The following are the three main types of machine learning: supervised learning, unsupervised learning and reinforcement learning.

(i) *Supervised learning:* According to Honda, Facure and Yaohao (2019), the primary characteristic of supervised learning systems is that the data used to train the model contains the desired response. The training data is previously annotated with the answers or categories to be predicted. We can mention linear regression, logistic regression, artificial neural networks (ANNs), decision trees and others among their best-known techniques. Examples of supervised learning include predicting products that customers are likely to buy or classifying images based on content (Hechler, Oberhofer, and Schaeck, 2020).

(ii) *Unsupervised learning:* It does not require a previously labeled sample of training data: its purpose is to cluster data points into different groups (Hechler, Oberhofer, and Schaeck, 2020). Unsupervised learning problems are considerably complex; thus, this model is at the frontier of machine learning knowledge. Examples of unsupervised learning are film or music recommendation systems, anomaly detection and data visualization. Among the known techniques are artificial neural networks, expectation-maximization, hierarchical clustering, essential components analysis, etc. (Honda, Facure and Yaohao, 2019).

(iii) *Reinforcement learning (RL):* It is based on learning through trial and error. In this approach, an agent interacts with the environment to learn how to perform tasks, improving actions based on rewards and punishments (Hechler, Oberhofer, and Schaeck, 2020). RL considers uncertainty and incorporates changes in the environment into the process of making the best decision. It is based on Skinner's behavioral psychology (Honda, Facure and Yaohao, 2019). As the model learns from the experiments, it is expected that it selects the outputs that generate the most significant rewards for each situation and avoids actions that bring the poorest rewards. The process is repeated until the computer can choose the best action for each scenario.

## 14.3 USER EXPERIENCE AND MACHINE LEARNING

### 14.3.1 Problems in UX-AI Intersection

Cramer and Kim (2019) denounce that the field where the user experience meets artificial intelligence is full of tensions. Addressing the intersection where UX has intertwined with AI, the two authors listed a range of problems.

Information architects and UX professionals well know the first reported UX-AI tension: there are conflicting goals for the various actors involved: users, business and company stakeholders. It implies that turning machine learning into a positive user experience will require proper integration between algorithm programming, business models and UX. Machine learning developers are trained to predominantly value features and quantitative aspects, such as accuracy metrics or click rate. However, they should be based on holistic criteria that consider the results for humans, ruling out possible harm to them—and this is not an issue yet solved.

The authors highlighted that algorithms are difficult to explain, which creates imbalances of power and understanding about how to influence their results. Cramer and Kim (2019) also warned us that if today we are facing a growing awareness of the idea of algorithmic responsibility, we must direct our attention both to human and social tensions as well as to ethical and environmental tensions. The spread of machine learning algorithms has encouraged the proliferation of principles to guide development. Fjeld et al. (2020) have pointed to a growing consensus around eight trends that should guide AI: privacy, accountability, security and safety, transparency and explainability, fairness and non-discrimination, human control of technology, professional responsibility and promotion of human values.

So, how to put algorithms under human control? It is a question already addressed by other researchers, such as Lovejoy and Holbrook (2019). They postulate that UX professionals need to learn a lot more about machine learning to help users feel in control of this technology. As the authors state, an in-depth study of users' mental models is essential because in machine learning there is a connection between the algorithms and these models. As people interact, they change the outputs they will see in the future, and this will influence and change the way people interact. That is a feedback loop.

Researchers observed that "conspiracy theories" regarding algorithms could arise from the feedback loop and influence user-algorithm interaction (Lovejoy and Holbrook). These "conspiracy theories" are generally bad for both users and the algorithms' results because users may create incorrect mental models and manipulate the results according to imaginary rules.

The usability researcher Budiu (2019) has profoundly studied the interaction between users and ML-based systems and has found that people produce weak mental models regarding algorithms; therefore, they lose control over their results. Budiu's research observed that recommender algorithms are not transparent to users. People cannot associate their interactions and results based on an adequate understanding of the process logic.

Users often consider the list of suggestions and recommendations as meaningless or random. Concerning information structure, algorithms often create categories according to obscure and not mutually exclusive criteria. From an exclusively statistical or mathematical perspective, grouped categories may even make sense, but they do not function as intuitive information architecture for humans. What we do have, in most cases, is a taxonomy centered on the logic of the algorithmic model.

One of the main problems signalized by Budiu is the so-called black-box model. The black-box model's issue has already been addressed by Herlocker et al. (2000) in their original article. According to the authors:

> *Often, there is not the opportunity or possibly the desire to convey the conceptual model of the system to each user of the system. In such cases, the ACF [automated collaborative filtering] system becomes a black box recommender, producing recommendations like those of an oracle.* (Herlocker, Konstan and Riedl, 2000)

So, when analyzing collaborative filters for recommendation systems based on ML algorithms, researchers point out that:

> *It is inevitable that some users will form incorrect conceptual models of the ACF [automated collaborative filtering] systems that they are using to filter information.* (Herlocker, Konstan and Riedl, 2000).

The above situation is unsatisfactory because users need to develop a robust mental model of how the system works to interact correctly and change or correct its results. The system must be clear about how it processes data and how people can change outputs, thus putting users in control. However, Budiu observed that users perceive cryptic and out of control inputs and outputs (Agner, Necyk and Renzi, 2020).

Budiu also noted that imperfect calculations might cause interesting items to be hidden and the presentation of low-relevance items during user-algorithm interaction. Similarly, the order in which the items appear may not make any sense. On the other hand, too much time between user interactions and the production of outputs that reflect those interactions makes understanding even more complicated.

### 14.3.2 Basic Guidelines for Human-Algorithm Interaction

There are recommendations for algorithms to increase the quality of the user experience. Harley is a researcher who suggested a list of guidelines to guarantee a satisfactory user experience in ML-based systems. These are just a few primary guidelines as proposed by Budiu and Harley (Agner, Necyk and Renzi, 2020):

(i) *Transparency:* The system must be specific and clear to the user about which people's data are tracked and processed to generate their personalized lists. A clear explanation helps users decide whether recommendations are relevant or not and will add credibility to the system. Working with transparency means informing people about which interactions are considered by the algorithm to help the user build a relevant mental model of interaction. Information and explanations about the model can remove the black-box feeling and benefit users in multiple ways, increasing acceptance (Herlocker et al., 2000).

(ii) *User control:* The UX designers need to provide the user with easy tools to rearrange the output list in a more relevant or familiar way. Categories should be formed more intuitively and close to traditional information architecture; therefore, it is essential to allow users to improve recommendations. Useful features must be provided to enter feedback or edit data to create recommendations and make it more relevant. An example is a tool to edit past actions: deleting items from a user's browsing history or previous purchases. Therefore, the algorithm would be instructed to forget atypical behavior—a way users have to train it.

(iii) *Categories and subcategories:* Personalized recommendation lists must have reasonable findability. The users view them as a valuable navigation resource amid information overload. Besides, regarding ML-generated taxonomy, users prefer to search for content in specific subcategories when browsing extensive inventories, such as Netflix, Amazon or Spotify. It is also essential not to repeat the content within various categories to lower the cost of interaction.

(iv) *Response time:* If users choose to optimize recommendations (by rating, adding items to a favorite list or updating their profile), the expectation is that the result will be fast, mainly when the feedback is negative (Harley, 2019).

(v) *Session-specific customization:* It must be avoided because session-specific art miniatures, descriptions and titles often increase interaction's cognitive costs. The practice of homepage customization (according to a session or device) restricts the learning of the layout, reducing usability (Budiu, 2019).

In many circumstances, researchers identify usability issues with AI systems and suggest solutions. Amershi et al. (2019) have proposed development guidelines, consolidating a set of 18 recommendations. With experts' participation, their work synthesized a guidance for designing human-algorithm interaction. Here we present just a few of their guidelines, selected according to their relevance to the present research:

(i) The user must understand what the system can do and how frequent its errors are.

(ii) The system must display information relevant to the completion of the user's task.

(iii) The user must receive an explanation regarding the system's behavior.

(iv) The experience must be delivered respecting the user's mental model.

(v) When the system makes a mistake, the user should be able to correct it easily.

(vi) The user should be able to provide feedback and indicate his or her preferences.

(vii) The user should be able to customize what the system monitors and how it behaves globally.

(viii) The system must present immediate information on how users' actions will change future behavior.

### 14.3.3 The Importance of Mental Models

In UX and information architecture, the notion of a mental model is a fundamental concept that has already been defined by Jakob Nielsen as follows: "A mental model is based on belief, not facts: that is, it is a model of what users know (or think they know) about a system." As stated by Lovejoy and Holbrook, a mental model means understanding how a product works and how users' actions affect it.

Considering that the mental model is a user's understanding of how something works (products, places or people), the mental models that do not correspond to reality or maladjusted can cause frustration. However, it is not uncommon for designers or developers to communicate incorrect mental models to users, failing to explain clearly how the product works.

"In case of a mental-model mismatch, you basically have two different options: Make the system conform to users' mental models or improve users' mental models" (Nielsen, 2020). The designer can achieve it by adding transparency features to the interface and better explaining the models. According to Nielsen, "it is a prime goal for designers to make the user interface communicate the system's basic nature well enough that users form reasonably accurate (and thus useful) mental models."

It is also essential to keep in mind that machine learning systems and products adapt, optimize and customize themselves according to their interaction with users. Consequently, it is crucial to communicate correct expectations about how the adaptation will occur, as mentioned above. Through user-algorithm interactions, there will be a co-learning process, as the machine learning models will be transformed as a function of these interactions, while the user's mental model will also be altered. Therefore, it is of utmost importance to communicate the non-human nature and limits of these products to build pragmatic expectations for users and avoid disappointments, preparing them for the changes that will occur after their interactions (People+AI, 2020).

In this context, explainability is one of the most critical AI qualities when considering its cooperation with user experience. Since explainability and confidence are inherently correlated characteristics, UX professionals help users understand and trust the ML system in the correct dosage by helping them build precise mental models.

Meanwhile, there is a recurring problem in the midst of all this. It occurs that explaining to optimize the user's understanding can become a challenge: even AI developers may not fully discern how the technology works to generate their outputs in some instances.

## 14.4 UNDERSTANDING RECOMMENDATION SYSTEMS

We are living in an era of the preponderance of the Internet and information technology. This scenario has been very challenging in terms of the amount of information and data that ordinary citizens must manage and interact with daily (Morrogh, 2003; Wurman, 2001).

It is essential to rely on some kind of information filtering, and the information architect understands this requirement very well. The number of options to choose from has overwhelmingly multiplied in almost every field of our life: videos, music, books, travel itineraries and restaurants, health safety, courses or even dates with partners. As consumers, finding goods and services classified as “Long Tail” (Anderson, 2006) is an arduous task and does not exempt the use of special filters (Agner et al., 2020; Pandey, 2019). For this purpose, there are computer programs known as recommender systems.

Machine learning algorithmic models can support us in decision-making processes. These recommender engines are tools that belong to the category of information filtering and predict which classification a user will give to an item based on calculations and statistical inferences.

According to Rocca (2019), recommendation systems can be defined as algorithms designed to suggest items relevant to the user in a very general way. These items can be music to listen to, films to watch, texts to read, products to buy or anything else belonging to an extensive catalog. They aim to solve two types of problems: forecasting (data used to predict the evaluation a user will give to an item with which he has not yet interacted) and rating (when creating a finite list of items to be presented to the user), as explained by Pandey (2019). These ML-based systems play an increasingly central role in our lives, as we use them from e-commerce shopping to entertainment services such as music on Spotify or videos on YouTube. These include Facebook, LinkedIn or Twitter, as well as high click-through ads.

According to Pandey (Agner, Necyk and Renzi, 2020), the qualities of a reliable recommendation system are the following: recommended items should be relevant and interesting to users; items that users are not yet familiar with should preferably be presented and lists of items should have diversification.

Recommendation systems use the collaborative or content-based filtering approach, as explained below. There is currently a significant incidence of hybrid systems (those systems that combine more than one approach).

Collaborative filtering relies on users’ past behavior (items purchased or ratings given) and other users’ similar decisions. Collaborative filtering can recommend items of all kinds without assuming knowledge of their content. As Rocca (2019) remarked, it is based on the (questionable) assumption that people who have already accorded in the past will accord in the future and that people will like items comparable to what they preferred in the past. The interactions recorded over time generate new data and make the system increasingly effective. Therefore, the more the users interact with the items, the more accurate the recommendations become.

We can observe that the mode of data collection to feed the model can be explicit or implicit. Explicit types of data collection include: search terms, evaluating items with like or dislike icons or creating a list. Implicit types of data collection can be observing navigation times, considering songs listened to, viewing product lists or analyzing the social network. The implicit data reflect the records of the user’s interactions with the system, which are interpreted as indicators of interest or disinterest.

With a broad set of tracked data, it is possible to describe clusters representing user communities with similar preferences to analyze their collective consumption behavior (Kathayat, 2019).

The second type of approach, the content-based one, requires information about both users and items, such as keywords representing each item and data for each user's profile. For example, age, gender, profession or any other personal data of the user, as well as genre, band, shows, country, music labels or other information for music files. Based on what the user liked in the past or is currently looking for, this type of algorithm finds and presents new similar items, but it has the inconvenience that it cannot become more efficient over time.

As Herlocker, Konstan and Rieldl (2000) explain, collaborative filtering technologies do not necessarily compete with content-based filtering: they can work together to provide a robust hybrid solution. Both approaches have strengths and weaknesses, so the hybrid approach is often adopted, fusing collaborative filtering with content-based methods and others (Pandey, 2019). The Netflix streaming platform is an excellent example of a hybrid system because its recommendations are based not only on consumption habits (collaborative approach) but also on similar video (content-based).

Despite their obvious benefits in mitigating the effects of information overload, and despite their contribution to more immersive and customized experiences, recommendation systems often receive severe criticism from various sources, including their scholars. For example, Irvine (2020) criticizes the use of algorithms because, by choosing practically everything for us and keeping us away from certain choices, they eliminate freedom of choice.

### 14.4.1 The Algorithms Implemented by Spotify

According to Iyengar (Irvine, 2020), the average individual makes over 70 conscious decisions a day. With the purpose to guide consumers through this labyrinth of choices, recommendation algorithms have become the most ubiquitous machine learning applications for products and services on the Web. A notable example of this is the Spotify platform.

Spotify is a digital, cloud-based music enterprise—founded in Stockholm in 2008—offering cross-device access to over 50 million songs, as well as podcasts and videos (Boyd, 2020). There are over 200 million users worldwide, 100 millions of whom are premium subscribers (Kelley, 2020). According to Johnson (2020), with such a volume of music files, the platform's challenge is: How do you recommend songs with an appeal to its listeners?

As the author stated, there are significant differences between the consumption of films on entertainment platforms and the consumption of music: (i) an extreme asymmetry in the size of the catalogs (Spotify's volume of options is enormous compared to Netflix's); (ii) unlike films, the consumption of songs can happen repeatedly; (iii) the music market is much more typified as being niche than that of movies or series.

Algorithms have changed the way people find, listen and interact with music (Irvine, 2020). This success' components are well-known playlists generated, personalized and cured, such as Discover Weekly, Daily Mixes, Release Radar or recommended suggestions of artists. The service has become one of the most successful platforms in streaming worldwide. Not only because it connects users through music, but also because it employs complementary algorithmic approaches to its recommendations. The methods that Spotify's recommendation system uses are three (Cornell, 2020; Ciocca, 2020):

(i) Collaborative filtering;
(ii) Natural language processing (NLP); and
(iii) Audio models.

One of the first companies to use so-called collaborative filtering (CF) was Netflix, considering users' film ratings to generate the learning about films to recommend to other similar users. After Netflix's success, employing collaborative filtering became popular among companies and a starting point for any recommendation model.

Collaborative filtering and natural language processing are beneficial for connecting listeners to the music that other listeners hear and comment on. Collaborative filtering is a type of algorithm based on metrics, streaming data and user visits to artists' pages. It starts by analyzing a user's behavior, comparing it to other users' behavior. Collaborative filtering approaches revolve around the strategy of determining user preferences from historical behavioral data patterns. Consumer behavior leaves a trail of data, generated through implicit and explicit feedback, which is collected (Johnson, 2020; Ciocca, 2020). If two users listen to the same sets of music or artists, their tastes are likely to be aligned, explains Irvine (2020). The connections between listeners create a list of recommendations that similar listeners appreciate.

It should be noted that, unlike Netflix, initially based on a star system assigned by users, Spotify opted for implicit feedback to train its model. According to Pasick (Irvine, 2020), examples of this feedback could include: songs played in repetition and songs ignored after a 10-second timeout. User data can also come from explicit feedback, such as the heart button in "Discover Weekly" or songs saved in the library or the "Liked from Radio" playlist.

For greater accuracy, Spotify also uses natural language processing to analyze the playlist as a "document itself" (Johnson, 2015). The NLP algorithm is based on blog posts and articles about music to connect music to artists. This model's source data are common words, tracking metadata, news and other Internet texts. At stake is a computer's ability to understand human speech as it is spoken (Ciocca, 2020).

Those algorithms tirelessly scour the Web to determine what users are saying about specific artists and songs. The goal is to identify clusters to determine what adjectives and terminology refer to artists and songs and which other artists and songs connect to them in the comments. The system classifies artists linked by comments on the network into vectors to recommend similar content to other Spotify users.

The third recommendation method is audio models—useful for analyzing raw audio data and recommending music that has not yet become popular. Adding a third model is vital to give more accuracy. Unlike the first two, this algorithm recognizes songs that are still unknown to the public because the audio models capture and consider tunes with few listeners.

This algorithm applies convolutional neural networks that use clustering techniques to identify similarities in tempo, key, mode, time and sonority of audio tracks (Cornell, 2020; Ciocca, 2020). Convolutional neural networks technology is already employed for facial recognition, and it was modified for audio data instead of pixels. After processing, the neural network builds an understanding of each song according to its technical characteristics. It allows us to understand the fundamental similarities between the songs and, therefore, which users may appreciate them based on their consumption history.

The three models described above are used with clustering techniques to produce personalized recommendations of songs, podcasts and playlists, such as the "Discover Weekly." It should be emphasized that the recommendation models only work well because they are connected to a broader ecosystem. This ecosystem includes gigantic amounts of data captured through user interactions (a fact people are not always aware of) and uses numerous clusters to make it work in huge matrices (Cornell, 2020; Ciocca, 2020).

## 14.5 RESEARCH METHOD: USERS' INTERVIEWS

As Kuniavsky (2003) explained, observation can be crucial for UX research. However, to deeply understand the user experience, it is necessary to ask him or her questions—and this is what an interview is about.

According to Courage and Baxter (2005), an interview is often used to study the user experience. An interview is a guided conversation in which one person seeks information from another. There are a variety of types of interviews, depending on restrictions and needs. A semistructured interview is a combination of structured and unstructured types. The interviewer begins with a set of questions to answer but can deviate from them from time to time. This kind of interview is not so structured, which is easier to analyze data, but it has the advantage of unexpected data.

A screening questionnaire was applied among students in order to select interviewees. Being a Spotify subscriber and an advanced user of the platform were selection requirements. As the data collection process took place during pandemic times, the 2020 second semester, remote communication was mediated by apps like Zoom and similar apparatuses. The questionnaire was useful to select the interviewees and to get to know them better.

As we developed qualitative research, there was no need to select a large sample of the population. We applied one-on-one semistructured interviews to a small sample of design and marketing students from four Brazilian universities with distinct characteristics and backgrounds: Universidade Federal de Pernambuco—Campus Caruaru; Pontifícia Universidade Católica do Paraná—Curitiba; Universidade Estadual Paulista—São Paulo; Universidade Federal Fluminense—Niterói.

The participants selected for the interview are undergraduate university students aged 20–39, mainly 20–25 years old. They are Spotify subscribers for over two years or more, managing personal profiles. The questionnaire and the interviews revealed that there are many media practices in common among them: daily access to the Internet for many hours; use of applications such as e-mail, news apps, social networks, instant messages and entertainment apps, among others; use of streaming content in smart TVs, notebooks or smartphones; file-sharing; and e-learning sites.

Interviewees may also be users of other streaming platforms, like Netflix, YouTube or GloboPlay. They consume music, preferably via Wi-Fi or downloaded songs. They use the app at home, car or on the bus; and while working or playing sports. During the coronavirus pandemic, some reported that they like to listen to Spotify while cleaning their households.

### 14.5.1 Interviewing Results

Here we present a summary of the responses to the semistructured interviews with Spotify users.

When answering how to find new music on the Spotify platform, some users surprised us by saying that they use Google and YouTube (a competing service). Some users were relying on social networks or recommendation from friends:

> "Sometimes I go on YouTube because I like to watch videos of the artists. I end up researching the artist on YouTube."
>
> "I find bands on the Internet, on Google, or a friend who knows a lot tells me about it. And mainly I find on YouTube, only then I migrate to Spotify."
>
> "I miss something that exists on YouTube Music: the related songs."
>
> "Recommendations are very similar to the Netflix catalogue: I keep passing by, just passing by, and I don't listen to anything."

However, Spotify's recommendations may play an essential role in the user experience. Users told stories that represented their emotional involvement with the platform's sharing resources and reaffirmed some social or cultural benefits provided by the recommendations.

> "I'm quite satisfied because before I had Spotify, my friends knew a lot more bands than me."
>
> "A friend of mine sent me a print of a sad song that I was listening to on Spotify. His web version has shown him. I hadn't talked to him for a long time, and this made us reconnect."
>
> "I ended up knowing a lot of music because of Spotify's recommendations."
>
> "When I was a teenager, I didn't have money to buy CDs, and I only listened to music through piracy. The positive thing about streaming is that the horizon gets much wider, right?"

Continuing the interview, users discussed their customized recommendations and how they could identify them instead of generic contents. Some interviewees indicated navigational, comprehensibility and information overload problems (classic issues related to information architecture). For some others, the personalized category and grouping labeling system has come to attention.

> "I don't think the lists of recommendations are highlighted enough because there is a lot of information, and I always get a little lost."
> "I just don't explore anymore because they recommend a lot all the time."
> "I noticed the group 'Songs that miss you,' and also the title 'Maybe you like it.' … These titles are funny."
> "Why do you have Daily Mix 1, 2, 3 and 4? What's the difference among them? I never really understood."

Some interviewees have shown that they are uncomfortable with generalist recommendations and always prefer personalized ones:

> "I don't think they directly promote songs for which they were paid to promote. On Netflix, I can feel it. … [I]t's terrible, so indiscreet."

Although some respondents were unaware of "Discover Weekly" playlist, others have confirmed to use it. Furthermore, lists or layouts generated to handle specific access devices may generate some confusion.

> "This week, 'Discover Weekly' has just one song that I already knew. These are rock, new wave and classic rock."
> "I always use it. In the mobile application, it's one thing; in the desktop and on the website, the recommendations are different. It's a bug."

We can say that, in general, the respondents considered "Discover Weekly" and other Spotify recommendations as of high relevance. However, the excess of recommended items was again criticized.

> "'Discover Weekly' is excellent. Spotify was killer because I liked 90% of it."
> "The only [negative] point is the excessive amount of songs, of artists that I have never heard of. … I don't have time to stop, to listen, and deepen!"

When asked how their recommendations were created, users could not confidently say what implicit actions were collected. This confirmed suspicions that users cannot build a complete or reliable mental model about how the system works.

> "I've never tried to understand this."
> "Only the searches …"
> "I thought that by adding in a playlist of favorites, I would be giving an indication that I liked. … But now I have doubts if this really instructs the algorithm."
> "Click and follow specific genres, click on releases of the week, I don't know."

"Spotify believes that because I'm listening a lot to a song, I must really like it. It's something indirect, never direct."
"I imagine it takes the styles and artists that I mostly listen to."
"If I listened to a song with the subcategories pop and rock, and another song that is rock and indie, Spotify will show me other bands with the category common to them, which is rock … although associated with other subgenres."
"Maybe they see how much time you spend listening to an artist."

We asked users how they could improve their recommendations. Although there are users who already do this or have a notion of how to do it, the answers indicated that not everyone employs methods to give feedback to the model. Some were thinking about this for the first time.

"I never thought about this."
"I don't know how to interact with the recommendations to improve them."
"I just don't need to show what I'm enjoying."
"I don't feel that giving like or dislike influences the recommendations."
"There were rare cases of songs that I haven't liked. Then I clicked on that little sign that looked like 'Forbidden.' I asked it to hide it so as not to pollute."
"On YouTube Music, the choices are explicit; … in Spotify, it seems to be something organic."
"I hardly evaluate … I don't feel comfortable showing it to anyone."

We asked users who gave feedback if they are satisfied with the response time and whether the system can keep up with their state of mind when receiving feedback. Many of them reported that the recommendations are not up to speed (but this was not unanimous).

"I think it takes a little bit, about a week to change everything."
"I would like the updates to be more frequent than once per week."
"I change my state of mind very quickly. On Spotify, it will take me a week to get a result."
"Recommendations do not go with the ideal speed to my moment of life, my state of mind."
"I noticed a change in my 'Discover Weekly' because of the quarantine: my playlists were very depressive. I think you can give some signs, but the change doesn't happen until a while later."
"The recommendations do not follow my life moment. They stay more or less in the same 'vibe.' If it's a depressive romantic song, Spotify will reinforce this psychological model."
"They don't follow my moments because they are commercial recommendations."
"I don't think it accompanies my state of mind."
"Yes, when I'm happy, starting to date and in love, it usually follows my mood."

In one of the reports, it was made clear that the human-algorithm interaction deserves a more restrained attention because it can have unpredictable consequences.

> "I try not to listen to sad music because of medical advice. I suffer from depression. But it's not every day that Spotify recommends me to listen to happy music."

Our research tried to find out whether users are comfortable having their consumption data collected and whether they saw any sign of a threat to privacy. Most interviewees demonstrated that they are aware of the risks posed by data collection and other privacy issues:

> "It's invasive because Spotify doesn't give me the awareness that he's measuring [and sharing] all this. I get a little scared, you know?"
> "I feel I don't have many choices if I prefer not to share my data. But I honestly don't feel uncomfortable."
> "I'm a little afraid about sharing data with platforms. There is a website that you connect with [Spotify's] login, and it gives you an invasive result. They found out that young Brazilians listened to depressive music during the quarantine."

Users reported issues related to other platforms that supposedly use private information for hyper-segmented advertising:

> "If you say something, then Instagram is offering an advertisement about it!"
> "It's your data and your emotions, music reflects it so much. It's another tool for the company to 'play' with you, so to speak. Selling products to you."
> "I said: I am in the mood to buy a skate. Then I went for a drink of water, and when I came back, a roller-skating ad appeared. It's crazy and frightening at the same time!"

Sometimes, respondents have shown a variety of "conspiracy theories" associated with their data's possible irregular use:

> "As in the WestWorld series, there is an exploration of the human mind and desires. I hope that Spotify does not use our information to [share with] others."
> "I don't interact, I don't give like or dislike, I don't give answers … I don't feel comfortable."
> "I used to share everything about my life and my family, but over time I gained the awareness that it is not exactly a danger of being attacked by a bandit but is more related to manipulation."
> "We think we are in control, but we are not. We would be very different if it weren't for this artificial intelligence that keeps throwing things in our faces."

"When you go on the Internet, you're already willing to throw your privacy away."

"I worry if they take my bank account or use my money."

## 14.6 CONCLUSIONS AND NOTES FOR DISCUSSION

The emergence of the current ML-based recommendation systems has strongly impacted user experiences, with the justification of contributing to smoothing the "information overload" problem. Algorithms demand that we update our look at information architecture—a discipline that traditionally deals with information landscapes' structural design by synthesizing organization, navigation, labeling and search systems.

Our study encouraged us to examine how information architecture has been reshaped by the introduction of collaborative filtering and machine learning approaches. By moving beyond its third phase—that of pervasive information, as identified by Resmini and Rosati—currently undergoing a rapid transformation toward algorithms' structured approach, information architecture is being compelled to coexist with new technological and automated ways to ensure findability and discoverability. That is because we live in times where gigantic catalogs full of options such as Spotify's may make users' navigation and decision-making unviable.

This research tried to understand how young Brazilian users consume streaming content on the Spotify platform. Our goal was to continue previous research, where we reported conclusions on the use of the Netflix platform (Agner, Necyk and Renzi, 2020).

Some user responses showed that recommender systems might involve dealing with typical information architecture issues such as the nomination and category grouping system. They revealed that information overload, findability and comprehensibility problems are not yet completely solved. As one respondent stated: "There is a lot of information, and I always get a little lost."

Experts and institutions involved in user experience and machine learning research generally agree that transparency and explainability are requirements for systems development and design, aiming to overcome the "black box" feeling. ML-based interfaces should inform users how they work, i.e., what implicit or explicit data is collected to create recommendation lists. However, we realized that users generally could not understand the fundamentals of how the system works and do not build a suitable mental model of it.

Explainability is essential because, according to Herlocker et al. (2000), it guarantees users' confidence in the recommendation system. Moreover, it contributes to greater understanding, involvement, education and acceptance of the system as a valuable decision-making aid. So, UX designers should strive to clarify the system's logic, which collects and handles user interaction data to generate personalized recommendations. It will help users to build a more concrete mental model that is closer to reality.

Most respondents have been sensitive to the suspicion that Spotify (and other services or networks) captures—in a non-transparent way—manages and shares their interaction data. When asked about their data's privacy, respondents pointed out fears of obscure use, robbery or marketing manipulation. As in our previous survey, these suspicions shaped what Lovejoy and Holbrook once called "conspiracy theories." A statement made by one interviewee highlighted this sort of concern: "It's your data and your emotions; music reflects it so much. It's another tool for the company to 'play' with you, so to speak."

The problem is that these theories influence how users will interact: some may avoid explicitly reporting feedbacks. It was the case for the user who stated: "I don't interact, I don't give like or dislike, I don't give answers. … I don't feel comfortable."

Some of the users seemed unaware of how they can interact with the algorithm to make the recommendations more in line with their goals or mood. Frequent users do not know precisely how to interact with recommended content to instruct the algorithm to improve lists and better suit their profile and personal preferences. They have not shown to be confident in their knowledge about the universe of possible inputs taken into account by the algorithms.

Human-algorithm interaction emerges as the new frontier of studies involving user experience design and information architecture. It seems that UX designers are not always aware of the recommendation system issues raised by this research. We have addressed some emerging problems that may have been so far neglected by UX professionals. The information collected with young Brazilian Spotify users showed several aspects of recommendation systems that deserve further investigation.

To conclude, we reaffirm the need for UX designers and information architects to update themselves to better understand the technical nuances of ML-based recommendation systems. Such dynamics should contribute to building experiences in which users feel confident and satisfied interacting and collaborating with these systems.

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# 15 Personified Virtual Assistants

## *Evaluating Users' Perception of Usability and UX*

*Claudia Mont'Alvão and Marcela Maués*

### CONTENTS



## 15.1 A BRIEF INTRODUCTION

Since the emergence of personal computers and their worldwide connection at the hand of the Internet, computing has evolved. As a consequence, the interaction with computing devices has matured as well. When there are more physical objects interconnected, and with processing capabilities of their own, the concept of computing gradually grows apart from the desktop device, leading to ubiquitous use.

Talking computers and voice user interfaces (VUI) have already been widely addressed in science fiction, but every day it is more common to find voice user interfaces on various devices such as desktop computers, smartphones, smartwatches, smart TVs and videogames. These interfaces have also been adopted in virtual

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assistants (VAs), systems that assist their users in daily functions, ranging from organizing the agenda to controlling smart objects.

There is plenty of literature and research in the area. However, most usually address the virtual assistants' usage in English-speaking subjects, which is the standard language in most of the systems. There are not many studies addressing the virtual assistants in their translated language forms with non-English subjects. In this research case, we address the virtual assistant with Brazilian Portuguese users, which aimed to understand better if the use of voice interfaces is understood and useful in daily needs and how this happens within the singularities of this public.

### 15.1.1 Voice User Interfaces

In the early days of personal computing, computer interfaces would resort to metaphors within the physical world to explain the functioning and to bring familiarity to new use cases. In the current state of computing, the digital medium is already more acquainted and allows more abstract patterns for interaction.

These new interfaces should follow the same principles for visual interface design: provide feedback, navigability, consistency and attractiveness, without losing their function. In this scenario, verbal communication as an option for interface design is reinforced.

According to Nass and Brave (2007):

> Speech is a fundamental means of human communication. Even when other forms of communication—such as writing, facial expressions, or sign language—would be equally expressive, (hearing) people in all cultures persuade, inform, and build relationships primarily through speech.

These authors also affirm that in the 200,000 years of evolution, humans have become voice-activated with brains that are wired to equate voices with people and to act quickly on that identification. Talking, listening and human society have elegantly co-evolved into a remarkably interwoven, effective and stable system.

Emergent technology interfaces evolved and are now capable of producing and understanding human voices, modifying the interaction between humans and computers, proposing a new model of "natural interaction." As a result of these automatic and unconscious social responses to voice technologies, the psychology of interface speech is the psychology of human speech: voice interfaces are intrinsically social interfaces. Designers must create voice interfaces for brains that are obsessed with extracting as much social information as possible from speech and using that information to guide attitudes and behaviors (Nass and Brave, 2007). These authors also affirm that humans usually do not make distinctions among talking to a "machine/computer," or with a person, once the same part of the brain is responsible for this interaction.

Pearl (2016) determines that we are now in the "*second era of VUIs*" and the "*infancy of this next phase*." She proposes to think about users and their use cases: "*The main question to ask yourself is: will your users benefit from VUIs?*"

### 15.1.2 Personified Virtual Assistants (PVAs)

Weiser (1994) suggests that as new technologies and ways of interaction are offered, new systems are created as virtual assistants. They received several names as "intelligent agents," "personal virtual assistants," "intelligent personal assistants," "personal digital assistants," "mobile assistants" or "voice assistants" (McTear et al., 2016).

As examples, we can mention Siri (Apple), Google Home and Google Assistant, Cortana (Microsoft), Alexa and Echo (Amazon) and Bixby (Samsung), among many others. These virtual assistants are systems that can perform many tasks using voice interaction combined with graphics and text on the screen. McTear et al. (2016) suggest the term "conversational interface to refer to the technology that supports conversational interaction with these VPAs, by means of speech and other modalities."

As affirmed by McLean and Osei-Frimpong (2020), "in-home voice assistants are designed to be more human-like than previous attempts and intended to be an important part of an individual's everyday life." Considering the growth of voice technologies, in the early 2010s it has been verified that people are interacting with voice assistants in daily life in the same natural way as with other humans (Sundar et al., 2010).

The use of voice-control technology has become mainstream and is growing worldwide. In the United States alone, the number of people who use voice assistants—including Amazon Alexa, Apple's Siri, Google Assistant, Samsung's Bixby and Microsoft Cortana—is increasing faster than previously anticipated. It is estimated that in 2019, 111.8 million people in the United States will use a voice assistant at least monthly, up 9.5% from last year. This data is equivalent to 39.4% of Internet users and 33.8% of the total population (eMarketer, 2019). This report presents that smartphones and smart speakers are the devices of choice for most voice assistant users, and millennials are the heaviest users.

## 15.2 METHOD

The success of a product is not only a result of the rational characteristics of it, and therefore this research was proposed to study the relationship of users with virtual assistants. The goal of this research was to investigate acceptance and opinions about VAs and how users interact with them, considering voice as an interface. The research assumption was that the personification and the use of conversational interfaces in virtual assistants would make their acceptance easier and would make their opinions about it more positive. Some research questions conducted the literature review and the field survey:

What is the impact of voice on the user experience of PVAs? Does the voice, instead of text, is understood as a benefit by users?

Does the literature review reflect the particularities and field studies in Brazil? What are the similarities and points of attention about his public?

How do Brazilians use or intend to use voice interfaces, now and in the future? What are their evaluation and opinions about PVAs?

The research was conducted in three stages. The first was the literature review that supported the discussions during the field survey among the users.

The second stage was a quantitative approach, which consisted of applying a close-ended online questionnaire aimed to understand the adoption and use of assistants in Rio de Janeiro. The questionnaire also aimed to identify participants for the qualitative phase, a focus group.

The third stage, defined after the results of the questionnaire, was a focus group technique aiming to collect data about the acceptance and the opinions of the resident of Rio de Janeiro about virtual assistants with a voice user interface. This qualitative approach was intended to map the relationship of participants with technology, highlighting its positive aspects, difficulties, concerns, as well as what they see as possibilities for future use.

### 15.2.1 Quantitative Phase: Online Questionnaire

#### 15.2.1.1 Questions and Respondents' Profile

The questionnaire is the main instrument for collecting data in survey research. It is a set of standardized questions, often called items, which follow a fixed scheme to collect individual data about one or more specific topics (Lavrakas, 2008)

This technique was applied to two types of questions: open- and close-ended. The close-ended questions are those for which the answer options are predefined. The open-ended questions are those that allow the respondents to write their answers. While close-ended questions enable measurable and accurate answers, open-ended questions allow a better understanding of the respondent's thinking process, which can qualify and clarify answers.

The purpose of applying this technique in the first step of this research is to understand the adoption and the user experience of assistants in a quantitative way. It would also help to identify participants for the qualitative stage, the focus group, as previously mentioned. With the objective to collect clear and objective data in quantity, the choice was to ask close-ended questions. The only open-ended question was to request contact information when the participant told that he/she wanted to volunteer for the qualitative stage, the focus group. In this case, e-mail and telephone should be provided.

The profile was established based on the following criteria: residents of the state of Rio de Janeiro of 18 years or above. The state of Rio de Janeiro is the second Brazilian state in the use of technologies and Internet access, and therefore, significant for the gathering of such information. Also, volunteers emerged for the qualitative phase, which required a face-to-face technique. Rio de Janeiro was where the researchers were located, so it was a determinant aspect. The Consent Term was presented to all participants so that they could give their consent and proceed with the questionnaire answers.

In the questionnaire, the first questions were demographic identifiers (location, age, gender and education) and filters to narrow the search to the established profile. The ones who fit the profile determined for the survey answered the next question: if they had used any virtual assistant in the previous three months. In that case, the following questions would be given only to those who knew voice assistants and would have a recent memory of the experience to give their opinion on it. Anyone who did not have recent contact with voice assistants would already be considered at this stage, and for the following questions, as a respondent who did not adopt this system.

Respondents who had had recent contact were conducted to answer questions regarding usage, opinion and general perceptions about the virtual assistant they had used. The questionnaire mapped which assistant was used, the access device, the purpose of use, the user evaluation of the experience and their adoption of the system. After all questions, the volunteer should state whether they would be interested in participating in the focus group—and if so—they were asked to give their contact details.

#### 15.2.1.2 Sample and Answers

A pilot study was carried out with eight respondents, and no significant changes were made in the definitive questionnaire. Subjects were contacted using the snowball approach, considering discussion groups, professional contacts and researchers, and was answered by 200 people, of whom 161 were residents of Rio de Janeiro, older than 18 years. Among them, 102 (63.4%) had used a virtual assistant with voice interaction in the previous three months.

Their primary means of Internet access were their smartphones, laptops and desktop computers. Only ten respondents that matched the aimed profile declared smart speakers (Google Home and Amazon Echo) as Internet access devices.

The most commonly used assistants were Google Assistant, telemarketing and sales representative virtual assistants, chatbots in Web sites and apps and Apple's Siri. However, 36.6% ($n$ = 59) of the respondents did not use these assistants or could not answer the question. The smartphone was the device most used, as mentioned by 93.1% ($n$ = 95).

Respondents also evaluated the PVAs according to their experience and use. Experience was considered "good" by 54.7% ($n$ = 56), while 20.6% ($n$ = 21) considered "indifferent" and 14.7% ($n$ = 15) as "bad."

Free answers in the questionnaires were valuable to define the technique for the qualitative step of the research. They highlighted different aspects of the voice as interaction. Some respondents recognized the benefits of using voice interactions, mentioning "laziness" as the main motivation.

> *Besides my experience is not good when using voice assistants, I believe that my main motivation to keep trying is laziness, mainly when I am in bed, or I do not want to look at a shiny screen. It makes me ask "Hey, Siri, what time is it?" or "Hey, Siri, how is the weather today.*" (Respondent evaluated use experience as "very bad," but keep using the Siri assistant.)

Other respondents mentioned the disadvantages of the voice as a way of interaction. One of the topics is the sharing of private information, a concern with privacy:

> *I prefer input data on the screen. I have more privacy.*

Another disadvantage is that the perception of "speed" to receive the feedback is bigger than typing on the screen, as explained by one of the participants:

> *I think that they are important (the voice assistants), but it is possible to receive the same information—and faster—with fingers.*

These answers pointed out the topics that should be investigated on a qualitative approach, considering not only the evaluation of usage and experience but also the motivations, constraints and other personal aspects that were not deeply discussed in the questionnaire.

### 15.2.2 Qualitative Phase: Focus Group

#### 15.2.2.1 Technique and Its Conduction

Focus group research is one kind of qualitative research methodology. This type of research is used primarily in the social and behavioral sciences, and usually involves some interviews with people, either in groups or one-on-one. The data collected are people's views, opinions and ideas, and the data are gathered through their own words (Glitz, 1997).

The groups usually have six to ten participants. Larger groups are difficult to manage; interactions between participants tend to be less effective and discussions are hard to control. However, some techniques allow the focus group with fewer than eight participants (Krueger and Casey, 2014).

The goal is to collect data that is of interest to the researcher, which compares data among groups. Discussions must have a "focus" in a natural, logical sequence, and research aims to understand the feelings of the participants, their comments and how do they discuss the proposed topics (Krueger and Casey, 2014).

To collect Rio de Janeiro residents' acceptance and opinions about virtual assistants, as well as to map their difficulties with the technology and their expectations for the future, the focus group technique was chosen to interpret in more depth the data obtained by the questionnaire.

#### 15.2.2.2 Pre-Session and Groups Profile

The pretest, a pilot session, was performed by a group of six males, aged 20–25, and as academic background, three were pursuing undergraduate courses, two had completed undergraduate and one was graduate. With regard to Internet access, all of them use a smartphone, desktops and laptops, and one has a smart speaker, Google Home, at home.

All of the participants were contacted a week before the meeting and instructed to ask questions on their assistants. So, all of them could participate in the debate with a recent memory for discussion. These questions were related to some answers to the questionnaire and are listed below:

- *Who are you?* Here the respondent would listen to how the personal assistant presents itself.

- *Which books Stephen King wrote?* This question mixed two languages (Brazilian Portuguese and English) in the same phrase, one of the problems mentioned by participants of the questionnaire.
- *What is the weather forecast for today?* In the questionnaire, many answers were about the use of these assistants to "make a question or search."
- *Call my mom (or dad); send a message to my boyfriend (girlfriend); how is the traffic to work/school?* These questions aimed to explore the terms used by the assistant that was not explicit (as an example, here was used "my mom" and not the mom's name). Besides, the idea was to instigate the users' curiosity about which personal information the assistant could find alone or suggest to the user.
- How do I get the PUC-Rio (university)? This question was related to the user´s geographic location in which the assistant would activate sensors and real-time information.

After checking the proposed conduction for the technique, it was verified that the tasks proposed in pre-session were adequate. Other aspects—such as the best place to set a camera or recorders; the possibility to offer some beverage and snacks—were also observed. These points were the changes to create a comfortable discussion among participants for the group sessions.

#### 15.2.3.3 Conducting the Focus Groups Sessions

The first focus group session has six participants, one female, five males, aged 23–34, and academically they ranged from incomplete undergraduate to graduate courses. All of them used a smartphone, desktop and laptop, and just one mentioned that he did not use videogames. About PVAs, one used Cortana (Microsoft), two Siri (Apple), three Google Assistant and one never used a personal assistant, just telemarketing virtual assistants.

In the second group, seven participants attended the invitation, five females and two males, aged 20–26, and academically they ranged from incomplete to complete undergraduate courses. All of them used a smartphone, desktop and laptop, and just one mentioned using videogames. About PVAs, two used Siri (Apple) and five Google Assistant, and one never used a personal assistant, just telemarketing virtual assistants.

When each group met, the researcher conducted the session considering two discussions: first, to understand their opinion about PVA better nowadays, and second, opinions about the future.

In the first part, the researcher asked participants to redo the tasks that they did at home, once some of them said that they did not have done. After that, the groups were questioned about their impressions and opinions about these tasks.

The following topics that led the conversation in both focus groups were as follows:

- The first part—about PVAs nowadays

  Which virtual assistant have you used recently? How was your experience with this assistant? Did you like it? Why? If someone used more than one assistant, which one you had liked most? Why? Could you perceive any similarity or difference among them?

In which language was the assistant you have used? In which device did you use it?

What was (were) your motivation(s) to use your assistant? It worked in the way you had expected? If not, tell me what happened.

Have you noticed any problem with your assistant? Have any concerns about it?

Can you remember how the voice of your assistant was? Male or female? Have you already thought about why this voice is offered in a certain gender? Did you like the voice?

What are your opinions about the assistant's "personality"? Can you remember if the PVA was sympathetic, formal, empathic, scornful, friendly? Can you imagine how this system is offered in this way? Did you like it or not?

Do you keep using the system? In each frequency. If you are not using it, tell me why.

- The second part—about PVAs in the future

Now we will talk about the future of these PVAs and your expectancies for them. Has someone here watched the movie *Her*? And the last Google presentation of Google Duplex, the system that can make an appointment at a beauty salon or restaurant? *(At this point, the researcher presented the videos mentioned to all groups, once part of the participants have not seen both videos—movie* Her *during the installation of 'Samantha' and the presentation of Google Duplex during Google IO 2018).*

*What do you think about these visions for the future of PVAs? Did you like any of these assistants? Can you consider using them? To do what? How do you evaluate their utility?*

*What do you expect these assistants in the future? Can you imagine some future possibilities for their use? What do you want them* ***to do****, ways to work? Moreover, what you* ***do not*** *want them to do?*

*Do you believe that these assistants can bring problems in the future? Which kind of problems?*

*Do you believe that these problems can affect the adoption of PVAs by users?*

*And how will be the voice of these PVAs? And their personality?*

*Do you want to comment on something that we have already discussed or want to bring up some new points for our discussion?*

A summarized result of the topics in the discussions in both focus group meetings—not considering the pretest session—is presented in the following sections, quoting non-identified phrases and words mentioned by participants as examples in italic and quotes.

#### 15.2.2.4 Focus Group Sessions' Results and Discussion

Since the purpose of this research was exploratory, the research findings were divided into broad categories of discussions that emerged during the online form and focus groups. The results are presented under relevant topics, illustrating what the participants mentioned, and comparing them with the information obtained in the literature review.

##### *15.2.2.4.1 Technical Limitations*

This first category addresses the problems caused by the technical limitations of virtual assistants and voice interfaces. The volunteers concluded that we would overcome these technical limitations as these technologies evolve and solve the mentioned problems. Some of them also concluded that sooner or later, virtual voice assistants will end up being commonplace, because people think they are fun, and there is not a big technological gap to overcome.

- *Network and performance perception*

Voice assistants have an invocation phrase that allows them to recognize the user's intent to use them. This invocation phrase is necessary, so these systems know when the user is talking to them, and they can identify when to listen and process what has been requested actively.

Apple iOS users stated that Siri was slow to activate and to respond after the invocation and sometimes did not respond. They blame this delay after their bad smartphone performance or slow data connection and poor signal. The frustration of these users can be connected to the fact that Siri did not have clear feedback when it had no Internet access and therefore did not make it clear when it was available by the time we conducted the focus group.

> *When you say "Hey, Siri," this brief time that it takes to process the "hey Siri" and activate the feedback is too much. … You never know exactly when you could keep talking, because I cannot say "Hey, Siri, wake me up at 7 am." If I talk straight, she does not understand.*

Although complaints about performance were restricted to iOS users, users of both operating systems dislike the need to have Internet access to use the virtual assistants. They believed that Internet access should not be necessary for all the functions, and some of the tasks could be available offline.

##### *15.2.2.4.2 Interpretation and Decision-Making*

Users of both operating systems had the perception that the assistants have a limitation when it comes to listening and understanding voice. Participants argued that assistants sometimes could understand what had been said word for word, but did not know what action they should take. Nevertheless, some voice interaction problems were attributed to the assistant not understanding some words of what the user had said.

> *I like Siri very much, but it disturbs me when I ask her something, and the answer is something completely different (from the expected answer).*

Participants stressed that assistants are more assertive when the environment is free of noise. In loud environments or when the user is in public spaces, their assistants make more mistakes. Another reported error is regarding the understanding of more than one language in the same sentence, as occurs when the user asks to play a foreign song. In the second focus group, participants stated that the assistant is better when used in English.

#### *15.2.2.4.3 Limited Navigation*

Another problem reported was the inability to use applications through speech after accessing them with the voice assistant. The assistant opens the application but does not allow continuing the interaction through the voice within it. The user must proceed through the visual interface from there. Just opening an application with a voice without the means to use it was seen as a "useless" feature.

In both focus groups, the perception that it was meaningless to use the voice when the user would have to unlock the phone and select options manually on the screen was unanimous, since "*if you are using the voice assistant, you are probably not able to use your hands*." There is an expectation of being able to usual things on the phone without manipulating anything, just interacting by voice.

One participant in the second focus group told us she did not like the way Google's approach to third-party apps within the Google Assistant. By prompting the user to talk to another entity, the user said, "*the system seems to be transferring the user to another department.*" Other participants had not yet tried this functionality by the time we applied the focus group.

#### *15.2.2.4.4 Usability*

This category addresses the critical points in the use and the problems regarding effectiveness, efficiency and satisfaction—usability—of voice interfaces. These are issues that should be considered and addressed by interaction designers who are designing for this type of interface. The lack of information about the possibilities of the system leads to difficulty in use.

> *The most difficult assistant that I had interacted with was Cortana, at Windows. This assistant did not understand my questions, and I became confused about its functionalities, I did not understand what she could do for me.*

None of the participants in either focus group could list what the assistants were able to do, and this fact was evaluated to be both "good and bad." Some participants have shown interest in exploring and discovering what their assistants could do and had fun while finding new features.

However, despite the great satisfaction when discovering something that works, a single bad experience could erode the user's confidence in that system. One of the participants exemplified this situation when he tried to impress his girlfriend, and the system did not respond properly, culminating in frustration and abandonment of the system.

Also, some of the users have said that they do not like to explore wizards and adjust the assistant to what they know is possible and was mentioned by both Siri (Apple) and Google Assistant users:

> *After a few unsuccessful attempts, people only ask for what they know the assistant is capable of and experience less.*

Most participants in both focus groups perceived the use of voice interaction and virtual assistants as an efficient way to shorten navigation paths in the mobile devices' interfaces. Tasks that depend on many steps, such as creating an event on a calendar or calling a contact can be achieved faster. However, some participants believe that it is faster to use the visual user interface.

- *Hands-free usage*

Some of the participants in both focus groups argued that the need to unlock the phone through the screen and select options manually makes it meaningless to use the voice assistant, especially when the user cannot use their hands, such as when driving a car.

Even when hands are free to use the phone, participants mentioned that they expect that the assistant does not depend on the selection of options on the screen after a voice interaction. This case happens, for instance, in cases of need for disambiguation.

- *Invocation*

During the discussion about invocation, there were declared some preferences divergencies. While some participants said they preferred to activate the assistants by voice—affirming that press a bottom is "*boring*" once it is a "*longer interaction"*—others said that interacting with screens is better, once in this way they do not activate the assistant by accident.

This behavior matches what is related by Pearl (2016) that today a lot of us work in open space offices, and what if everybody decides to "talk" with our computer to do tasks, like "Computer, find all my Word documents this week." It will be chaos. Furthermore, "when you 'talk,' which computers are listening?"

Another point was the need to *repeat* the invocation more than once during the same conversation with the assistant. Some participants suggested that conversation must be active until the user asked to close the application or concluded the task. A counterargument was discussed that a continuous interaction could be a problem when the user is not dedicated to the interaction within the assistant.

Siri´s users, in both groups, mentioned frustration once they sometimes do not know if the system is "listening to them" when there is no signal or the signal is weak, once there is no feedback sound when the phone is soundless. Siri users agreed that they invoke the assistant and it takes a while, or do not answer, without explaining to the users if she/he is being heard or not.

Both groups commented and agreed that inadequate feedback indicates that more development on new design options to present non-visual feedback is needed.

- *Smash the natural conversation*

Beyond the discussion about invocation, a point of complaint about all participants concerning Apple Siri was the loss of dialogue context. These users related that all phrases seem to be a "new conversation," once this assistant does not retrieve information or "remember"' of what is in the discussion. That is an attention point, the conversational interface of Apple Siri in Brazilian Portuguese is not yet well-developed and sometimes works as command interface and voice control.

Another aspect emphasized for both groups that can demotivate voice interfaces is when the assistant gives a long answer to the user, for a brief and simple question. When it happens, the user drops out a voice interface to look at the answer on the screen; in worst cases, the users feel coerced to reformulate the question, as a tentative to obtain a specific and more exact answer.

#### 15.2.2.4.5 Accessibility

Regardless no person with special needs participate in the discussions; the participants commented that they believe that voice assistants can be useful for those who are not able to use graphic interfaces. The humanization brought by the PVA "persona" was considered positive, once the system becomes familiar. It was also mentioned in both groups that "talk" with an assistant must be faster than using a screen reader in a graphic interface.

Besides this, one of the participants criticized that the group was discussing accessibility for a chance. He does consider that:

> *"These systems were not designed to be accessible. It was just convenient that they are, once make them saleable."*

#### 15.2.2.4.6 Other Topics Debated by the Groups

Assistants are considered as a way of entertainment, not a tool; once they are being developed and adopted more because they are fun than because they are useful.

Motivations for using the assistants are related to laziness and entertainment. They explained the laziness when they want to set a clock to wake up or when they need information and do not want to stop and look it up. Another mentioned situation was to take a shortcut during screen navigation, for example, ask for the weather forecast on a trip, search for a contact to call or set an event on the agenda.

The users consider the PVAs entertainment once they like to test the functionalities for curiosity, talk with the assistant to check joking in the way they work or to find *easter eggs* (secrets hidden in the application that has humoristic aspect).

The assuredness in both groups is that PVAs will be more useful in a fully connected world. The clear benefit is to substitute what today is done in a "mechanical way," without touching the phone, PVAs will need to know what must be bought for the pantry, control the lights, adjust the air-conditioning temperature and so on. The centerpiece was used in the domestic environment, which is noiseless, and the user has more freedom to speak with the system. However, not all of them agreed with this idea; once they remarked on it, they felt uncomfortable with the idea of controlling their lives.

- *Customization*

During discussions, participants considered as essential the PVAs adaptation to different levels and types of customization, as adequate to user´s humor, accept preferences configuration, fit the way of speaking, among other aspects.

This aspect is following what was affirmed by Nass and Brave (2007), which highlight social identity as an important point of adoption and good evaluation of voice interfaces. Dashtipour (2012) explained the Social Identity Theory (SIT):

> It has been characterized as a theory that is primarily focused on social transformation because it illustrates how social identities change and how categorization is involved in collective action. (…) Group belonging is important as a basis for self-definition. Individuals, therefore, search for positive in-group distinctiveness and discriminate against groups.

Focus group participants agreed that when everything is connected, it is easier to know everything about a person; it makes the system more personalized but implies safety and privacy negatively.

- *Humor adequacy*

Participants have the same opinion that to be "personal assistant," the system must be capable of knowing well its users and recognizing users' moods, adapting their way of communication. Users mentioned that they would not like to be treated in the same way when they are in a good mood or a bad one. One of the participants summarized it:

> *If she (Siri) is sarcastic in a day, I´m in a very bad mood; I´ll kick the phone!*

Nass and Brave (2007) also discussed mood and affirmed that users prefer consistency among the emotional state of content and voice. Users find it unusual when a sad content is said happily, and something exciting is said with a sorry voice.

- *Automation and passive customization*

In both groups, participants evaluated as positive have an assistant—in the future—that knows them very well. So well that it can solve activities without users' interference, as setting appointments on the agenda, once it knows your schedule. In a connected world, assistants could also help to configure house appliances, like light and temperature, before the user arrives at home.

- *Configuration and active customization*

Active personalization was also a point of discussion. The PVA must adapt itself to the user but must also allow customization, considering from voice tone to system personality. This need for customization could be verified during participants' discussions: some commented that PVA could be more trickster and friendly, while others prefer a straighter and polite system. The way of interaction must be an agreement between the user and the PVA, and each person could decide whether to interact by voice or not. Just one person mentioned that it was possible to configure a male/ female voice in a PVA.

- *Filter bubble*[1]

Few participants mentioned the filter bubble during discussions, but those who mentioned demonstrated a big concern about it. To these people, users must take care with an excess of personalization, that "*can fit these PVAs in a bubble, in which you just see what you want, what you like, and what you know.*" Even if it is not a problem related strictly to PVAs, once the topic was brought to the discussion, they agreed that this bubble could deepen with them, once these systems are present during the users' full day.

- *"Forced humanization" than lack of conversational interface*

Participants mentioned telemarketing virtual assistants as an example of a bad interaction, as "*a lack of natural interaction*," a "*forced humanization*" once the system speaks with you like a friend and "*keeps a long time to conclude the service*." It is related to the fact that it is not possible to "talk back" with a recorded message of these telemarketing virtual assistants. This interaction becomes artificial (or not natural) and is necessary to wait for a long set of instructions, as type an option or specific word to start the service. Participants affirmed they feel impatient during listening to all instructions, and when it is possible, they skip directly to a "real person" agent. It was also mentioned that this artificial interaction delays the service, once it is not possible to skip the preset tasks, and the "real agent" is always the last step during this interaction.

Participants considered that to simulate a real situation, the interaction must also be natural. If not, interaction is inconsistent and promotes frustration once the interaction with customer services always occurs in cases of problems, complaints and stress.

- *PVAs personality*

It is considered positive when the personalization of a PVA has a natural interaction, and it is expected that these systems can be improved in the future, according to the discussions in focus groups.

The participants that use iOs mentioned that Siri´s behavior of "*making jokes,*" "*be a rebel*" or "*talk in a sarcastic way*" gives her personality, but this aspect could be personalized by each user, as explained by one of the participants:

> *Siri is not* **my** *Siri; she's de same Siri for everyone.*

During discussions, Google Assistant was considered more "neutral" than Siri and opinions were divided: for some of the users, this system is always "*passive*" and "very helpful," but "*does not have a strong personality.*" For others, this assistant is "*cool*," "*friendly*" and "*helpful*."

- *"Forced" social interaction*

More introverted participants commented that they do not want to interact by voice with PVAs. They justify this decision: "*the system is one more person that I´ll need to deal with every day*." Participants that mentioned this aspect appeared to be shy and reserved during the focus group session, and also highlighted that they are "*feeling obliged to use PVA at risk to be excluded in social groups*."

- *Social rules of voice interaction*

All participants referred to PVAs as "he" or "she," determining some human characteristics as "stupid," "polite," "friendly," "sarcastic." One of the participants said he always asks "*please*" and gives "*thanks*" to the PVA.

Even participants mentioned that they like voice interaction, some of them say they prefer text, once using during walking is not ok to speak loud, or about private issues.

This behavior is pointed out by Pearl (2016), mentioning that many people spend hours in their mobiles, usually texting. That is their default mode, and maybe they will not change to voice mode.

Even when they are not in public areas, some participants mentioned that they do not like to talk on the phone, and use chat instead, and this is the same behavior with assistants. They consider this attitude positive once they do not feel comfortable using PVAs in public, and it can be a barrier to the adoption of these systems.

As said by Pearl (2016), "Although VUIs are becoming more commonplace, not everyone feels comfortable speaking out loud to a computer, even in private."

- *Social behavior and other impacts*

Although the rich discussion about technical aspects such as usability, accessibility and customization, among others, abridged in the above topics, the major concern during discussions was the impact of PVAs on society and people's life.

a. *Voice's gender*

The fact that PVAs use as default female voices was discussed by both groups and participant's opinions were divided. For some of them, the female voice was seen as a "*heritage of subservience of female role in society"* that was transposed to PVAs. To other participants, this fact was not important once they are conditioned; once a female voice is better and preset by the system.

The female voice preference may reflect just for these discussion groups. On the other hand, the mentioned system default reinforces the stereotypes that participants consider negative for women's role in society. While it was also mentioned that both male and female voices are still "robotized voices," in the future they expect that voice scenario will become more plural.

A UN report (EQUALS, 2019) affirms that by naming voice assistants with female names (as Alexa, Cortana and Siri) and using female voices by default, tech companies have habituated users to fall back upon old-fashioned and injurious women's perceptions. The report highlights that companies were not able to design exposure controls against abusive, aggressive and gendered language. One of the problematic aspects is that the assistants have a positive reaction (as jokes) when assaulted.

b. *Privacy*

The discomfort of using PVAs in public areas was unanimous, not only to be a shy person but the "*feeling to be exposed,"* once "*there is no privacy in asking something to PVA with people observing*," even recognizing the practicality of voice interaction.

Another aspect concerning privacy is related to share personal information with strangers, not only the system. This idea led the group discussions to the need for transparency about what data is being collected by the system, how it is done, how data is stored, distributed and mainly, who will access it. Some participants said they are already "*resigned*" that their data are being stored and believe that this fact is not bad at all, once this data can personalize the system. This group defends that to design a personalized system; it must learn how the user speaks and relates with others—loose privacy is one aspect that will imply better PVAs.

All of them believed that data privacy is already a concern, and PVAs are not establishing a new problem, making the problem worse.

This aspect was also mentioned by Pearl (2016):

> If they discuss a health issue, most users won't want to do so by speaking to their phone on the train ride into work. It's not just privacy for what the user says to systems, either—it's the potential privacy violations of a VUI automatically regarding your text messages out loud."

c. *Sale and sharing of personal data*

Another concern shared by participants was the fact that companies share and use their private data. A preoccupation is that once PVAs are automatized and can decide on the user, it gives a bias for advertisers. One of the participants gave an example of this situation if he asks the assistant to buy a pair of shoes. In this case, he believes that:

> *The system will consider not only users' preferences and specific configuration, but also will indicate a "partner" to this purchase.*

This example started a new discussion: some participants affirmed to be "invaded" with personalized ads, while others feel passive, once in this case, they received interesting ads.

They all mentioned that Web site and apps terms of service documents they need to accept or are not allowed using the product/ service, as explained by one of the participants:

> *Or you accept, or you will be excluded from everything and everyone for not using (the app), and it is human nature be included, accepted.*

d. *Reinforce of bad behavior*

A point mentioned during discussions was about personalized assistants that stimulate and reinforce ideas and bad behaviors. As an example, a racist person can personalize the assistant that will agree with anti-ethical attitudes and generate a "filter bubble."

One of the participants that has a technical profile discussed this aspect, mentioning that there is a risk not only for personalization but also for classificatory systems. In this case, the assistant could support prejudice and stereotypes when identifying user's profiles and label them. In this case, the assistant could identify, as an example, a disease in a certain user (by mistake or not) and wound her/his privacy making decisions on alerting the family or health insurance companies. All of them agreed that this kind of situation could be a disaster in people's lives.

e. *Inequality and unemployment*

Inequality was also a topic of discussion by groups. The cost of this technology is understood by participants as a segregator, once it can prevent the access of part of the population, or allow the access for just an outdated and low-quality technology. On the other hand, once technologies drive forward, they cost less and become more popular. Finally, it was also highlighted that "*in Brazil, until now (2019), there are citizens with no internet access.*"

The topic of unemployment was discussed, considering how virtual assistants would substitute humans in certain jobs. Some of the participants believe that the human factor is important, and that one day he/she will lead the same situation (as customer service, for example) and will have empathy with the user. Others believe that this is naïve thinking, that one day people will have more free time in their days, that one day the technology will take humans' place in performing simple tasks.

One of the participants mentioned that this substitution of humans with machines would generate more inequality and would affect jobs needing less skill. On the other hand, even the more advanced assistants would not be able to replace professionals who perform intellectual activities, or this kind of exchange would not be financially viable.

f. *Impact on new generations and their social behavior*

During discussions it was mentioned that PVAs would leave people lazy and pampered, and they will be unprepared to perform basic tasks alone. As an example, it was cited that since smartphones became popular, people started to type and write with errors (due to the use of abbreviations), and lost the practice of handwriting.

It was also debated that virtual assistants can lead to human seclusion. Some argued that isolation would happen, once no social interaction will be necessary for daily life and in the distant future, people will create a stronger relationship with VAs rather than with other persons, as was said by one of the participants:

> *It's being designed a technology that seems a person for no need to talk with a "real" person.*

Some participants mentioned that technology would minimize daily tasks, and people will have more free time for human interactions that care. They expressed that nowadays there is an opposition between talking and interacting with people because everyone prefers using chats, and maybe virtual assistants could bring back the natural speak.

In the face of this argument, participants remembered that assistants do not have as the only function perform tasks, but also a social role. Social and amusement roles are expected with great potential for those who cannot socialize "in person," such as the aged, the ill or those with mobility problems.

#### 15.2.2.4.7 Future Adoption

The common understanding is that virtual assistants can be useful tools, and will evolve to be in our daily lives, more than today. In the future, these assistants will be needed, and people will have a good experience with them, not only as entertainment.

## 15.3 TAKEAWAYS AND FUTURE RESEARCHES

The research presented in this chapter addressed the personification and the use of conversational interfaces in virtual assistants with the premise that these traits would facilitate their acceptance and make the opinion about their uses positive. At the end of the study, the result showed that the personality of these assistants indeed facilitates their adoption and has positive effects on the user's perception. However, voice user interfaces still cause discomfort when used in public environments. The biggest concerns raised by users regarding voice assistants were not technical or usability problems, but reflections on the impact of assistants on society and people's lives.

It is possible to point out some answers to the research questions:

*What is the impact of voice on the user experience of PVAs? Does the voice, instead of text, is understood as a benefit by users?* Besides, voice interaction was evaluated as a benefit—as the possibility of interaction with occupied hands, shortcuts to navigations, accessibility—users related that they still feel uncomfortable to use these systems in public areas, as well interact with unanimated objects (as computers and mobile phones), what can demand a difficulty in these systems adoption.

*Does the literature review reflect the particularities and field studies in Brazil? Which are the similarities and points of attention about his public?* Nass and Brave (2007), Pearl (2016) and UN report EQUALS (2019) are some of the authors that supported the focus groups discussion analysis, but topics like privacy, social and ethical aspects and the preference for female voices regardless of the user's gender were also observed during the discussions. Some of these points must be studied in future research.

*How do Brazilians use or intend to use voice interfaces, now and in the future? How are their evaluation and opinions about PVAs?* The majority of focus groups participants as questionnaire respondents does not use all the functionalities that these systems offer, but they believe that there is a potential for this technology, and consider their adoption once PVAs involute and become more usual. The connected scenario and the presence of assistants in the home environment through smart speakers are shown as potential influencers of their adoption. Results also lead to user's perception of personification and voice interface as positive aspects for adoption and experience.

Although the results can be supported by the studies conducted with the English-speaking public, there are singularities in the Portuguese-speaking public usage of PVAs.

It is not just a new technology that presents itself, but a different expectation that people have, different relations with a system that people will set in their everyday activities, with other interconnected devices, along with other human beings.

Usability and users' experience are issues that are fundamental for the adoption or not in the future and is related to decision-making, efficiency, ways of interaction (voice, text), social behavior, customization, personalization, privacy, social interaction, equality and the feeling of belonging to a society. Each of these topics needs to be investigated deeper, once they are related to cultural aspects, the role of each of us in society.

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## NOTE

1. "Filter bubble" is a term coined by Pariser (2011), which means an intellectual isolation that can occur when websites make use of algorithms to selectively assume the information a user would want to see, and then give information to the user according to this assumption. A filter bubble, therefore, can cause users significantly less contact with contradicting viewpoints, causing the user to become intellectually isolated.

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# *Section 5*

## *Usability and UX in the Currency Context and Emerging Technologies*

# 16 User Experience in Remote Context
## *Emerging Needs*

*Maria Lucia Leite Ribeiro Okimoto*

**CONTENTS**



## 16.1 INTRODUCTION

This decade stands out in human development worldwide, with changes resulting from the pandemic SARS-CoV-2, generically named COVID-19. Not only has the health protocols for disease prevention been changed, but together it has also brought about profound social changes across the planet. The first sign of change appears in human behavior. Unfortunately, the urgency of the current pandemic situation, resulting from the SARS-CoV-2 virus, did not allow humanity to go through an adaptive stage. And the health measures imposed by WHO to reduce the impact of the virus through social isolation brought with it several consequences. Thus, the global crisis resulting from the pandemic brings a strong transforming trend reaching beyond the health systems, the economy, politics and culture. And humanity, still supporting these changes, has been adapting very quickly, seeking its self-regulation. This concept of self-regulation is one of the conceptual elements, a component of the complex biological system, as pointed out by Varela, Maturana and Uribe (1974).

This is a time of transformation and adaptation of life to new world trends. And certainly the year 2020 will be in the eyes of the next generations as a landmark of historical transformation of humanity. Within this new context, some expressions appear and become popular, such as quarantine, social distance, restriction to circulation, confinement and lockdown. The user experience takes on new dimensions, hugs are replaced by emojis, face-to-face meetings and classes by remote

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conferences, traditional tourism by virtual tourism, offices by Work from Home and artistic presentations by lives. In this way, humanity has sought to reinvent itself, readapt, change habits, rethink concepts and rediscover new values. Behavior, the way to manifest and transmit information and emotions are being drastically replaced in this period.

## 16.2 USABILITY, USER EXPERIENCE AND USER CONTEXT

Usability is typically defined as the "capability of being used," in other words, the capability of an entity to be used (Bevan, Carter, and Harker, 2015). Usability is part of the user experience (UX). According to ISO 9241-210: 2019, the user experience is defined as user's perceptions and responses that result from the use and/or anticipated use of a system, product or service; whereas users' perceptions and responses include the users' emotions, beliefs, preferences, perceptions, comfort, behaviors and accomplishments that occur before, during and after use. The user experience is a consequence of brand image, presentation, functionality, system performance, interactive behavior and assistive capabilities of a system, product or service. It also results from the user's internal and physical state resulting from prior experiences, attitudes, skills, abilities and personality and from the context of use.

The user context is the basis for assessing usability and user experience. One must understand the specific contexts of use, considering the characteristics of the users, objectives and environments of particular interest to the user. For digital systems, the user context is included in ISO/IEC 25063: 2014.

Considering aspects of accessibility and aspects of context of use, we can take population data as a reference to realize the percentage of users who need some kind of help so that they can effectively access information and interact, in order to expand autonomy. In Brazil, we have a population of approximately 208 million and 900,000 people. Of these, 24% declared to have some disability, according to IBGE (2010). In this scenario, more than 50 million people are excluded due to the lack of accessibility resources. Accessibility is important for people with different disabilities and abilities: either by using the keyboard for navigation without the "mouse" or by the difficulty or inability to see the screen, by cognitive difficulties, by the use of the Brazilian virtual sign language, VLIBRAS or by other particular issues.

## 16.3 CONTEXT IN THE PANDEMIC PERIOD

The global pandemic scenario has changed the experiences of users and UX professionals. There were few specific studies in this period of the pandemic observed from April to November 2020 that deal together with the theme of user experience and remote activity. However, the actions of the NN/g (Nielsen Norman Group) stand out in the promotion of instructions and training for professionals and of UX tests remotely. Kate Moran (2020) from NN/g presents a study on behavior changes before and after COVID-19. According to the author, before COVID-19, the population routinely performed the following actions: commuting every day to an office; taking children to school or daycare; exercising in a gym; socializing in large groups at bars; buying products in stores; going out to eat in restaurants; going to a movie theater; going on international vacations; visiting a doctor's office; visiting a government office to complete paperwork. After the health rules and recommendations of the World Health Organization, many actions were modified, and during the period of greatest rigidity with restrictions, and recommendation intensifying social isolation, while remaining local rules to prevent contamination. And, even a few months after the most critical periods, Moran (2020) still observes the following changes in people's routine: no commuting and working from home; homeschooling or caring for children at home; exercising at home, outdoors or not at all; buying products online; ordering food to be delivered at home; renting a movie at home; going on a local road trip; using a telehealth app from home.

Evidently, depending on the local culture, there may be differences in people's behavioral changes. And these changes can be more complex, due to the virus itself and the age group of the population that has the greatest restriction, these being people over 60 years old. In addition to this impact of restriction on mobility, economy, education, hospital infrastructure, public policies and consequently the entire global production chain were affected. The magnitude and exact nature of the changes can only be tested in a few years. However, individual behavior change will certainly be part of people's experience, and according to Moran (2020), this may be a short-term change, but it may also have long-term consequences for all related sectors. On the other hand, with regard to emotional impacts, which emerge from the consequences of the restrictions of the pandemic state, people who are more sensitive and in situations of greater vulnerability in this case are subject to a greater risk, tending to depression and anxiety.

Pfefferbaum (2020) considers that public health emergencies can affect health, safety and well-being causing insecurity, confusion, emotional isolation and stigma to individuals, as well as affecting the communities, due to the economic factor, loss of job and school and lack of financial resources for medical assistance, among other factors. The authors consider that the consequences may have repercussions on the emotional part or with changes in unhealthy behavior, through the excessive use of chemicals, alcohol and other illegal substances. The authors point out that other research indicates that emotional suffering is ubiquitous in populations affected by disaster situations, and that this fact may echo in populations affected by the COVID-19 pandemic. About this issue, Pfefferbaum (2020) describes psychological sequelae in quarantined people and health professionals and the main symptoms are stress, depression, irritability, insomnia, fear, confusion, anger, frustration, boredom and stigma. Even symptoms that persisted were identified, even after the quarantine was lifted.

Thus, it is a consensus to affirm, corroborating with the arguments of Moran (2020), that this year people have different expectations and concerns than they had in 2019, and some of these differences may be lasting. And in this context of a pandemic, there was a need to break paradigms to readjust human supplies. At first, the traditional way of acquiring and purchasing food and the place where the work was carried out was broken. In this change, the bases of human survival prevail, to remain protected individually, or family, as well as for their economic protection. In this first paradigm break and behavior change, there was a considerable growth in online shopping. In this way, we can perceive the role of self-regulation of the human biological system, as pointed out by Varela, Maturana and Uribe (1974). This change favors opportunities for this "new user," as their needs change radically. Thus, it is a strategy for obtaining necessary inputs—electronic commerce. A large flow of new potential customers with different emerging needs quickly appear in this scenario.

And technology has been the means of interaction and the solution to meet the basic needs of this global society during the pandemic period. Thus, remote working raises social and technical issues. The crisis has sparked a mass shift to working from home. As a result, the use of remote collaboration tool, particularly videoconferencing platform, has surged. Another major impact of a paradigm shift was on distance learning. The technologies of distance learning have increased significantly in recent years, gaining confidence little by little, above all, in the professional training of adults. Distance learning with its own rules has, in this short time of the pandemic, passed from a complementary system to a necessary and emergency teaching support. Thus, remote education has expanded at an accelerated rate, being above all a means of access to all levels of education, from the preschool phase to the highest level of postgraduation. And in this way, people started using digital platforms and media for all possible day-to-day interactions, sharing cake recipes, solving small problems and other tips on an innate need to share their actions, skills and knowledge.

Chen et al. (2020) investigate user experience in digital teaching platforms in China during the COVID-19 pandemic. They point out that social education has shifted from face-to-face to online in order to avoid large gatherings and crowds for blocking the transmission of the virus. The authors argue that these platforms provide strong support and aid for education during the pandemic period and bring to users a new experience, but also bring a lot of controversies. Because of that, it was necessary to analyze changes in user concerns on these platforms before and after the epidemic. And they analyzed the impact of the virus on user experience and deeply retrieved users' requirements, about seven major online education platforms before and after the outbreak of COVID-19, by combining the emotional analysis, hot mining technology, as well as relevant literature. In this way, they developed a systematic method with weighting of the variables, thus adopting a comprehensive evaluation method to analyze user experience before and after the outbreak of COVID-19, and finally finds out the change of users' concerns regarding the online education platform. The authors evaluate in terms of access speed, reliability, timely transmission technology of video information, course management, communication and interaction and learning and technical support and explore the supporting abilities and response levels of online education platforms during COVID-19, and puts forward corresponding measures to improve how these platforms function.

Initially the authors first collected comments from users of seven traditional online education platforms, and then punctuated the emotional aspects in the comments and presented a platform rating index system. Weight to the index was defined, thus the variation coefficient method and the entropy method were used for the calculation. Based on the index weights obtained, the user experience of each platform before and after the outbreak of COVID-19 was assessed in order to analyze the impact of the pandemic on the user experience.

Surveys related to user experience must also meet the ethics in research recommendations. In Brazil, the National Research Ethics Commission (Conep) of the National Health Council (CNS) guides the adoption of the guidelines of the Ministry of Health (MS) arising from the pandemic caused by COVID-19, in order to minimize potential health risks and the integrity of research participants, researchers and members of the Research Ethics Committees.

## 16.4 STRATEGIES FOR CONDUCTING USER EXPERIENCE STUDIES IN THE CONTEXT OF A PANDEMIC

The remote communication strategy extends to all areas, and in the context of the user experience, takes advantage of new dedicated digital platforms with video resources, just as it did for use in distance learning. In this way, the user experience remotely expands and consolidates protocols and techniques already developed, including some strategies considered complementary, such as remote usability testing, in the face of direct approaches, of interaction between the UX professional and users.

The first environments for usability tests, considered as observation aquariums, sought to block the physical presence of the evaluator in order to reduce the emotional and distraction aspects of the task. And these usability test environments, even if in person, sought to have a specific environment in order to isolate the researcher's in-person variables from the participant. According to Bradner (2004), almost 20 years ago, the remote usability test started to become popular through the use of technology. For remote usability tests, the digital conference telephone call system was used, using call audio in conjunction with screen sharing. One of the tools used was Microsoft NetMeeting or Live Meeting. This technology was the first step to allow remote-assisted performance observation in a virtual laboratory. Some advantages of the remote test are pointed out by the authors, and the fact that physical restrictions on access to the site and physical space for testing are eliminated, also impacting on the final cost-reduction of this process.

The face-to-face interaction brings us some advantages for the established practices of UX, which is the easiness for the participants to build a bond of trust and professional relationship than remotely. An effective point of face-to-face interaction is greater concentration, since the participant is immersed in that context that involves the product. Thus, the time for concentration and attention may be longer according to Kapla (2020). However, in the event of a pandemic and possibly on other particular occasions, we cannot always perform user experience activities personally. There can be many unforeseen events: limitations of budget, time, travel or other unforeseen circumstances can make the face-to-face form impossible. At this moment, when the planet is going through a pandemic, this may be the most efficient and safest solution for everyone, whether they are participants or professionals.

Kapla (2020) points out the benefits that remote UX sessions offer: flexibility in project funds, the remote sessions reduce travel expenses; increased inclusiveness, the location and space are no longer limitations with remote sessions; participant convenience—promotes greater convenience to participants that does not require them to leave the office or home, also saving time.

So the main point of investigation of UX is to identify the new habits and behavioral changes of the new users during the pandemic. The experiences of the NN/g Norman Group, reported by Moran (2020) in user experience with different companies, emphasize that each user group is unique, and that's why everyone needs to do their own research. Depending on who is your user populations, their behavior and preference changes may be different from another user population. Moran recommends that when assessing COVID-19's impact on your users, consider whether there are behavioral shifts; psychological shifts; changes in user groups; regional effect; and temporal effects.

The NN/g Norman Group at their Web site https://www.nngroup.com provide training to conduct remote UX research. This group clearly and concisely presents the need to pay attention to UX practices for this new context. Also, they emphasize the need to adapt the methods, software and the context of isolation that the user finds. Best practices need to be reviewed and moderated and unmoderated remote user experience research improved. The team highlights specific recommendations within each sequential stage of the UX process planning: practice using technology; recruit additional users; plan technology challenges; provide instructions; and adjust the consent forms.

It is also recommended that a good training should be provided to researchers on new technologies, in order to increase the tool's familiarity, and to do previous tests with the team with the new technology. And particularly for remote and unmoderated sessions, it stresses the importance of clear instructions for entering and completing tasks. It is important to plan and conduct an initial pilot test with some users to adjust the technology and other factors as needed before starting the study. They emphasize that because they are remote tests, they can become unusable due to the technology itself, so having an additional number of users is quite appropriate in these cases, creating a proactive safety net.

They recommend that the researchers should always prepare an alternative form of communication with the user, which in a simple way can be through a telephone call. Another alternative is to use a Web link for interviews with users: preferably accesses that do not require participants to download anything to join the session. It is essential to provide instructions if the technology tool is complex or users are going to configure and use it for a long time. Evernote's shared notebook can assist as a tool to arrange the necessary forms, especially the consent forms. If it is necessary to record the face, voice or screen of the participant during a remote session, it is important that the consent form is updated with the appropriate permissions for each of these items, as well as other authorizations.

Remote user research can be conducted in the same way as UX that normally uses several research methods according to the objectives of the study. The NN/g recommends in remote and unmoderated sessions: tools to capture qualitative perceptions of video recordings and loud voiceover by users. The most used are Lookback, dscout and Userbrain. And for quantitative metrics, such as time spent and success rate, software such as Koncept App and Maze are used. The UserZoom and UserTesting platforms have qualitative and quantitative resources.

Today, in fact, there are many platforms for UX testing available, with costs relatively adequate to each situation, from a small usability test to others of higher cost that can provide greater variability of the user experience. The vast majority of platforms, including in the period of the pandemic, released videoconferencing systems with screen sharing, call recording and videos free of charge. Most meeting platforms allow you to schedule meetings in advance. Among the platforms used are Jitsi meet, Zoom, GoToMeeting, Microsoft Teams, Google Hangouts Meet, Skype Business, etc.

## 16.5 SURVEY OF PERCEPTUAL ASPECTS OF USERS OF DIGITAL PLATFORMS FOR REMOTE ACTIVITIES

A questionnaire was applied to survey the perception of the use of remote systems for the use of work activities. The research was carried out in the city of Curitiba, Brazil, in November 2020. The objective was to try to identify aspects of interaction with the platforms and the main difficulties and dissatisfactions for carrying out work tasks. The survey was conducted on Google Forms, which is a search management application launched by Google. In the survey, 49 people participated, with 16.3% in the 18–24 age group: 12% in the 25–30 age group; 12.2% in the 31–40 age group; 24.5% in the 41–50 age group; 24.5% in the 51–60 years age group; 6.1% in the 61–75 age group; and 4.1% in the 66–70 age group. Searching in this sample is to seek representatives of age groups that use digital platforms intensively.

Participants were asked about the context of occupation, work, study and type of professional relationship. It was also questioned whether they performed activities related to teaching, whether as a student or teacher. In this group of users, 55% exercise registered work activities, and 12% exercise professional activity independently, 22.4% are students and 16% do not currently have a professional activity. Of this audience, 83% use the digital platform for work or teaching. The time of use of digital systems was reported by 22.4% who used for more than 10 hours daily, another 22% used between 8 and 10 hours daily. A total of 42.4% use more than 5 hours daily. And 95.9% of users selected the notebook for the virtual meeting of work activities. For family reunion activities, only 40.8% of them used a digital platform for this purpose. And 57% of users reported using the digital platform for teaching purposes, while 34.7% of users reported that they teach remote classes.

The digital platforms used were the following: Microsoft Teens by 37.6%; Google Meet 26.5%; Zoom 14.5%, Cisco Webex 6.12%, Discord 6.12% and with less use the Google Classroom platforms; Jitsi, Skype Business and Whatsapp. Below we list the comments of 32 users who responded about what they dislike most about conducting a remote virtual meeting activity on the platforms chosen for their activities.

U01. I hate to use headphones, but it is necessary.
U02. Access difficulty.
U03. Not being able to know if students are actually participating.
U04. People don't know how to use technology. Time is wasted, a lot of time, with things that are extremely simple and straightforward.

U05. It takes time to understand the interface, which leads to delays in the development of the meeting.
U06. Unstable Internet.
U07. The concern with the status of the connection and also the context in which I am inserted. At home, there are several distractions and other responsibilities that influence and hinder concentration, such as sharing the same environment with another person who works remotely.
U08. It is different from a physical meeting in the sense of public engagement.
U09. Lack of help for people who don't know the platform, the lack of a tutorial makes it difficult.
U10. Connectivity issues.
U11. Delay to enter due to passwords, sudden disconnection of the call.
U12. Due to long periods in front of screens, it causes discomfort in the eyes, in addition to sleep, and the greater ease in being distracted by other things.
U13. I need more control of the speaker's window. To be able to transmit to another platform. To be able to quickly choose to teach between mosaic and just one window, using keyboard shortcuts.
U14. People with camera off.
U15. When the video freezes.
U16. You have to close the microphone or there is a lot of noise.
U17. Very tiring.
U18. Interruptions.
U19. Don't see the students' reaction. Most keep the camera closed.
U20. The system can stop at any time.
U21. Interruption when power is lost or when the connection fails.
U22. I miss personal contact.
U23. It is very tiring when the meeting lasts more than 2 hours.
U24. I get discouraged when the transmission stops at my meeting.
U25. Connection failure is annoying.
U26. People do not turn on the video camera when sharing the screen.
U27. In classes: the silence of the audience. The sloppy physical environment, lack of lighting, sound in the environment, low-quality Internet of participants.
U28. Complexity.
U29. Inconveniently opened video cameras.
U30. When all participants turn off the camera, turning into a meeting of machines.
U32. The digital platform is not so interesting to extend discussions, answer questions, interact to explore aspects of the conversation. In my opinion, this fact makes the relationship more impersonal, since the listeners are in the same virtual environment, but not with the same level of collective interaction.

It can be seen in the results that the negative experiences that were presented by the users are recurrent for several users with regard to the aspect of failures and interruptions due to technological issues. But the vast majority of reasons for dissatisfaction refer to the behavior of users in front of the cameras, in an attempt to remain incognito in the virtual meeting. Fear of exposing the environment where you are, difficulties to isolate noise from your environment.

## 16.6 CONCLUSION

To the detriment of social isolation measures, professionals in the field of design and usability had to reinvent themselves and adapt, bringing new possibilities, given the need to stay at home. And this context brings us reflections on the conduct of user experience studies in a remote context. In this sense, in this chapter new paths were pointed out for professionals in the area which have brought significant results, providing greater security for the reproduction of techniques already established for face-to-face contact in the remote form.

But for that, as a post, it is necessary to understand this new context, the user, their expectations, fears and anxiety in the face of this pandemic and post-pandemic moment. Therefore, new adaptations to the methods of conducting research and data collection are essential, which at this stage is being revitalized and reframed.

Since the COVID-19 pandemic has drastically affected user behavior worldwide, different cultures have also responded in a unique way adapting to the restrictions of remote data collection methods, which do not allow personal interactions. The use of digital platforms has significantly remodeled and innovated the way we relate to people. Digital platforms undoubtedly have the potential to play an important role in the dissemination and reformulation of the user experience practice. And the COVID-19 pandemic is an opportunity to iteratively optimize remote abilities for the UX teams.

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# 17 Applications of Infrared Thermography to Evaluate the Ergonomics and Usability of Products with a Gestural Interface

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## CONTENTS



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## 17.1 INTRODUCTION

The human being constantly seeks to perfect the artifacts that help him in his daily life. Technology has advanced a lot, and the possibilities are immense. New products are emerging and incorporated into people's daily lives. At the same time, old products are being updated, and new forms of interaction are part of these changes (Rogers et al., 2013). Devices such as smartphones, tablets, interactive videogames, home robots and others, which recently did not exist, are now essential to perform domestic tasks, work and entertainment. Equipped with features that fascinate their users at first contact, these artifacts can be manipulated through various tactile actions, voice commands and body movement recognition, instantly understood by the device's system (Wigdor and Wixon 2011).

Gestural technology is today one of the main novelties, both in new products and in updating existing products (Wigdor and Wixon 2011; Rogers, Sharp, and Preece 2013). The best-known application is the touchscreen, a type of interface that requires the user to touch the device directly to interact with the interface (Saffer 2008). However, body movement recognition sensors such as Kinect and Leap Motion are being disseminated and interact without direct contact with the product.

The popularization of these new technologies, as previously mentioned, is causing changes in many consumer products. However, there are artifacts with different functions and complexities. It is necessary to study the possibility of applying these new forms of interaction to identify each situation in the most appropriate way. Ten years ago, Norman and Nielsen (2010) made an alert that remains current. The authors stated that the gestures would form a valuable addition to the repertoire of interaction techniques. Still more time and studies are needed to make them more appropriate, to understand better how to implant them and to develop conventions, so that the same gestures, which mean the same thing, can be applied in different systems.

The benefits and damages of the applications of these new technologies are not yet fully known. Gestural interfaces, despite their rapid acceptance in the market, are still little studied, and the consequences for the health of their supporters are not fully understood. Therefore, in this study, we will present the use of digital infrared thermography, as an auxiliary tool, in the ergonomic evaluation through the verification of pain and usability through the evaluation of the level of psychological and physiological stress in the users. The study was performed in a 3D modeling software that uses a fully gestural interface in order to identify non-conformities and serve as a model for future evaluations of the same category (Vitorino 2017).

## 17.2 GESTURAL INTERFACES FOR 3D MODELING

The gesture is, in the specific approach of gestural interfaces, any physical movement that a digital system can identify and respond without the need for physical devices such as a mouse, joystick, pen, etc. These interfaces can be categorized as touchscreen or freeform. In the touchscreen, most of the time, the user touches the device directly. The second category is that which does not require direct physical manipulation with the device, is originated from any movement or state of the body and can be a head movement, a wink or a hand wave (Saffer 2008).

The "old" mouse, still efficient, has been replaced by the touchscreen. The gestural interface may be the next logical step for this transition as it allows for very intuitive selection and manipulation of content in a 3D environment (Adhikarla, Jakus, and Sodnik 2015). However, Norman and Nielsen highlight that sign interface projects have neglected consolidated concepts and principles of interaction design being highlighted: visibility of affordances, feedback, consistency, reversibility of actions, detectability of functions, scalability of screen resolutions and reliability of operations. Although gestural interfaces have the function of making people's lives easier, they are sinning in important interaction requirements, which can cause frustrations, errors and misuse of the interface (Norman and Nielsen 2010).

It can be observed that most studies on 3D modeling with gestural interfaces are basically quantitative and comparative, where researchers measure the time of execution of tasks and compare them with the time of performing the task with the mouse, and at the end of the experiments, the interviewees express their opinions on the use of the system (Yang et al. 2012; Oliveira 2013; Coelho and Verbeek 2014). In such experiments, there is a more significant concern with the system's performance, neglecting the user's satisfaction and comfort when interacting with the system. This is probably because most studies deal with computer systems development and programming for preliminary tests, such as moving, rotating and scaling simple 3D objects, such as cubes and spheres.

## 17.3 LEAP MOTION AND SCULPTING

Leap Motion is a device that tracks the hands and fingers of the user within their field of view, without the need for other equipment (Figure 17.1), to manipulate some interactive application (software, application or game).

Leap Motion is an optical tracking system that works through two cameras and three infrared LEDs. It captures the movements in up to 200 frames per second, giving a 150° field of view, with approximately 240 $cm^3$ of interactive space. It has the shape of an inverted pyramid, positioned at about 80 cm, as illustrated in Figure 17.2. This device can track the ten fingers with an accuracy of 0.01 mm. It is a rectangular block-shaped artifact about 8 cm wide × 1.1 cm high × 3 cm deep, and its weight approximately 45 g (Reiten 2014; Fanini 2014; Leap Motion 2017).

The Leap Motion developer provides a number of interactive applications for users to download from its Web site. Among them are some applications for 3D modeling and painting. Sculpting (Figure 17.3) is one of the applications that are available. Known previously as Freeform, this application uses a metaphor similar to sculpting real objects and allows three-dimensional modeling with a variety of tool options to manipulate shapes (press, flatten, smooth, grow, etc.), tool sizing,

**FIGURE 17.1** Leap Motion device in use (Ultraleap 2020). Reproduced with permission from Ultraleap.

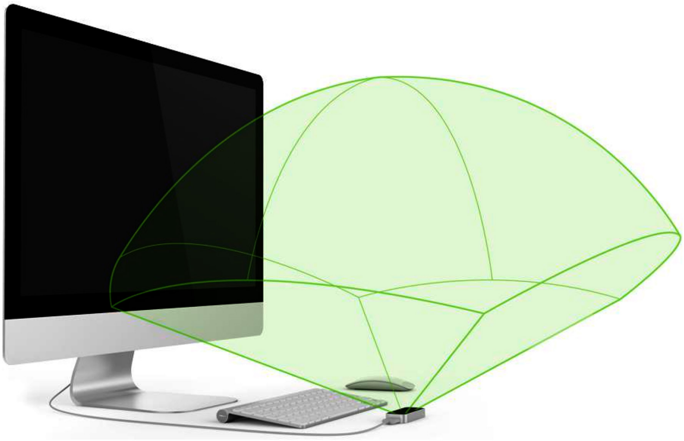

**FIGURE 17.2** Inverted pyramid-shaped interactive space (Leap Motion 2017). Reproduced with permission from Ultraleap.

choice of materials, colors and sizes for the paintbrushes and choice of manipulable shapes, among other options, in addition to the manipulation of rotation and camera approach. All these are done using hand and finger movement. The software allows saving objects in .ply, .stl and .obj formats, which can be viewed in other 3D modeling software or used to be printed on 3D printers, something that is being very popular today (Reiten 2014; Leap Motion 2017).


**FIGURE 17.3** Interface of Software Sculpting (Leap Motion 2017). Reproduced with permission from Ultraleap.

## 17.4 DIGITAL INFRARED THERMOGRAPHY

Infrared thermography is a non-invasive method that allows the capture of heat images (thermograms), which are not visible to the human eye through an infrared thermographic camera. All objects emit infrared radiation, and the intensity of this radiation depends on two factors: the temperature of the object and the object's ability to emit radiation, known as emissivity. Thermography was created in 1960; however, it was in the 1990s that the current high-sensitivity infrared sensors appeared (Brioschi, Macedo, and Macedo 2003; Mendonça 2005). The human being is homeothermic. That is, it has the capacity to keep the body temperature relatively constant. It is a complex phenomenon, and this heat to be regulated must be lost to the environment. The skin is the interface organ between heat production and the environment and constantly adjusts the equilibrium between the internal and external conditions. This heat transfer control phenomenon is called thermoregulation and depends on the autonomous nervous system to function (Brioschi, Macedo, and Macedo 2003).

### 17.4.1 Applications of Digital Infrared Thermography

The thermography method is used in several areas such as medicine, engineering, sports and industry, among others (Prakash 2012). Studies confirm that it can be used for inspection such as verification of the structure of buildings, plumbing, electrical wiring and machines and for diagnostics of diseases in organs, bones, muscles, etc. (BARROS 2016; Barros et al. 2016). Thermography can be a good instrument to provide quantitative and physiological indicators, thus avoiding subjective variables (Marçal, Silva, and Neto 2016). However, there are also studies that prove the efficiency of thermography in the study of psychophysiological conditions, which aim to evaluate conditions of emotional arousal such as stress, fear and sexual arousal, among others, through the capture of thermal images of the face (Merla and Romani 2007; Clay-Warner and Robinson 2015; Cruz-Albarran et al. 2017).

In the design area, we can also identify studies that prove the efficiency of thermography and its potential to verify users' physical and emotional relationship with products. It is possible to use thermography in ergonomic analysis to prevent injuries and illnesses at work, and its use is recommended to complement other traditional ergonomic evaluation methods (Padilha 2013). It can also be used to measure the cognitive load and change of affective state during user-product interaction (Jenkins, Brown, and Rutterford 2009).

In a study on the evaluation of consumer products, Barros (2016) used thermography to analyze user satisfaction and proved the efficiency of this method and recommended, in an innovative way, its use combined with electroencephalography and eye tracking for evaluation of consumer products. Wang, He and Chen (2020) studied the use of thermography to evaluate thermal comfort in virtual reality headsets by measuring the temperature distribution at the points of contact between the user's face and the product.

Thus, we observe that digital infrared thermography is an efficient, proven method that has a wide potential for the design area. Thermography can be used to evaluate the physical and cognitive ergonomics of users during the use of artifacts, without the direct interference that other evaluation methods may require, such as the use of gloves and special clothing, and can be used even in tasks with greater physical movement of the user.

### 17.4.2 The Operation of Digital Infrared Thermography

The healthy human body naturally exhibits a thermal symmetry (Houdas and Ring 2013). Thus, the regions of interest of the study must be exposed to a constant temperature environment. However, when any thermal asymmetry is identified between the sides of the body being analyzed, it allows detecting neurovascular alterations, inflammatory processes, fractures, etc. It also includes the study of pain to verify its presence in an objective way, being possible to evidence several types of pain. Therefore, the internationally standardized cutaneous thermal evaluation is always performed comparing the corresponding hemibody of the human body (Brioschi, Macedo, and Macedo 2003; dos Santos and Seis 2014; Marçal, Silva, and Neto 2016).

Figure 17.4 presents a thermogram comparing the hands of a subject during an experiment after the effort in the task of opening PET bottles (Barros et al. 2016).

### 17.4.3 Emotional Measurement with Digital Thermography

There are several studies involving human emotions associated with thermography (Cho, Bianchi-Berthouze, and Julier 2017; Merla and Romani 2007; Ioannou, Gallese, and Merla 2014; Pavlidis, Levine, and Baukol 2000; Puri et al. 2005). These studies are usually used to verify the response in situations of ambush, empathy, guilt, shame, sexual arousal, stress, fear, anxiety, pain and joy (Ioannou, Gallese,

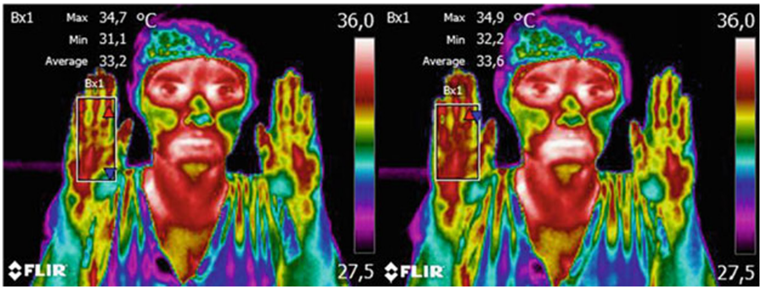


**FIGURE 17.4** Thermal asymmetry detected in user hands after PET bottle opening task (Barros et al. 2016). Reproduced with permission from the authors.

and Merla 2014). In general, the areas studied are located on the face, as shown in Figure 17.5. Researchers indicate that the tip of the nose and the perioral region are stronger when it comes to changes; however, they point out that the corrugated muscle of the supercilium and the chin were also correlated with the experiential nature of stress (Engert et al. 2014).

The person's response to emotional stimulation can increase or decrease in these areas of the face (Ioannou, Gallese, and Merla 2014). In Figure 17.6, the same authors present a summary of what happens in each region, according to the type of emotion felt. The arrows represent the increase (up arrow) or decrease (down arrow) of temperature in the regions considered of interest in emotional states.

The exploration of thermal images in the analysis of human interaction with products and environments is more applied at the physical level, where there is a wide application of thermography in medical and ergonomic research to analyze physical

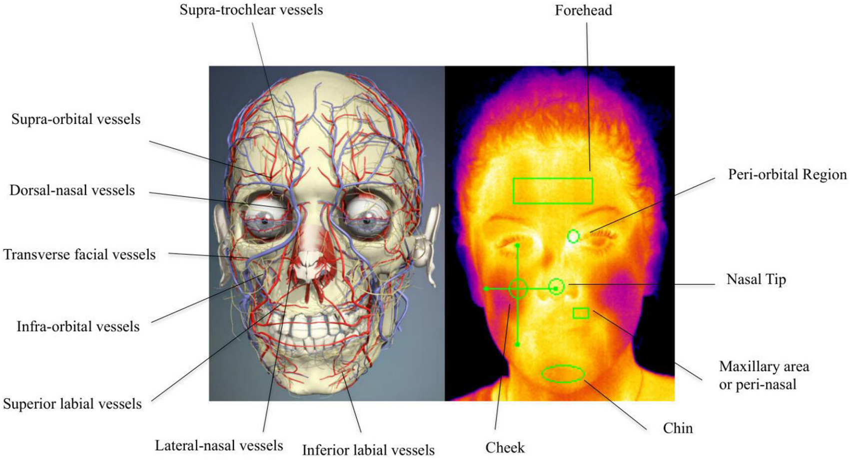


**FIGURE 17.5** Vascular representation of the great vessels affecting the subcutaneous temperature of the face and infrared thermal imaging (Ioannou, Gallese and Merla, 2014). Reproduced with permission from the authors.

| Emotions | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Stress | Fear | Startle | Sexual arousal | Anxiety | Joy | Pain | Guilt |
| Regions | | | | | | | | |
| Nose | ↓ | ↓ | | ↑ | | ↓ | | ↓ |
| Cheeks | | | ↓ | | | | | |
| Periorbital | | | ↑ | ↑ | ↑ | | | |
| Supraorbital | | | ↑ | | ↑ | | | |
| Forehead | ↓↑ | ↓ | | ↑ | ↑ | | ↓ | |
| Maxillary | ↓ | ↓ | ↓ | | | | ↓ | ↓ |
| Neck–carotid | | | ↑ | | | | | |
| Nose | ↓ | | | | | | | |
| Tail | | ↓ | | | | | ↓ | |
| Fingers/palm | | ↓ | | | | | ↓ | |
| Lips/mouth | | | | ↑ | | | | |

**FIGURE 17.6** Temperature variation in the regions of interest considered through emotions (Ioannou, Gallese and Merla, 2014). Reproduced with permission from the authors.

conditions (Brioschi, Macedo, and Macedo 2003; Marçal, Silva, and Neto 2016). However, some studies begin to explore the potential of infrared thermography as a method for monitoring stress levels during human-computer interaction (Puri et al. 2005; Yun et al. 2009; Abdelrahman et al. 2017; Akbar, Mark, et al. 2019; Akbar, Bayraktaroglu, et al. 2019).

There are studies that have used thermography to diagnose emotions, capturing thermal images of five facial expressions such as joy, disgust, anger, fear and sadness (Ioannou, Gallese, and Merla 2014; Engert et al. 2014; Clay-Warner and Robinson 2015; Salazar-López et al. 2015). It is observed that in these studies, the regions of interest were nose, cheek, forehead and jaw, proving the efficiency of thermography and providing accurate information about the emotions felt by the research subjects.

## 17.5 RESEARCH MATERIALS AND METHODS

The methodology used in this study has a descriptive-exploratory characteristic of being configured through the observation, recording and analysis of the phenomenon studied through the usability and ergonomic evaluations, using tests and interviews. For this, it was necessary that these experiments be approved by the Ethics Committee of the Federal University of Pernambuco, Brazil.

The techniques aimed at identifying ergonomic, usability and user-experience problems fall into the following three categories (Cybis, Betiol, and Faust 2017):

- *Inspections*, which occur when the evaluator uses a checklist to indicate the points that must be checked and the criteria that the interface must satisfy to meet these points. Although this is a systematic approach, it is limited in its possibilities.
- *Expert evaluation*, where a team of experts examines the interface and evaluates the characteristics from the point of view of adaptation to the user and the task that the user performs with the software. It is a more subjective evaluation, and the result depends on the competence of the evaluation team.
- *Tests with users*, which occur when a sample of users is called to use the interface in front of an evaluator. He or she evaluates the time to perform the task, the rework and blocks in interaction, among other problems. It is the most reliable technique and also the most expensive.

Considering the possibilities of these three categories of evaluation techniques, we used in this study two of these techniques: (1) the Expert Evaluation (Field Study 1) to identify the problems preliminarily, and (2) the Tests with Users to prove these problems and verify new problems through tests with real users or representative of the target population in a context of real operation (Cybis, Betiol, and Faust 2017). It is important to note that in the user test, the Emotional Assessment (Field Study 2) and the Pain Assessment (Field Study 3) occurred simultaneously, using the same activity to examine both aspects. Figure 17.7 illustrates the methodological scheme of the research and the objective of each field study.

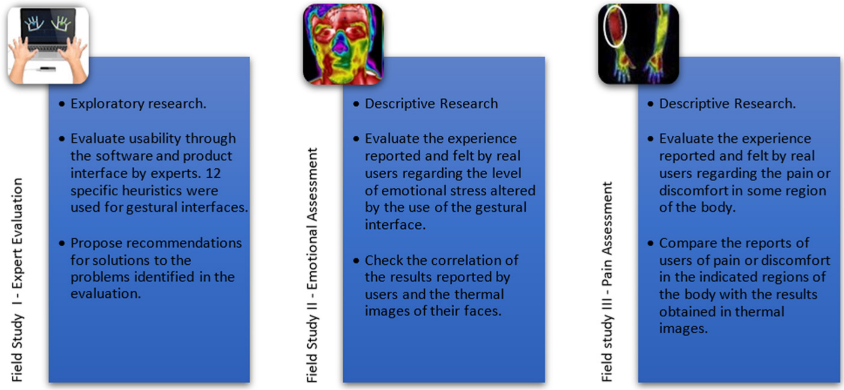


**FIGURE 17.7** Methodological scheme of the research. Source: The authors.

### 17.5.1 Hypotheses

Through the research problems, three hypotheses were proposed:

*1st Hypothesis:* The Sculpting software, together with the Leap Motion gesture interaction device, does not allow users to perform 3D modeling effectively and efficiently. Effectiveness is understood as the quantity and quality of goals achieved by the user; efficiency is the number of resources employed by the user to achieve his goals, such as time, physical and/or cognitive effort (ISO 2018).

*2nd Hypothesis:* Digital infrared thermography can identify emotional changes in users by using a gesture interface and can help investigate user satisfaction in usability tests.

*3rd Hypothesis:* The use of gesture interface for 3D modeling can cause musculoskeletal problems in its users. The use of digital infrared thermography can help ergonomic evaluation methods identify physical issues while using this interface.

### 17.5.2 Usability Assessment

For the usability evaluation, a test was developed with a sequence of tasks to be performed by users. These tasks were developed according to the orientation of the specialists obtained in the heuristic evaluation. They were tested with real users to prove the problems through the experience reported in the questionnaire and the observation of the specialist during the tests, following the evaluation model used by Vosinakis and other researchers (Vosinakis et al. 2016). The tests followed the below steps:

- **Presentation:** Explanation of the study, test instructions, and ergonomic recommendations.

- **Familiarization:** The user was asked to freely explore the software and express his thoughts about the experience through verbal language, i.e., concurrent verbalization (Cybis, Betiol, and Faust 2017).
- **Start of the test:** A sequence of tasks was presented to be executed without interruption. The time and number of errors made were recorded.
- **Test:** The user performed the test following the guidelines.
- **Post-test:** Post-test observations and application of questionnaires were performed.
- **Diagnosis:** The information collected in the tests was analyzed.

Users were allowed time to learn about the Leap Motion device and the Sculpting software. Ergonomic and user instructions were given to prevent damage to the user's health. After the first learning contact, taking as a reference the procedures used in the usability evaluation in the Barros (2016) research, users were photographed with a thermographic camera and filmed with a conventional digital camera.

### 17.5.3 Ergonomic Assessment

From the user's observations, conventional digital camera footage and infrared thermographic camera photographs were taken during the tests. An ergonomic analysis was performed to identify problems related to physical ergonomics such as posture, handling and inadequate movements—this analysis aimed to propose recommendations for improving the conditions of use of the product.

After obtaining the data from the physical ergonomics analysis, the information was analyzed, as indicated in the literature. This information was then related to the results of the usability analysis, with the purpose of ascertaining whether the physical variables of the gestural interaction interfered with the performance of users during the manipulation of the Sculpting interface.

### 17.5.4 Study Design

#### 17.5.4.1 Definition of the Sample of Users

Nielsen (2006) recommends 20 participants as the suitable number for quantitative studies, to obtain a reasonably tight confidence interval. However, for qualitative studies, which is the case of this research, the authors recommend five users. However, because it involves the tool of digital infrared thermography, it was necessary to obtain a larger sample, to have more expressive results, and to facilitate the conclusion of the hypotheses raised. Dumas and Redish (1999) indicate, for usability test, the use of 6–12 users in two or three subgroups. Barros (2016) conducted a usability study involving thermography and involved 12 volunteers and found satisfactory results with this sample. We will keep the same number of 12 participants used by Barros (2016).

#### 17.5.4.2 Test Location

Usability tests with users were performed in an air-conditioned room set at 22°C. The work environment had a notebook, support for the notebook, keyboard, mouse, Leap Motion device, desk and chair. A facilitator performed the following procedures: (a) informed the tasks to be completed by the users, (b) observed the activities and (c) ensured if the camera operator at the beginning and end of the test was following the recommendations of Cybis, Betiol and Faust (2017). Users were previously alerted that audiovisual recordings would be made with a digital camera and visual recordings with a thermographic camera.

#### 17.5.4.3 Equipment Used

To register the thermal images, the users conducted the tests in the city of Campina Grande, Brazil. For this, a Flir T600 digital thermal camera was used, which had a real integrated resolution of 480 × 360 (172,800 pixels) and sensors that allowed temperature measurement ranging from −40°C to +650°C. According to the manufacturer (Flir 2020), the camera's sensitivity detected temperature differences of less than 0.04°C and an accuracy of ±2°C.

A second thermal register was conducted with users in the city of Recife, Brazil. At that time, the Flir E60 camera was used. This camera had an integrated resolution of 480 × 360 pixels (172,800 pixels), sensors and allowed measuring temperature range of −20°C to +650°C. It had the sensitivity to detect temperature differences of less than 0.05°C and had an accuracy of ±2°C to absolute temperature according to the manufacturer's specifications (Flir 2020).

An Incoterm Digital Thermo-Hygrometer was used to monitor room temperature and humidity, with an accuracy of ±1°C from 0°C to 50°C, ±2°C for the rest of the range and the ability to measure the internal temperature range of 0–50°C and humidity range of 15–95% RH (Incoterm 2020).

## 17.6 FIELD STUDY

The data collected for this research was conditioned to submission and analysis by the Research Ethics Committee of the Federal University of Pernambuco, Brazil, and only began after its approval. The researcher verbally explained the study to the volunteers, and after its acceptance, the Term of Free and Informed Consent was signed by the participants. The confidentiality and privacy of the volunteers were guaranteed, and the results of the research would only be presented anonymously. Such research results were only used in scientific events or publications.

### 17.6.1 Field Study 1: Expert Evaluation

Expert Evaluation is a technique where specialists examine the usability of an interface guided by heuristic principles or ergonomic criteria (Cybis, Betiol, and Faust 2017; Falcao, Lemos, and Soares 2015; Nielsen 1994). In this case, the heuristics were developed, considering that they were not found in the heuristics literature to evaluate 3D modeling software interfaces with the interaction through free gestures on air. These heuristics were based on the studies of Maike et al. (2015), Falcao, Lemos and Soares (2015) and Chuan, Sivaji and Ahmad (2015) and can be verified in Table 17.1.

**TABLE 17.1**
**Heuristics for 3D Gestural Interfaces**

| No. | Heuristics |
|---|---|
| 1. | Feedback |
| 2. | Correspondence and recognition |
| 3. | Clear outputs indicated |
| 4. | Error prevention and correction |
| 5. | Clarity |
| 6. | Consistency |
| 7. | Compatibility and adaptability |
| 8. | Support and documentation |
| 9. | User resources |
| 10. | Comfort |
| 11. | Immersion |
| 12. | Learnability |

The evaluation was performed by five experts in the areas of ergonomics and usability. All participants had at least two years of experience in the area and were students with master's degree and/or doctorate completed, or in progress, in the area of design, in the research line of ergonomics and usability. The evaluation lasted about 40 minutes to be performed by each expert. The procedure for heuristic evaluation followed the following steps:

- Filling in and signing the Informed Consent Term
- Explaining the study by the researcher
- Inspecting the interface
- Filling in the form through Google Forms

The inspection step followed the following tasks in the interface:

- See tutorial (General);
- Select sphere (Object);
- Select tool (Tool);
- Select tool dimension (Size);
- Hide menu (Gesture presented in the tutorial is called "Hide Menu");
- Sculpt object (Mario Bros. game Red Mushroom);
- Show menu (Gesture presented in the tutorial is called "Show Menu");
- Paint (Color);
- Save project.

If necessary, other menu tools were also used when the evaluator found them.

At the end of the assessment, the evaluators presented a report with the annotations relating the heuristics for gestural interfaces. Besides the comments, each item

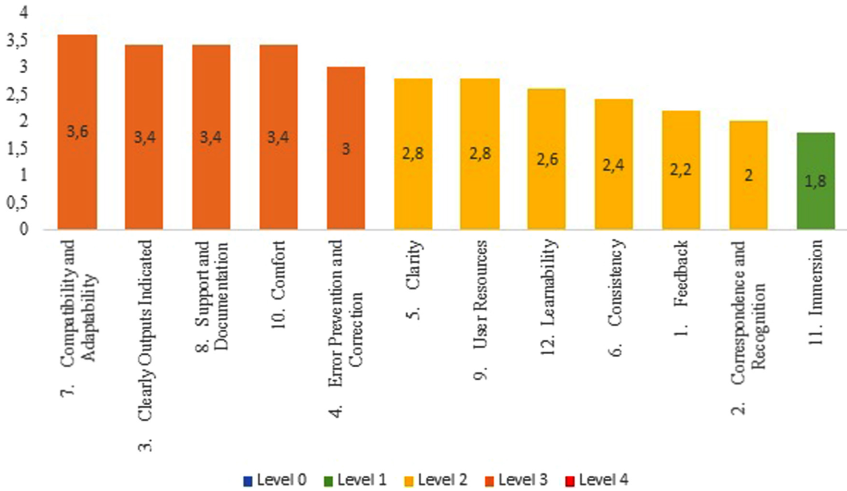


**FIGURE 17.8** Graph of heuristic gravity levels.

had a scale of gravity levels from 0 to 4. The higher the numbering, the higher the non-conformity, and the need to correct the problem. After the experts' evaluation, the answers of the forms were compared with the list of all the errors found, according to the 12 heuristics available.

Regarding the degree of importance of the problems and the need for correction, the heuristics presented problems of a superficial, severe and catastrophic level. The heuristics of feedback, correspondence, recognition, consistency and immersion reached the superficial level, where correction is necessary with low priority. The clear indicative outputs (possibility to cancel/close a function), error prevention and correction, clarity, help and documentation, user resources and learnability presented high correction priority. The heuristics of compatibility and adaptability need to be repaired with greater urgency. Figure 17.8 shows a summary of the average levels according to the answers of the five experts.

The tasks categorized as negative and caused the greatest problems and frustrations were hiding and showing the menu, selecting the menu options, 3D modeling, painting the object, and rotating the object. These tasks are essential to obtain effectiveness in 3D modeling software.

This evaluation served to detect problems and select the tasks for testing with the real users (Field Study 2 and 3). Thus, it was possible to evaluate the usability in real situations of use in order to prove these problems and observe how the participants reacted to this type of interaction, from both a physical and a cognitive point of view.

### 17.6.2 Field Study 2—Emotional Assessment

Conventional usability evaluation techniques, which evaluate the user-experience, do not provide an objective measure of whether the experience reported by the user corresponds with the felt experience (Barros et al. 2016). The authors state that infrared thermography, associated with usability analysis, is an effective tool to compare reported experience with felt experience. Thus, we use digital thermography images to compare with pain and emotional questionnaires, applied before and after the test with users.

#### 17.6.2.1 Assessment of the Reported Stress

In order to evaluate the stress with the use of thermography, a questionnaire was applied before and after the use of the software called visual analog scale (EVA) (Marçal, Silva, and Neto 2016). In this questionnaire, the volunteer marked the stress condition that was at the time he or she was questioned on a 10 cm line with numbers ranging from 0 to 10 (Figure 17.9). Thus, it was possible to compare this information with the thermal images of their faces, which were recorded before and after the usability test (Soares, Vitorino, and Marçal 2019).

According to the answers obtained with the application of the questionnaire, the moments before and after the use of the software were compared. Twelve participants participated in the evaluation: eight males and four females. We obtained the following results: 58.33% ($n$ = 7) of the participants answered that they felt an increase in their stress level after using the software; a total of 33.33% ($n$ = 4) reported a decrease in their stress level after using it; and 8.33% ($n$ = 1) recorded that their stress level remained unchanged after using it. Thus, according to the experience reported in the questionnaire, we found that more than half of the participants obtained an increase in their stress level.

Although we noticed an increase in the stress level based on the counting of the participants' responses, it was necessary to perform statistical analysis, with the help of SSPS 19 software, of the moments before and after the test to check if this increase was significant. The data found show that there was no significant difference in the 12 participants of the test.

The descriptive statistics show that the group increased the stress level from 3.8 (before) to 5.3 (after), but this increase was not significant to confirm that the activity stressed the participants. In the analysis of the Student $t$-test, it was verified that the significance level was 0.108, which is higher than $\alpha$ 0.05, i.e., the $p$-value observed is more elevated than $\alpha$ (significance level) defined for the study ($p > 0.05$). Although there is no significant difference, we can see that there was an increase in the mean, showing a tendency for participants to become more stressed after the test. However, a larger number of $N$ sample would be needed to check whether this increase in

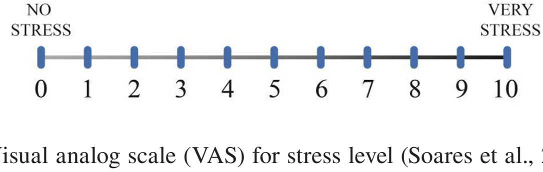


**FIGURE 17.9** Visual analog scale (VAS) for stress level (Soares et al., 2019). Reproduced with permission from the authors.

stress could be significant, as the current sample did not provide an acceptable result because it was a subjective measure.

#### 17.6.2.2 Assessment of the Felt Stress

To verify the felt experience, we use digital infrared thermography to record participants' faces before and after the use of the software. The images were analyzed using the Student *t*-test for the paired sample. Three regions of the participants' faces were analyzed, selected according to studies that indicate that if the person is more stressed, and a drop in temperature can be expected in the regions of the nose, cheek and forehead (Pavlidis, Levine, and Baukol 2000; Merla and Romani 2007; Or and Duffy 2007; Ioannou, Gallese, and Merla 2014).

For the analysis of the images, the three areas of the participants' faces (forehead, cheek and nose) were demarcated. The maximum, minimum and average temperatures in degrees Celsius were collected in the images before and after the test. Then, a statistical analysis of these data was performed, with the help of the software SSPS 19, of the 12 participants ($n$ = 12), in the regions ForehF (forehead), Cheek (cheek) and Nose (nose), in the periods A (before) and F (final), and temperatures Max, Min and Med (maximum, minimum and average) observed in Table 17.2.

**TABLE 17.2**
**Descriptive Statistics of the Face Regions Analyzed Before and After the Test with the 12 Participants of the Experiment**

| Region | Minimum | Maximum | Average | Standard Deviation |
|---|---|---|---|---|
| ForehFAMax | 32.50 | 36.20 | 34.8250 | 1.09804 |
| ForehFAMin | 31.30 | 34.30 | 33.4333 | .98658 |
| ForehFAMed | 31.90 | 35.60 | 34.2000 | 1.09627 |
| ForehFFMax | 32.60 | 35.80 | 34.6750 | 1.04718 |
| ForehFFMin | 31.30 | 34.50 | 33.4250 | 1.04631 |
| ForehFFMed | 32.10 | 35.20 | 34.0917 | 1.00856 |
| CheekAMax | 32.00 | 35.40 | 33.7083 | 1.21540 |
| CheekAMim | 30.10 | 33.70 | 31.8000 | 1.27778 |
| CheekAMed | 30.90 | 34.50 | 32.6417 | 1.29296 |
| CheekFMax | 31.20 | 35.00 | 32.9917 | 1.36812 |
| CheekFMin | 29.10 | 32.80 | 30.9583 | 1.18203 |
| CheekFMed | 29.90 | 33.50 | 31.8250 | 1.26572 |
| NoseAMax | 29.50 | 35.00 | 32.0000 | 1.73048 |
| NoseAMin | 25.90 | 33.20 | 29.1417 | 2.21583 |
| NoseAMed | 27.00 | 34.10 | 30.4583 | 2.24680 |
| NoseFMax | 28.10 | 33.20 | 30.9083 | 1.74848 |
| NoseFMin | 23.40 | 32.00 | 28.2083 | 2.67835 |
| NoseFMed | 25.30 | 32.60 | 29.1000 | 2.30691 |

**TABLE 17.3**
**Student *t*-Test for Paired Sample**

| Regions Before × After | Significance |
|---|---|
| ForehFAMax × TestFFMax | .670 |
| ForehFAMin × TestFFMin | .983 |
| ForehFAMed × TestFFMed | .761 |
| CheekAMax × BochFMax | .012 |
| CheekAMim × BochFMin | .002 |
| CheekAMed × BochFMed | .002 |
| NoseAMax × NarFMax | .003 |
| NoseAMin × NarFMin | .047 |
| NoseAMed × NarFMed | .002 |

In the paired sample results, it was possible to verify a significant difference of maximum, minimum and average temperature of the cheek and nose. In Table 17.3, we can confirm that the significance level of these areas (cheek and nose) is lower than $\alpha$ 0.05. However, the same did not occur in the forehead region, where $p >$ 0.05) is not significant to indicate a decrease in temperature. Thus, we found that a decrease in temperature occurred in two areas (cheek and nose) after the test, suggesting a functional change after the use of the analyzed software, which means an indication of stress in the participants (Pavlidis, Levine, and Baukol 2000; Merla and Romani 2007; Hahn et al. 2012; Ioannou, Gallese, and Merla 2014).

Table 17.4 presents Pearson's correction between the temperatures of the face regions before and after the test (felt experience) and the values indicated by the participants on the stress-level scale before and after the test (reported experience). Thus, the closer the value of $\rho$ (correlation coefficient) is to the value "1," the stronger the correlation, meaning a correlation between the two variables analyzed. The closer the value of $\rho$ is to the value "0," the weaker the correlation, being this our result, where the correlation was close to "0." Thus, it was verified that the correlation between face temperatures (forehead, cheek and nose) and the stress level reported by the participants did not present significance ($P > 0.05$).

### 17.6.2.3 Analysis and Discussion of Emotional Assessment

Thus, we noted that the experience reported in the emotional questionnaire did not present significant statistical data in correlation to the experience felt in the thermography. The temperature is a more sensitive variable to perceive changes than the variable of the stress-level ruler. Therefore, it would be necessary to increase the sample number $N$ to check the correlation again because the current sample could not confirm.

It is important to note that thermography checks the autonomous nervous system (ANS) response since temperature control is associated with emotional reactions (Brioschi, Macedo, and Macedo 2003; Kreibig 2010). In this way, the emotional

**TABLE 17.4**

**Correlation between Face Temperatures and the State of Stress Reported Before and After the Experiment**

| Before | | | After | | |
|---|---|---|---|---|---|
| Temperature × Reported | Correlation | Significance | Temperature × Reported | Correlation | Significance |
| ForehFAMax × StressA | –.096 | ,767 | ForehFFMax × StressA | .067 | .837 |
| ForehFAMin × StressA | –.133 | ,680 | ForehFFMin × StressA | .087 | .789 |
| ForehFAMed × StressA | –.112 | ,730 | ForehFFMed × StressA | .150 | .642 |
| CheekAMax × StressA | –.021 | ,947 | CheekFMax × StressA | .187 | .561 |
| CheekAMin × StressA | –.021 | ,948 | CheekFMin × StressA | .132 | .683 |
| CheekAMed × StressA | –.017 | ,959 | CheekFMed × StressA | .099 | .759 |
| NoseAMax × StressA | –.039 | ,904 | NoseFMax × StressA | –.194 | .545 |
| NoseAMin × StressA | .021 | ,948 | NoseFMin × StressA | –.077 | .811 |
| NoseAMed × StressA | .058 | ,858 | NoseFMed × StressA | –.070 | .830 |

perception of the person, through the reporting in the questionnaires, may not represent what the organism is manifesting. According to Kreibig (2010), although feelings are usually conscious, where the individual knows what is happening in that emotional experience, conditions may arise in which they are not aware of what is happening.

The opinion of users in a questionnaire can be different from their thoughts, feelings or impressions about using a product, so what our brain perceives can be different from our reports when we are questioned (Barros et al. 2016). In some cases, participants may have reported that they were not stressed, but the neurovegetative responses, i.e., the spontaneous response of the body, characterized the participant's significance of stress or irritability. Thus, we verified that the neurophysiological response is superior to the subjective response since the body responds that the individual has no control over. Thus, we reinforce the importance of expanding the usability studies with the use of more objective tools, such as thermography, since the user reports are not accurate and subject to inconsistencies (Marçal, Silva, and Neto 2016).

However, in general analysis, we can see that there has been an increase in stress on users with the use of the gestural interface of the 3D modeling software. This is clear from the observation of users' reactions, the final result of the 3D modeling and especially from the thermal images' records (Figure 17.10). In the latter, we can see the decrease in temperature in the nose and cheeks, indicative of increased stress in the individual (Pavlidis, Levine, and Baukol 2000; Merla and Romani 2007; Ioannou, Gallese, and Merla 2014), and which have been proven in statistical analysis.

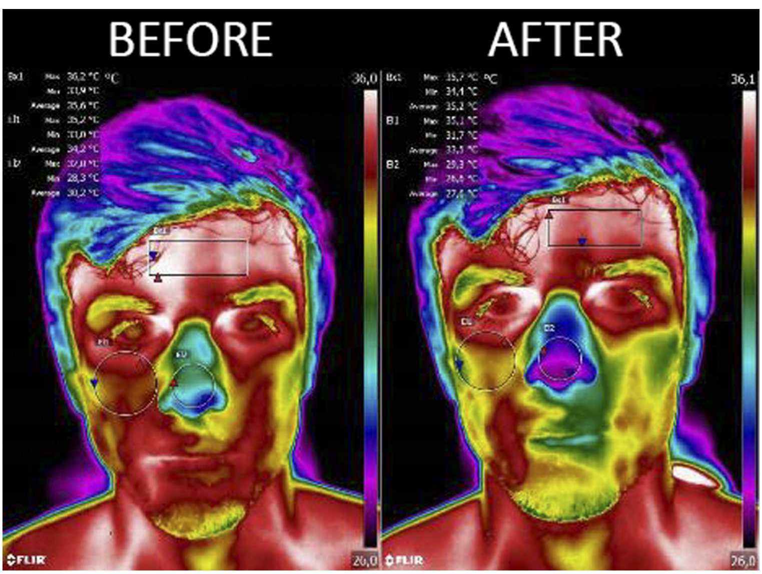


**FIGURE 17.10** Thermal image of the face before and after the test.

Thus, as some researchers state (Or and Duffy 2007; Jenkins, Brown, and Rutterford 2009), we confirm through this experiment the feasibility of using infrared thermography to evaluate an interface, proving reliable to indicate changes in stress states (Engert et al. 2014). The advantage of thermography, apart from being a non-invasive method, is that it allows evaluating interactions with movements. It is not limited to static postures and the need to fix devices on individuals by using pre/post-event sampling technique (photographic recording), instead of continuously monitoring changes in states on continuous video (Jenkins, Brown, and Rutterford 2009).

In this study, we emphasized the nose and cheek's sensitivity to verify changes in the state of stress. The temperature difference occurs due to vasoconstriction of blood vasodilation mediated by ANS (Or and Duffy 2007; Brioschi et al. 2010; Cruz-Albarran et al. 2017). The study by Or and Duffy (2007), which evaluated the stress in people, also pointed to the sensitivity of the nose and that the forehead temperature remained stable and constant. Confirming what happened in this study, we found no significance in the reduction of forehead temperature of the participants. The tip of the nose and the perioral region are stronger when it comes to changes. However, they point out that the supercilium's corrugated muscle and the chin also obtained correlation with the experiential nature of stress (Engert et al. 2014).

Based on the results presented, we suggest using digital infrared thermography for the development and evaluation of computer interfaces. Through this study with the gestural interface applied to the manipulation in a three-dimensional modeling environment, we can confirm the efficiency of thermography, allied to the usability methods, to evaluate the users' stress level when interacting with the gestural interface. This study's findings can contribute to future studies in the area and offer important information to understand these new forms of interaction that are emerging.

### 17.6.3 Field Study 3: Pain Assessment

This study was conducted from the footage of the participants performing the experiment, pain questionnaires (Figure 17.11), observations and analysis of thermal images recorded before and after the experiment. In the end, the data were crossed to verify the relationship of what was observed by the researcher, reported by the participants and recorded in the thermal images.

#### 17.6.3.1 Assessment of the Reported Pain

For this evaluation, a pain/comfort questionnaire (Marçal, Silva, and Neto 2016) was applied before and after the usability test, serving as a reference for the evaluation of thermal images, i.e., the regions indicated by the participants with pain complaints were checked on the thermal images to see if there are indications of thermal changes.

This questionnaire has the representation of the human figure from front and back and a Visual Analog Pain Scale (EVA) with numbers from 0 to 10.

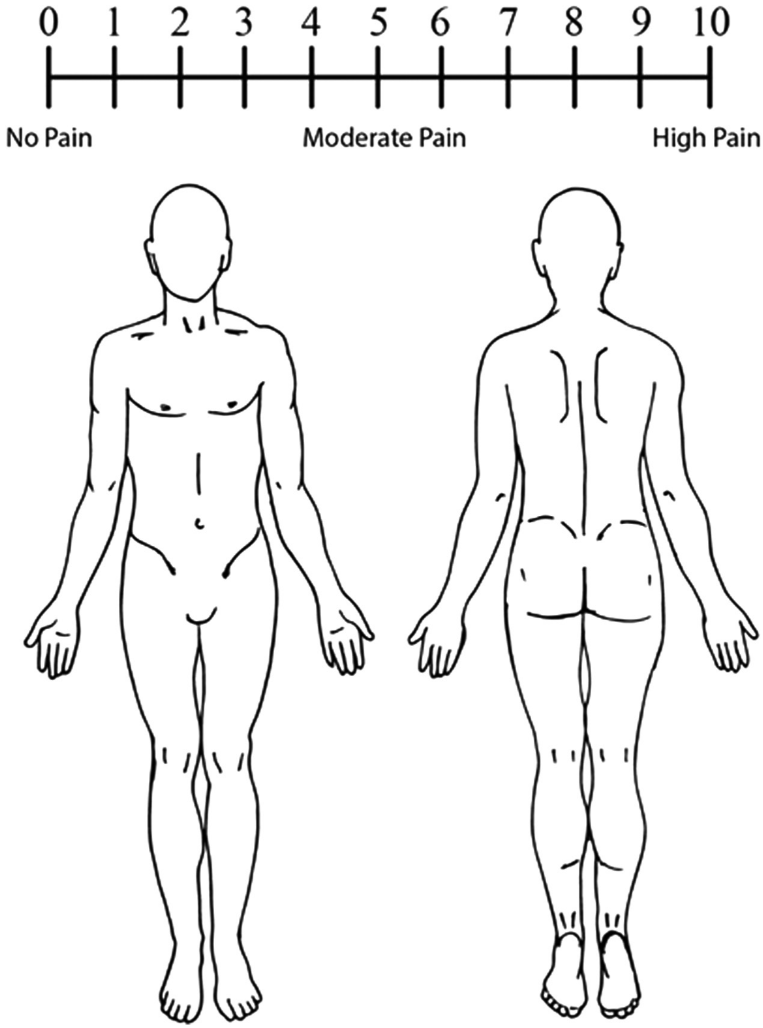


**FIGURE 17.11** Pain questionnaire with EVA from 0 to 10 and human figure front and back.

Before the experiment, each participant was asked if he or she was feeling any pain in the body at that moment and asked to mark with a pen the area of the complaint of pain in the representation of the human figure, which could indicate more than one region. It was also requested to mark the level of pain in each region, using a scale of 0–10. After the test, the same procedure was performed to verify the appearance of any pain complaint after the use of the software. Figure 17.12 shows the graph of the regions of pain complaints before and after the experiment indicated by the participant. It was possible to verify the appearance of pain in several regions after the use of the system. None of the participants indicated pain in the region of the hands. Only one participant indicated tingling in both hands.

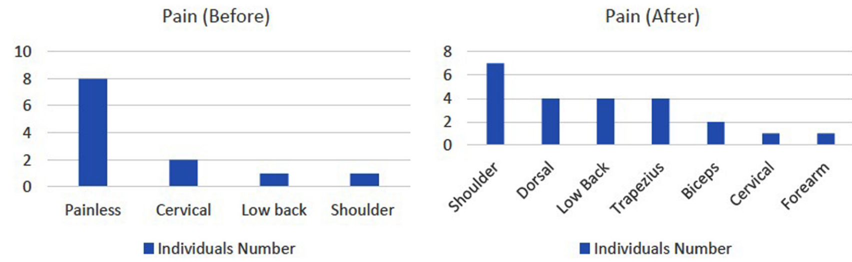


**FIGURE 17.12** Pain complaints before and after the test.

### 17.6.3.2 Assessment of the Felt Pain

The answers of the participants in the pain questionnaire served as a basis for the analysis of the thermal images of the moments before and after the test. The pain complaints indicated by the participants were confronted with the thermal registers to confirm if there was any indication of temperature change. This procedure made it possible to verify some patterns of thermal changes in the participants that helped to understand what occurred in their body when performing the activity.

An increase in the activity on the right shoulder of the participants in the thermal images was observed, i.e., after the test, most users (91.66%, $n$ = 11) presented these changes in the thermal images (Figure 17.13). This justified the complaint of pain in the region reported by more than half of the individuals (58.33%, $n$ = 7).

A drop in temperature of the upper limbs was also identified after the test detected in 66.66% ($n$ = 8) of the participants, mainly in the region of the hands (Figure 17.14). This result is typical of activity with arms suspended for a prolonged time and physiological response to activity with a predominance of static contractions in relation to dynamic contractions. However, when we checked the responses to the pain questionnaire, no significant complaints were reported in these regions.

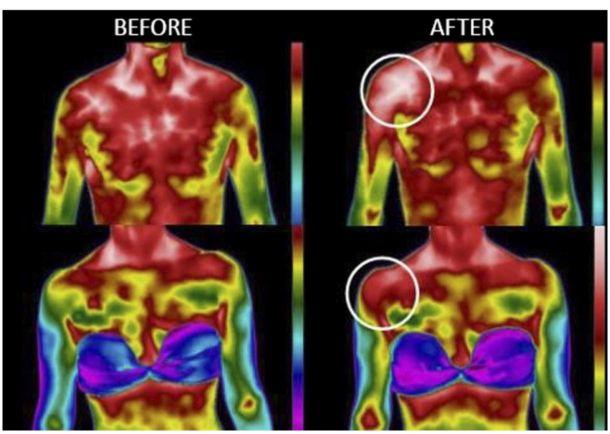


**FIGURE 17.13** Increase in right shoulder activity after the test.


**FIGURE 17.14** Temperature drop in upper limbs after the test.

The only complaint of tingling reported by one participant can be justified by the vasoconstriction and cooling of the region.

Some participants pointed out slight pains in the region of the forearm of the member who used most for the activity. This occurred due to the limb's continuous use without rest or alternation between the right and left arm along with the 3D modeling (Figure 17.15).

A total of 66.66% ($n$ = 8) of the volunteers complained of back pain in different regions of the body (cervical, dorsal and lumbar) as a result of the static posture of the trunk for a prolonged time. Thermal images proved these indications (Figure 17.16). This result confirmed the efficiency of thermography as a tool for checking pain,

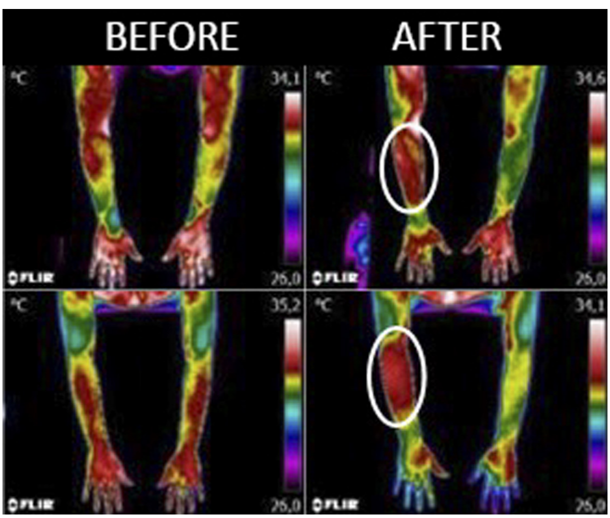


**FIGURE 17.15** Increase in forearm activity.

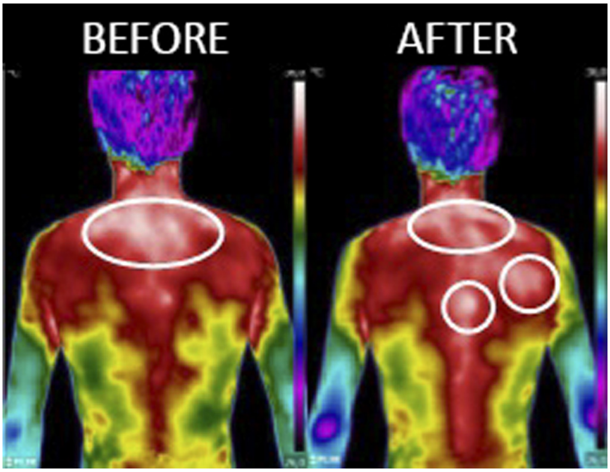


**FIGURE 17.16** Functional changes indicative of pain.

complementing the subjectivity of the individuals' reports and offering more objective data for evaluation.

#### 17.6.3.3 Analysis and Discussion of Pain Assessment

Through the analysis of thermal images, we notice several ergonomic problems that make it difficult for users to interact well with the gestural interface of the 3D modeling software. The realization of interaction for too long with the elevated limbs, without rest and compensation through variation between right and left limbs, was one of the biggest problems verified. According to Iida and Buarque (2016), one should not project activities with high limbs for more than 2 minutes without rest. Maybe this is the cause of shoulder and back pain problems because these regions bear the upper limbs' weight. The activity with the predominance of static contractions in relation to dynamic contractions resulted in a cooling of the upper limbs, causing tingling and fatigue.

With respect to hand gestures, not many complaints of discomfort in the hand region or indicative changes in thermal images have been identified. The main indications of greater biomechanical activities were in the forearm of the most used limb, which may have occurred due to the pointing gesture with the contracted musculature, resulting in the work of this muscle group, causing mild pain in this region.

## 17.7 CONCLUSIONS

Regarding the general objective of this research, which was to analyze the ergonomics and usability aspects of the gestural interface applied in 3D modeling software, using the Sculpting software and Leap Motion device as a case study, we obtained relevant results, thanks to the selection of appropriate methods and tools which benefited the evaluation of this type of interface. We are convinced of the importance of this analysis and its usefulness as a model for future evaluations of software of this category and analysis of the usability of consumer products.

The first study began with the evaluation by usability experts. For this purpose, specific heuristics for sign interfaces were developed based on current and relevant studies. It is important to draw attention to the fact that the heuristics developed for the study followed the essence of conventional heuristics applied and accepted in the study of usability. This step was essential to identify the most severe usability problems and, at the same time, helped in the configuration of the usability test for real users. In this way, it was possible to estimate the time of execution of the experiment and the tasks to be performed. It was also observed as the opportunity to investigate emotional issues through thermography since experts reported an increased level of stress when using the interface, as well as the existence of fatigue and pain during the use of the software, suggesting problems of physical ergonomics.

In the second study, tests with real users made it possible to verify if the integration of the Leap Motion device and the Sculpting software were in accordance with the principles of usability. It was possible to check compatibility issues of the gestures used for the interface manipulation, checking the performance and the users' opinion when using the software. It was possible to evaluate the stress level of the experiment participants. For this, the moments before and after the use of the 3D modeling software were compared. Thus, it was verified that there is a tendency for users to be stressed due to frustration of not being able to reach their goals due to the usability flaws of the graphical interface and also due to difficulties in executing the gestures.

The third study focused on questions of physical ergonomics, verifying points of discomfort or pain in users during the use of the software and the interaction gestures made in the interface. For this, the moments before and after the use of the 3D software were checked. Several problems related to inadequate postures and repetitive movements that caused musculoskeletal overload and static muscle contractions causing fatigue in the users were verified.

Three hypotheses were proposed for this study. The results were as follows:

1st Hypothesis—The Sculpting software, allied with the gesture interaction device Leap Motion, does not enable users to perform 3D modeling effectively and and efficiently.

This hypothesis was confirmed through heuristic and usability evaluation. According to the results found, the 3D modeling with the Sculpting software manipulated through Leap Motion does not have an acceptable level of effectiveness due to the low number of users who managed to reach the objective of modeling the proposed object. The study revealed severe problems in the control and precision of the modeling. This result can be considered a serious problem since 3D modeling is the main objective of this type of software. With regard to efficiency, even those users who managed to achieve the proposed objective in the experiment found it challenging to perform the tasks easily, taking time to complete them. Difficulties were presented through verbal reporting and observation of errors during use. Thus, the three types of tasks—selection and manipulation in a 3D environment, navigation and control of the system—that are usually offered in 3D interaction environments proposed by Iacolina (2014) do not meet the requirements for the system interface under study to have been considered effective and efficient.

*2nd Hypothesis:* Digital infrared thermography can identify emotional changes in users by using a gesture interface and can help investigate user satisfaction in usability tests.

This hypothesis, verified through the usability evaluation, has been confirmed. With the results of the tests, we found that through digital infrared thermography, it is possible to identify changes in users' level of stress by using a gestural interface that presents usability problems. In this study, we compared the reported experience, obtained through the emotional questionnaires, with the felt experience, obtained through the thermal images of the faces of the participants, before and after the test. Thus, we observed that the use of the gestural interface caused a drop in temperature in the selected areas of the users' faces (nose and cheek), indicating an increase in the stress level. This finding was confirmed in the literature by other studies that also used digital infrared thermography (Pavlidis, Levine, and Baukol 2000; Merla and Romani 2007; Ioannou, Gallese, and Merla 2014). We concluded that this increase in stress could influence user satisfaction and the desire to continue using the system.

*3rd Hypothesis:* The use of a gestural interface for 3D modeling can cause musculoskeletal problems in its users. The use of digital infrared thermography can help ergonomic evaluation methods identify physical problems while using this interface.

This hypothesis was confirmed through ergonomic evaluation and tests with infrared thermography. We found that most of the participants of the experiments reported fatigue in the upper limbs, besides some kind of a pain in the region of the back, trapezium, shoulder and arms, through a pain questionnaire filled out before and after the activity. This information was compared with the thermographic images that were recorded before and after the use of the interface. Thus, we obtained expressive results that proved that the areas indicated by the users in the pain assessment questionnaire had functional changes in the thermal images. It was proved that the use of infrared thermography to evaluate physical questions could be efficient in the evaluation of usability, particularly in the study of gestural interfaces in a 3D interactive environment. This ergonomic evaluation was complemented with the observation of users, audiovisual recordings and the aid of specific bibliography, which indicated evident problems in the physical ergonomics of 3D modeling with gesture interface.

Therefore, at the end of the study, we can conclude that it was possible to achieve the objectives outlined and prove the hypotheses raised. Thus, we emphasize that applying the gestural interface in the Sculpting software is not yet adequate to obtain results with effectiveness and efficiency. Therefore, it is necessary to improve the interface in order to obtain better usability and physical comfort.

One of the great learnings of this research was the importance of exploring new evaluation methods and tools in order to complement the traditional usability methods already used for product analysis. Digital infrared thermography has proven to be an efficient tool for evaluating physical and emotional stress issues in users, offering more objective and measurable results.

## ACKNOWLEDGMENTS

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# 18 Advanced User Experience Evaluations Using Biosensors in Virtual Environments

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*Ernesto Filgueiras, João Valente and Paulo Noriega*

## CONTENTS



## 18.1 INTRODUCTION

Traditionally, user experience (UX) measures taken before or after the human interaction with products and services are done using subjective measures. Examples are scales with emotions where users report emotions during interaction with a product (Watson, Clark & Tellegen, 1988; Sacharin, Schlegel & Scherer 2012; Bradley

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and Lang, 1994) or pictorial representations of the emotion felt. This could be static (Desmet, Overbeeke and Stefan Tax, 2001) or dynamic (Desmet, 2003). Most of those methods are free to use (Exception for *Premo*, Desmet, 2003) and are easy to implement, but they have many disadvantages: (i) They are dependent on an interpretation of the user about the emotion felt. That's not always a straightforward process, because user must look for the emotion felt in measurement tool and thereafter decide the intensity of the emotion; (ii) when the experience is too long, it is not possible to know the emotional reaction in the experience's different phases or in real time, the identification is done after the experience; in those cases, asking the user to answer a questionnaire in those phases breaks the experience and poses problems of evocation; (iii) usually emotional reactions are evaluated in an interaction context, which is not always totally controlled by researchers. Thus, the physical environment and the researcher can influence the user emotional reaction and behavior.

In addition to these aspects, we can have limitations to measure the human experience with products and services in situations that do not yet exist. It is true that we can develop physical simulation scenarios, or future physical scenarios, to test forthcoming user interactions, but the time and financial costs to build them are high. Another problem is related to critical situations, for example, an emergency situation with fire, where we cannot measure the user experience due to ethical restrictions.

Considering the previous limitations, there are a need to have complementary ways to measure the emotional reactions and behavior in UX evaluations.

The use of biosensors makes it possible to have in real time quantitative data about arousal and valence, without interruptions or the problem to remember an emotional reaction after an interaction. However, it is not easy to use biosensors to evaluate the user experience; they are subject to noise, if the control of signals acquisition is not high. Some artifacts (e.g., smartphones) can generate electronic noise, but also from body movements or improper placement and adjustment of the electrodes in the skin. These interferences can be misinterpreted and skew the analysis, leading to false diagnosis; however, they can be detected and removed by using filtering algorithms. Related to the control of the interaction context, virtual reality (VR) can also be a good tool (Rebelo, Noriega, Duarte and Soares, 2012). VR, integrated with biosensors, offers a strong way to evaluate UX through emotional reactions. Particularly, immersive VR can isolate the participant from the external environment stimulus, having a higher control of his/her integration inside the virtual environment. Also, immersive VR allows the possibility to get, in real time, data from the user's displacements to evaluate, for example, how the product attracted users' attention to interact with it or proved refusal. VR generates emotions similar to those obtained in real-life situations (c.f. Oliveira, Noriega, Rebelo, Heidrich, 2018) and is possible to simulate critical situations, related, for example, with emergency or time pressure (Vilar, Rebelo, Noriega, Duarte and Mayhorn 2013; Almeida, Rebelo, & Noriega, 2019), to evaluate the human decisions in those situations.

Following the previous limitations and opportunities, this chapter discusses, in a first step, the usability and user experience concepts and the measures involved to evaluate them, particularly those related to the biosensors. In a second step, it aims to discuss the concept of virtual reality and its potentialities of use in user experience studies. Finally, this chapter presents and discusses the proposed model that integrates the analysis of the situation, virtual reality with biosensors to evaluate the user experience.

The insight provided by this chapter can support the researchers and specialists in UX to get a better understanding of the field and be able to use the most suitable technique for their work.

## 18.2 ABOUT UX CONCEPT

It is common to have some confusion about the concepts of usability and user experience (Zaharias and Mehlenbacher, 2012); although both concepts are associated with the user interaction with a system, there are differences between those concepts. Usability is defined by ISO 9241 as the effectiveness, efficiency and satisfaction with which specific users archive specific goals in a particular environment. Effectiveness means the accuracy and completeness that the users archive specific goals in particular environments. Efficiency introduces another parameter, the resources expended, by the same specific users, goals and environments. Satisfaction comes from the user's perception that accomplished their specific goals in specific conditions. In this context, usability is connected with user performance, where the measures are related to objective information, like success to accomplish a task, time and number of errors. Satisfaction, in this perspective, is related to the user's perception of his own performance. There are some tools to evaluate the satisfaction, such as the questionnaires for user interaction satisfaction (QUIS) (Chin et al., 1988), and other more general tools to measure user's perception about usability, like the system usability scale (SUS) (Brooke, 1996), and post-study system usability questionnaire (PSSUQ) (Lewis, 1995).

For user experience, ISO 9241 defined as the user's perceptions and responses that result from the use and/or anticipated use of a system, product or service. The user's perception and responses include the user's emotional reactions and decisions that occur before, during and after the interaction. Those perceptions and responses derive from the user's prior experiences, skills, attitudes, beliefs and mood. Effect and emotional appraisals of the users are the methods traditionally most used to evaluate the user experience.

Those methods evaluate the human emotional states, like the PAD model (Mehrabian and Russell, 1974) or the circumplex model (Russell, 1980; Posner, Russell and Peterson 2005) to measure the emotional states. To avoid misinterpretation of words and to be universal, representative pictorial assessment tools were developed, like the Self-Assessment Manikin (SAM) (Bradley and Lang, 1994), Emocard (Desmet, Overbeeke and Stefan, 2001), and product emotion measurement tool like the Premo (Desmet, 2003). Another approach, proposed by Nagamachi in 1995, is the kansei engineering, which can be used to extract and define the aesthetic characteristics of products.

Together, usability and user experience contribute to a good human interaction with a product/system, but, in some cases, a good user experience cannot correspond to a good usability. The user experience manifested by the positive emotional reaction of wearing an elegant pair of high-heeled shoes is not related to the performance (usability) in walking in degraded floors or to needing to run a few meters to cross a road, or even to using them for a long time. In the same way, a pair of running shoes that provide a user with efficiency to run can have a bad user experience if the user thinks that the shoes do not match with the outfit style.

The example of the shoes shows the possibility of usability being independent of user experience. Agarwal and Meyer's study (2009) shows an example of this independence. In their study of interfaces, they used typical usability metrics and also emotional measures. Although there were no significant differences in the usability metrics of the interfaces, the emotional pattern obtained was different for each of the interfaces. However, with this we do not defend that usability should not go along with the user experience. In fact, as the study of Noam Tractinsky cited by Norman (2004) demonstrates, a good aesthetic component associated with the user experience can have a positive effect in terms of perception of usability of the interface. This effect can be easily explained by the psychological effect that a positive emotion has on how it makes the brain open, and makes it face problems in a more positive way, viewing them as opportunities and not difficulties as shown in the studies of Alice Isen, also cited in the book of Norman, *Emotional Design* (2004).

Thus, while usability is related to a rational subject (human performance), using objective measures, user experience is more related to human decision and emotional reactions. For this reason, usability and user experience don't use the same tools and metrics to be acquired and measured (Figure 18.1). Most of usability measures are objective: success to complete a task, time to accomplish a task, number of errors and time needed to learn a task and can be easily quantified. Only the satisfaction measures are subjective, but they are related to performance during the task and product recommendation, where the levels of subjectivity are lower (Harvey and Stanton, 2013).

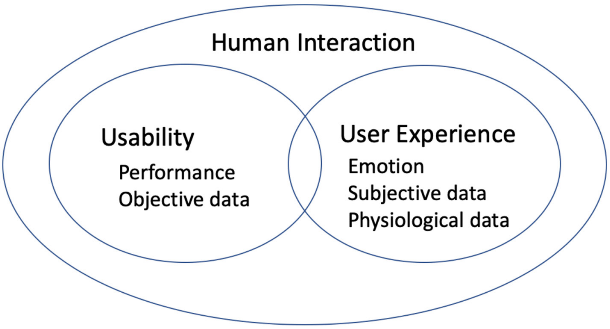


**FIGURE 18.1** This figure shows that usability and user experience in the evaluation of human interaction are different concepts. The word usability is inserted in an ellipse together with the words performance and objective data and the word user experience is next to it, in another ellipse, with the words emotion, subjective data and physiological data. Surrounding these two ellipses we have a larger one with the word's human interaction.

Traditionally, the UX measures are subjective and are related with the emotional reactions captured by questionnaires.

## 18.3 VIRTUAL REALITY IN UX MEASURES

The UX evaluation in laboratory setups has a high internal validity, allowing greater control of the variables and a good possibility to change the experimental conditions. This control allows replicating the study by other researchers but does not guarantee that the participants are involved with the interaction with the product, as it can happen in their real lives, thus not allowing its ecological validity. Despite this fact, most UX studies and assessments are conducted in laboratory settings or in makeshift settings, without proximity to the real context of use, limiting the UX evaluation results. One possible justification for this practice can be explained by the high economic costs and human effort involved to conduct experimental evaluations in a field situation.

Even if UX's assessment in the real situation was possible without major economic or financial efforts, there are also several problems that limit this approach. This field of studies provides a real interaction situation, but the control of variables is very difficult due to the complexity of the real world. In the field, it is very difficult to control all the environmental (e.g., light and noise, other people and unpredictable events) stimulus that can occur during the UX test. Another problem that limits UX evaluations in the field occurs when the interaction involves real dangers. Evaluation of the UX with a smartphone in an urban space can involve danger, particularly if the participant walks on the road and can be hit by a car.

In conclusion, both laboratory and field tests have advantages and disadvantages to conduct UX studies. There is a need to find a new paradigm that can have a high control of the experimental conditions in an ecological situation. Virtual reality (VR) can give a good answer to this challenge. One of the main advantages of using VR to measure UX is the possibility to create a virtual environment (VE), with higher ecological validity than a laboratory setup, and at the same time allowing a higher control of the user's interaction with a product (Moehring and Froehlich, 2010; Rebelo, Noriega, Duarte and Soares, 2012).

VR has been defined according to two different perspectives: one related to the used devices technology, and another associated with the human experiences when interacting with the virtual environment. The first perspective was proposed by Steed (1993), defining VR as a computer-based system containing several key components, such as head-mounted displays (HMD), tracking systems in the body and manual input devices in the hand, to allow interaction with the VEs, audio output and database. In the same perspective, Burdea and Coiffet (2003) define VR as a sophisticated interface between people and computer, which can be used to generate virtual environments for the participants to experience. VR equipment needs to respond, in real time, to the participants' inputs (i.e., body movements, voice, eye movements and brain activation), allowing the user to interact with the VEs.

The second perspective that is associated with the behavioral sciences defines VR as an advanced form of human-computer interface that allows users to interact with and to become immersed in a computer-generated environment in a naturalistic way (Schultheis, & Rizzo, 2001). Our perspective highlights the human experience; Rebelo, Noriega, Duarte and Soares (2012) defined RV as a way of transporting a person to a reality in which they are not physically present but seems like they are there.

There are diverse opinions about what is a VR system. Gutiérrez, Vexo and Thalmann (2008) proposed three groups: virtual reality, which involves images and sounds; augmented reality (AR), where digital graphics are superimposed over the real-world images; and augmented virtuality (AV), where imaged portions of the real world are integrated within the virtual world, for this situation the authors designated them as mixed realities.

In the last few decades, VR has been applied in a variety of situations. Parsons and Rizzo (2008) used RV to treat mental health disorders (fear of heights, public, substance disorders and schizophrenia). Ottosson (2002) used VR in the product development process, and Vilar, Rebelo, Noriega, Duarte and Mayhorn (2014) studied the effects of competing environment variables and signage on route-choices in simulated everyday and emergency way-finding situations.

## 18.4 COMPONENTS OF A VR SYSTEM

A VR system is composed of input and output devices and a software application. Normally, the input devices are composed of trackers and command devices to capture the trajectory of the body movements that will be replicated in the virtual character of the participant. The body movements will allow the avatar displacements, launch, grab, push or pull elements in the VE. It can also integrate voice, eye tracker and electroencephalography inputs that can allow the same interactions with the VE objects.

The output devices are composed of visual displays, aural sound, olfaction, tactile and proprioceptive devices. User actions, for example, head movements, explore the VE and body and manipulation motions, activate the input devices, allowing different levels of immersion and interactions.

A generic VR system involves a computer with a graphic card, with the capacity to handle real-time graphics and sound, in the function of the input-user interaction in VE. The VR system also includes a software application that allows the management of the devices, in the function of triggers and associated events.

## 18.5 PROPOSED MODEL

The new UX evaluation model (Figure 18.2) involves four steps that start with an analysis of the situation to define a concept and finishes with the user interaction with the immersive virtual reality environment.

### 18.5.1 Analysis of the Situation

In function of the project, this phase optimizes an existing interaction situation, or develops a new interaction for a new product or service. There are different

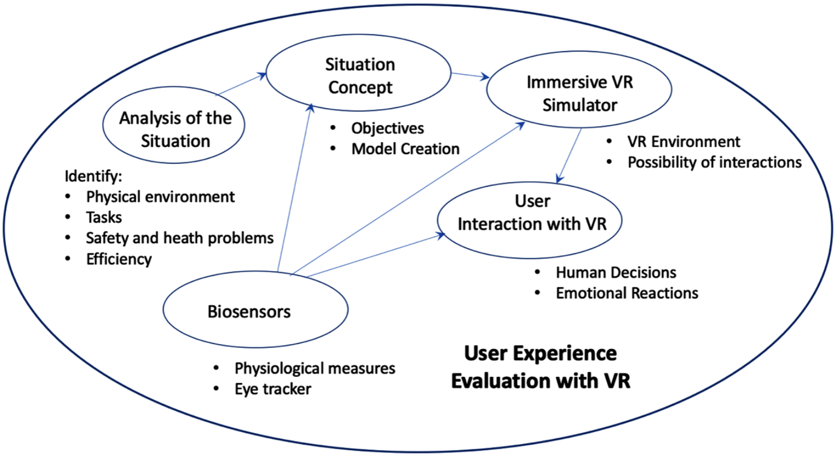


**FIGURE 18.2** This figure shows a schematic representation of the proposed model. It consists of a set of ellipses that correspond to the steps for using biosensors and virtual reality to evaluate the user experience. It starts with an ellipsis with the word situation analysis and beside it, a text with: identify, physical involvement, tasks, health and safety problems, efficiency. The previous ellipse is connected with an arrow to another, on the right side, with the words: situation concept with the text: objectives and model creation. The previous ellipse is linked with an arrow to another with the words: immersive simulator in virtual reality with the words next to it: VR involvement and possibility of interactions. The previous ellipse is linked with an arrow to another with the words: User interactions with VR, with the text on the side: human decisions and emotional reactions. Finally, a last ellipse with the word biosensors and the text: physiological measures and eye tracker, with three arrows connecting this ellipse to the following ellipses: situation concept, immersive VR simulation and user interaction with VR. Surrounding all the previous ellipses, we have a larger one, with the text: user experience evaluation with VR.

approaches, however, for both; the main objective is to identify the existence of possible problems related to user's safety and well-being and with the efficiency of the system.

To optimize an existing interaction, it is necessary to understand the way in which different aspects of the components of the environmental system influence and are influenced by the user interaction. For a new user interaction situation, it is necessary to identify similar existing situations to conduct an interaction analysis in order to enable a diagnosis and identify the specifications for the new interaction situation to be designed. In both situations, task analysis can be considered a good design tool to identify user interaction problems and enable a diagnosis to identify problems and to set the requirements for the new virtual environment to be designed. In this analysis, it is important to consider the differences between prescribed operations, related to the procedures and instructions given to the user and the interaction performance tasks actually performed by the user.

To have a better understanding, we also recommend an interaction analysis to evaluate how the tasks are performed, considering the interaction context, the user characteristics, their needs and expectations, in relation to their performance. An interaction analysis requires the use of a combination of tools that goes through observation of the user interaction and techniques for gathering their opinion through questionnaires and interviews. It is also necessary to cross this information with the context characteristics (physical, environmental and social) that can influence the user interaction.

A literature review about the interaction situation problems with the product and similar products, reported in case studies, is also fundamental to understand the factors that can be associated with problems and possible solutions to fix them.

The output of this analysis is a description of:

- The physical environment characteristics, involving the space and object dimensions;
- The characteristics of the social environment, involving the organization and eventual people, that can be present during the user interaction with the product;
- The tasks to achieve the proposed goals with the product;
- The user complaints about difficulties to accomplish the tasks to reach the objectives and muscle-skeletal pain, related to body movements; and
- The reported or observed user interaction errors.

### 18.5.2 Situation Concept

Situation concept uses the results achieved from the previous phase and has as its main goal the development of the virtual reality concept to be implemented. This phase begins with the definition of the study objectives that can be related to a problem to be investigated.

In a project to study human compliance with safety information that showed low levels of compliance, Duarte (2011) proposed the following concept for a VE simulator to study this problem:

- The VE should be a work-type environment, subdivided into several rooms, with corridors having some open and closed doors. The corridors should be organized in a symmetrical manner, so the participants' ability to learn the spatial configuration could be reduced as much as possible and the cognitive load, associated with the search task, could be potentiated.
- The rooms should have only one entrance and exit to reduce the number of alternatives given to the participant and, therefore, to facilitate the measurement of data such as time and distances and, consequently, to facilitate the measurement of data such as time and distances.
- Inside of the rooms should contain hazardous products and equipment that could give rise to an accident. The furniture, objects and decorations should be adequate to this type of facility, reproducing a common workplace.
- The VE should be adequate to a performance of a search task, for example, look for a target and comply with a warning/posted sign indexed to it.

- The complexity and the space of VE should allow a participant interaction for less than 15 minutes.
- Should have an area with space routes, with a sequence of a series of T-shaped intersections interconnected, without relevant marks that could bias the participant decisions. This area ends with an exit point, where participants find an exit door.
- The T-shaped intersections should be all blind-t type (i.e., the corridor in which the participants were traveling through ended and they could turn either left or right, and one of these directions was always a dead-end, but not visible from the decision point).
- The walls should have free space to display the safety information, which should be required in the VE.
- The VE should contain adequate details to look realistic, reproducing the illumination, shadows, reflections, textures and sounds without producing performance in the computer that can affect the participant interactivity.
- All the buttons and generally hand commands after being pressed should produce a feedback (sound, animation movement and color change) and trigger an event in VE.
- A narrative to create meaning for interaction with VE and to engage the participant in this interaction. In this narrative, the participant is confronted with a history where he must imagine that his family was unemployed, and he would have the opportunity to have a well-paid job. To have this opportunity, he would have to succeed in completing a set of tasks that will be given to him within the virtual environment.
- The warehouse has no people because the action takes place at the end of the day. In this context, the participant needs to turn on the company's security alarm systems, which are in several rooms.
- Inside the VR the participant in a given moment is confronted with an explosion followed by a fire and is expected that he or she leaves the building soon.
- In the egress, the participant could rely on exit signs to help them find the right way out.
- The compliance assessment with the safety information was accomplished in two moments. The first moment occurs when the participant was requested to perform an end-of-day routine where he has the task to turn on the security alarms. In the second moment, the compliance with exit signs during the emergency egress is evaluated, in response to an explosion followed by a fire.

Brainstorming and focus group meetings with the VR team (i.e., designers, software engineers and researchers) and the main stakeholders are a good solution to get ideas about possible concepts in the function of problems.

In conclusion, the output of this phase is a detailed description of the VE concept to engage the participants in the main objective of the project.

### 18.5.3 Immersive VR Simulator

A VE simulator is composed of the following components: objects and space geometry; textures that define the appearance of the objects, lighting and shadows; environmental sounds; animations and triggers that call events.

#### 18.5.3.1 Object and Space Geometry

The implementation of a VE project concept for the space and objects geometry could be done at the beginning using a computer-aided design program to have a high level of control of the dimensions. Great care is required considering the number of polygons that make up the geometry of objects. Objects with a large number of polygons have a good appearance; however, they imply a high computational load, jeopardizing the fluidity of the user interaction with the VE. A general rule is: if the object is not important for the user experience or it is not involved in the participant's main tasks, a high level of detail is not required. For objects far away from the participant's eyes, and if this information is not important, photographic images may be used instead of objects with volume.

#### 18.5.3.2 Textures

Textures are pictures used to define the appearance of an object in a VE. It is possible to apply one or more textures to a material, and then apply this material to an object. Textures are very important to give more details and consequently a good VE realism, but high-resolution textures spent video memory and will take more time to download from the disk or from the Internet, slowing the participant's interaction. The use of smaller textures will minimize the previous problems, but will affect the details of the images, reducing the VE realism. To optimize the texture size, it is important to know which objects will need high-definition textures. A small object that use a few pixels in the screen doesn't need a 4K texture, but a frame with text to be read for the participant need to have a high resolution to have a good detail to be read easily. Another way to reduce the computational charge is the use of compressed texture formats when possible, and use of 16-bit textures over 32-bit textures. For each texture, a new material is created that needs to be called at rendering time—draw-call. To have a good performance, avoiding loss of performance of the computer graphic engine, a technique to reduce the computational charge is the UV mapping. This technique is created after modeling a three-dimensional object and uses the same mesh structure as the original object, but the mesh is converted into a bidimensional space with the consequent deformation. In this bidimensional mesh is applied different textures, allowing the possibility to group them in a unique texture and reducing the number of draw-calls.

#### 18.5.3.3 Lightening and Shadows

Selecting the number, localization and the best type of light is a complex subject which requires a balance between a good user experience and the computational performance of the VE. The common types of lights used to create a VE are as follows:

- Spotlights, which emit a light in a cone format that can put in evidence a specific object or area. Normally spotlights are used to capture the attention of the participant for an event of something that is important for the participant to see.
- Point lights emit the light in all directions from a light point. This light can be used as baseline to lighten a room to create an environment.
- Area lights are surfaces that emit light along one side. This light can be useful, for example, to create a false window. A real window is costly from the point of view of computer calculations, particularly if we are interested to render the interior. Electroluminescent surfaces in curtains, placed in front of a window, can add a sunny glow and get more realism for the VE.
- Tube lights simulate the traditional tube fluorescent lights used in publicity. This light can be useful to emphasize a piece of information to be read by the participant in the VE.
- Emissive materials simulate the glow coming from a surface and can be used to create more realism in VE.

Dynamic lights and surfaces can move due to wind forces and create shadows that move. This action implies a high computational cost and can affect the user experience. To manage this problem, it is possible to set the light to render real lighting, baked or mixed.

Real lighting creates the best user experience, with dynamic shadows, but requires computational resources. They should be used only in special situations, for example, to explore a dark room with a focus light.

Baked light is a strategy to reduce the computational calculations using lightmapping. This technique calculates the light for a static geometry and saves it as textures. This technique does not allow to have dynamic shadows and can reduce the participant user experience. A better strategy could be a mixed solution considering lightmapping shadows, using static lights, and real-time shadows, using some dynamic lights, for moving objects.

#### 18.5.3.4 Sound

Sound is a very important aspect of the VE because it enhances the emotional impact in the participant experience. We have a high-level perception of sound localization that allows a very good accuracy of where a sound comes from. The common applications to create VEs give the possibility to define the sound localization, allowing the participant to have an immersive experience.

#### 18.5.3.5 Triggers and Events

When a participant touches a virtual object, for example, a button (an action), a door will open (an event). The actions can be combined by Boolean expressions. For example, an event will occur only if the participant touches first the button A and next the button B.

A common participant action in VEs is the first person colliding with objects, and manual commands collide with objects, which can activate events like objects animations (i.e., open or close a door); change a variable status (i.e., score); and show a piece of information inside the VE or in the display canvas.

The actions and triggers are developed with computer languages by programmers but can be implemented with visual programming languages.

### 18.5.4 User Interaction with VR

Before beginning user interaction studies to evaluate UX, it is very important to evaluate if the VE model can measure the participant experience interaction. In this context, it is important to have experimental trials to verify the participant performance and get his/her opinion about the quality of the interaction.

Some important aspects to evaluate in the experimental trials are as follows:

- *The participant accuracy:* Verify if the participant can move and place or reach objects in the VE prototype.
- *Ease of use:* Verify if the devices and proposed interaction are easy to use.
- *Discomfort:* Verify if the participant experiences discomfort, pain, motion sickness and other negative symptoms that can affect the participant experience.
- *Motivation:* Verify if the participant is motivated to have similar experiences in the future.

The measures related to participant behavior inside VE are associated with the proposed narrative and tasks that the participants need to do. Those measures may differ in function of the previous proposals; here we suggest the following:

- Approaching or moving away from a product or a stimulus (attraction or repulsion) inside the VE;
- If we use eye-tracking with the VR, the eye gaze and the areas of visual interest are interesting measures to evaluate the product attraction in the VE;
- Forced choice situations, when the participant needs to choose a product or a situation, are interesting to measure the participant preferences.

The common measures from subjective participant's perception can be related to adaptations of tools to measure the emotional reactions inside the VE. The measures need to be acquired inside the VE to avoid external influences. The use of scales can be a good solution to avoid participant interaction problems. Another important aspect to be considered in this measure is the moment where the measures are taken. Stop the participant task inside VE to get this data break his/her engagement.

The common measures acquired from biosensors will be described next.

## 18.6 BIOSENSORS

The use of biosensors is increasing day by day in the real world to improve the quality of life, providing monitoring of vital signs of patients, athletes, premature babies, children, psychiatric patients, people in need of long-term care, the elderly and people in impassable regions away from health and medical services (Ajami and Teimouri, 2015).

With technological advancement, cost-reduction and ease of use, biosensors are beginning to be used in human-machine interaction and even in VR and VE scenarios, making the interface simpler and more intuitive. Use of eye-tracking in the control and positioning of the screen during games, measurements of the blink of the eye, fixations, movement speed and return visits are measures that have long been used to infer interest in the game, product or advertising. The physiological signals such as breathing, sweating, heartbeat and galvanic skin response have been used as indicators of comfort or stress when performing certain tasks. The use of electroencephalography (EEG) in the so-called brain-computer interface (BCI) has become more and more a reality and there are applications in spelling and object control, among others.

However, the efficient use of biosensors in all these new areas still faces great challenges and requires multidisciplinary knowledge so that the data obtained is reliable. We found challenges in the variability of signals from subject to subject, in the correct placement of the sensors, in the knowledge of the sensor's own characteristics, in the conditions of signal acquisition, in its treatment and finally in its interpretation when associated with the protocol. At this point, we will look carefully at these aspects that must be considered when designing an experiment involving biosensors.

There are several biosensors and here we will essentially address the so-called physical sensors. A physical sensor is made of a material that changes one of its characteristics according to the quantity to be measured, and a transducer is a device that converts energy from one form into another. The transducer may be either a sensor or an actuator. A sensor is a transducer that generates an electrical signal proportional to a physical, biological or chemical parameter. An intelligent transducer consists of a sensor or actuator; at the same time, it has a processing unit and a wireless communication unit, allowing it to be connected in a network in order to serve larger systems (Song and Lee, 2008). Its use finds place in several areas such as home automation and Internet of things (IoT).

According to the variables we intend to measure, the sensors can be pressure, speed, displacement, acceleration, temperature, flow, resistance, capacitive, inductive, electromagnetic, thermoelectric, photoelectric and others. The biomedical physical sensors can be divided into four classes based on their following features:

1. Radiation sensors address the X-ray- and gamma ray-based sensors.
2. Mechanical sensors include ultrasound and pressure sensors.

3. Thermal sensors include a range of sensors such as thermocouple, thermistor, thermopile, optical fiber devices, P-N junction diode and infrared sensors.
4. Magnetic sensors include blood flow and magnetic resonance imaging systems (Ahmad and Salama, 2018).

When considering a measurement system, the first concern is knowing which variables we want to measure, and the second which sensor is best suited for the intended purpose. This choice is not easy, it requires a thorough knowledge of the features of the sensors and their implication in the result. Not knowing the true performance of your instrument could lead you to incorrect readings, and the cost of this error could be very high. Figures 18.3–18.14 show some of the most important features.

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***Accuracy:*** Difference between the measured value and a reference value ("true" value). High accuracy mean coincides with the true value and low accuracy the average of repeated measurements which is far from the true value (Figure 18.3).

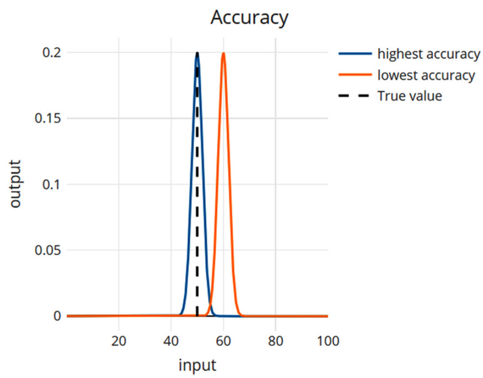


**FIGURE 18.3** A black gaussian curve, whose average of the random measurements coincides with the real value 50, is an indicator of a high accuracy sensor. The right gaussian curve has the same standard deviation, but its average is deviated from the actual value by an offset of 10, indicating a low accuracy. This error is usually easy to resolve through a calibration process by adding or subtracting the offset from the measured value.

***Precision:*** It is inversely related to standard deviation. High standard deviation low precision and low standard deviation high precision (Figure 18.4).

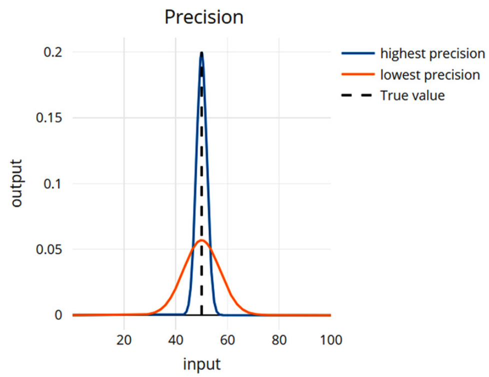


**FIGURE 18.4** Both gaussian curves have the same accuracy (same average coincident with the true value) however one curve has a higher standard deviation, that is, there is a greater dispersion of the central value, and the sensor is less accurate. This type of phenomenon is more difficult to correct as it is usually related to a greater sensitivity of the sensor to other environmental conditions such as, for example, temperature, humidity, pressure.

***Sensitivity:*** It is defined as the slope of the output characteristic curve (dy/dx) or, more generally, the minimum input of the physical parameter that creates a detectable variation in output (Figure 18.5).

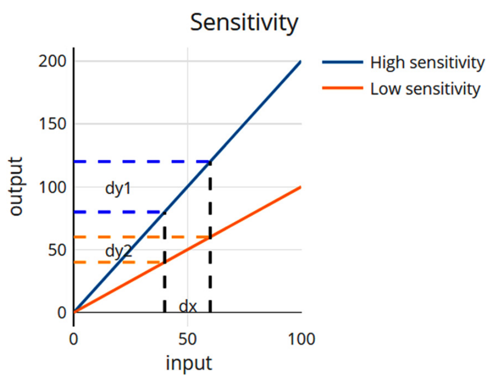


**FIGURE 18.5** The upper line shows greater variation to a change in the physical quantity to be measured than the gray line. In the figure it is possible to verify that the same change in the input x (dx) causes a greater variation in the output dy1 in sensor 1 than in sensor 2, that is, dy2<dy1 sensor 2 (gray straight) is less sensitive than sensor 1 (straight to black). This behavior can be improved with the use of signal amplifiers, however, by amplifying the signal we are also amplifying the noise.

***Drift:*** As variations occur in temperature, pressure and other environmental conditions, certain static sensors features change, and the sensitivity to disturbance is the measure of the output values (Figure 18.6).

– Zero-drift (or offset or baseline drift or bias)

– Sensitivity drift.

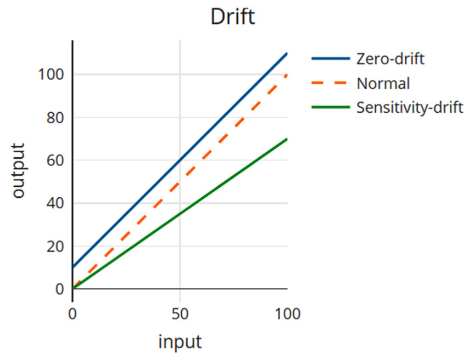


**FIGURE 18.6** This figure shows the zero-drift represented by the upper line where it is shown an offset in relation to the real middle line. This phenomenon may be related to, for example, the relaxation of a spring, which over time changes its equilibrium position. In the other case, sensitivity-drift, represented by the gray line, there is a change in the sensitivity of the sensor that is associated with the loss of spring elasticity, that is, the spring for the same weight stretches less. In the case of the spring, both types of drift can occur simultaneously, normally due to use, aging or environmental conditions to which the sensitive element of the sensor is subject.

***Range or Span:*** Defines the minimum and maximum values of a quantity that the sensor is fabricated to measure (Figure 18.7).

***Full-Sale:*** It is a difference between the maximum and minimum, expressed in the units of variable.

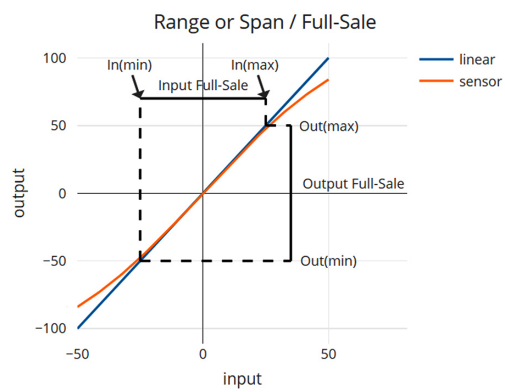


**FIGURE 18.7** This figure shows that ideally, there would be sensors with an infinite full-scale, that is, they would maintain their characteristics for any input value. However, in real life this does not happen, we cannot use the same scale to weigh gold and trucks. In fact, sensors are built to respond well to a certain range of measurement values.

***Transfer Function:*** It gives relation between input and output signal and is the mathematical representation of the relationship between the input and output of a system (Figure 18.8).

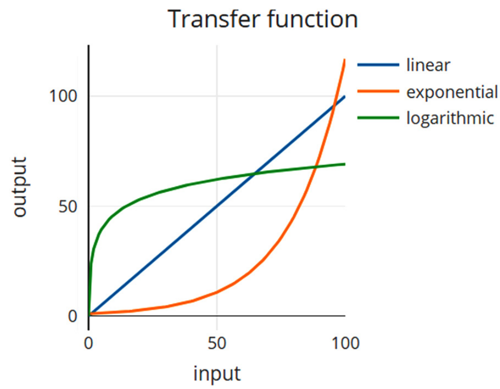


**FIGURE 18.8** This figure shows the representation of three sensors with different transfer functions linear (a straight line), exponential (a line concave up) and logarithmic (a line concave down). There are many more characteristic curves of the sensors and techniques of linearization of these curves using inverse functions are usually applied.

**Linearity*:*** When the input-output points of the instrument are plotted on the calibration curve, the resulting curve may not be linear (Figure 18.9).

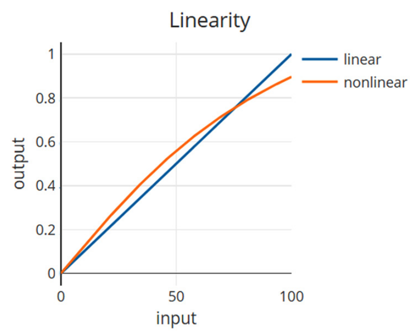


**FIGURE 18.9** This figure shows the behavior of the output in relation to the input is considered linear when the transfer function can be represented by the equation of a line, example of the black line in the graph. In fact, even for systems with linear behavior, there is always a tendency to have fluctuations in their linearity. Linearity is a measure of the maximum deviation expected by the sensor from a line that minimizes deviations.

**Linearity***:* If a linear relationship between $y$ and $x$ exists, then this can be expressed as $y = mx + b$, where the coefficients $m$ and $b$ can be estimated using least squares method (Figure 18.10).

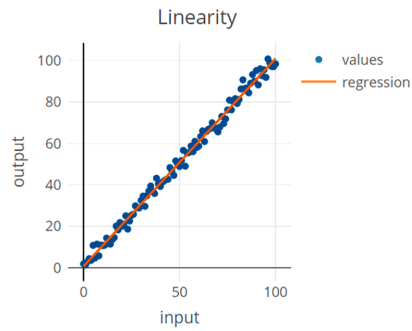


**FIGURE 18.10** The figure shows a set of points obtained from random measurements of a sensor with linear behavior. The way to estimate the line that best fits this set of points is to use the least squares method, where the values for the slope of the line and the ordinate at the origin are estimated.

### 18.6.1 Dynamics Characteristics

***Bandwidth:*** Bandwidth, also referred to as *frequency response*, is an indication of a displacement sensor's ability to respond to changes in the measured displacement. It is measured at the -3 dB (Figure 18.11).

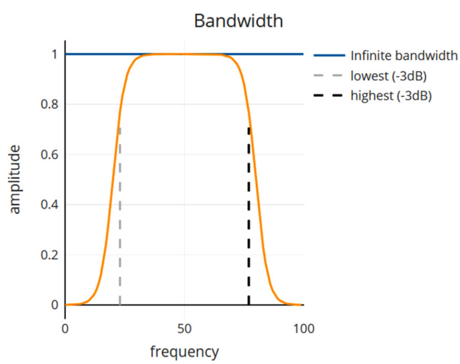


**FIGURE 18.11** This figure shows the concept of bandwidth. The bandwidth is represented in the amplitude/frequency graph, with the horizontal axis representing the frequency and the amplitude in dB on the vertical axis. The dashed boundaries represent the points where the amplitude drops by 3dB. When the input signal presents values in frequency higher than the cut-off frequency, it is considered that the sensor is behaving like a low-pass filter and does not allow the components of the signals with frequencies higher than the upper cut-off frequency to pass. Identical behavior happens at low frequencies. When the input signal has components with frequencies below the low cutoff frequency, the sensor behaves like a high pass filter and will pass signal components whose frequencies are greater than the low cutoff frequency.

***Saturation:*** Sensor operating limit when stimulus variation no longer responds (Figure 18.12).

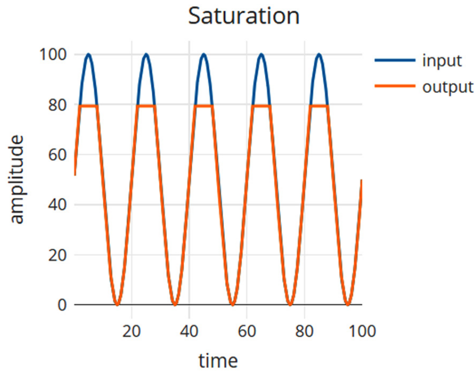


**FIGURE 18.12** This figure shows the sensor saturation. The saturation phenomenon occurs when the input signal is greater than the sensor's range in amplitude. In the figure we can see that if a sensor is designed to obtain output signals up to 80, if there is a signal whose expected amplitude at the output is 100, at the output the sine wave produced will be truncated at 80, that is, values greater than 80 will be displayed with values of 80.

***Resolution:*** It is a lower limit on the magnitude of input stimulus which is necessary to produce an observable change in output (Figure 18.13).

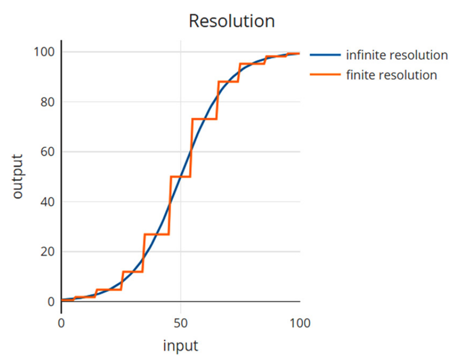


**FIGURE 18.13** This figure shows the dynamic response of a sensor. The resolution of a sensor is usually associated with sensors with digital outputs, representing the number of bits used to encode the amplitude range of the input signal. For example, if an 8-bit analog-to-digital converter (ADC) is used, 256 levels are available to represent the output values. This quantization, represented in the graph by a "scalloped" graph, approaches a high-resolution signal (smaller steps) as the number of ADC bits increases. Even in analog sensors there is a minimum value of variation that causes a change in the output and from there the sensor resolution can be estimated.

***Dynamic Response:*** When an input is applied to a sensor or a measurement system, the sensor or the system cannot take up immediately its final steady-state position. It goes through a transient state before it finally settles to its final steady-state position (Figure 18.14).

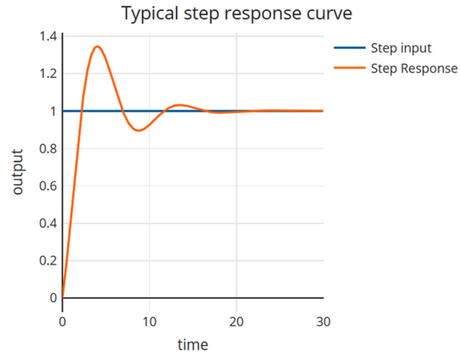


**FIGURE 18.14** This figure shows the sensor's response to a sudden change in the input value is not instantaneous and there is a transition period until this value stabilizes. The straight line represents the instantaneous change of the input signal from 0 to 1. The gray signal represents the oscillation of the output until the value stabilizes. Usually, the most desirable thing is for the output to converge as quickly as possible to 1 without flickering.

***Repeatability:*** For repeatability to be established, the following conditions must be in place: the same location; the same measurement procedure; the same observer; the same measuring instrument, used under the same conditions; and repetition over a short period of time.

***Reproducibility:*** Reproducibility, on the other hand, refers to the degree of agreement between the results of experiments conducted by different individuals, at different locations, with different instruments.

Usually these and other features can be found on the manufacturers data sheets. However, the project is not finished and there is a necessary set of steps until the signals are ready to be displayed.

### 18.6.2 Signal Acquisition Chain

The data acquisition chain can be more or less complex, depending on the number of sensors involved and their specificities. It can be displayed using a block diagram.

BITalino is a low-cost wearable electronic device where several biosensors can be connected (Batista et al. 2019). The BITalino offers flexible user interface for data transmission through the Bluetooth to a personal smartphone, tablet or laptop (Silva, Fred, and Martins, 2014).

A typical block diagram is shown in Figure 18.15. It integrates various sensors to monitor multiple human biometrics in real time. This example includes in particular a set of biosensors, Respiration (PZT), Electrocardiography (ECG), Electrodermal

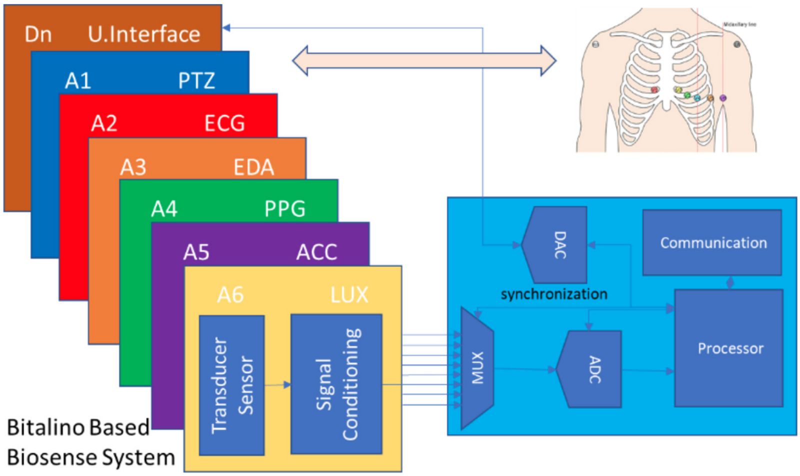


**FIGURE 18.15** This figure shows a data acquisition system including several steps necessary to acquire a signal. The sensors or transducers responsible for converting a physical quantity into an electrical grid connected to analog inputs A1, A2, A3, A4, A5 and A6 are Respiration (PZT), Electrocardiography (ECG), Electrodermal Activity (EDA), Pulse Sensor (PPT), Accelerometry (ACC), Light sensor (LUX) respectively. These six inputs pass through a multiplexer device (MUX) that is controlled by the processor and aims to sequentially measure the value of each sensor individually, that is, the processor selects input 1 through the multiplexer and passes to the ADC where the signal is converted. to digital and supplied to the processor, then it switches to input 2, passes the ECG signal to the ADC and performs the conversion to the processor, followed by this process in an infinite cycle that passes through all the other sensors. On the other hand, if it is necessary to provide some feedback, three digital outputs are available, represented by Dn, where a digital-to-analog converter can be used to convert digital values to an analog output or simply have digital outputs that oscillate between 0 and 1. communication represents the bluethood module used by BITalino to communicate with external devices such as a PC or mobile smartphone.

Activity (EDA), Pulse Sensor (PPT), Accelerometry (ACC), Light sensor (LUX) and a led or button can also be used as a user interface.

### 18.6.3 Collection of Physiological Signals

The collection of physiological signals should only be carried out by technicians or researchers who have enough knowledge to understand the conditions that need to be observed. Poor collection can be detrimental to the diagnosis and have serious consequences for the health of patients in the event of a medical examination. The following are some of the steps in the data collection process:

1) Verification of calibration, quality and warranty terms of the sensors. Environmental conditions and minimum required characteristics of the computers used are essential procedures to ensure good signal collection.

2) Correct application of the protocol used in the study. Each physiological signal monitoring process has a specific purpose, for example, vital sign monitoring, diagnostic examination and stress testing, and, depending on the end goal, the protocol may change considerably the placement of the sensors, number of sensors, type of sensors, sampling frequency or even acquisition time. Minor changes in sensor placement can completely alter the pattern and quality of the signal obtained. In this step, it is necessary to ensure that the protocol is respected.
3) Treatment of obtained signals
   - *Reformatting of signals.* Signals are not always formatted in the physical quantities of the monitored variables. Often, we can find the so-called RawData with the ADC coding used; for example, if an 8-bit ADC is used, the signals are with values from 0 to 255 and if 10 bits are used, the values are between 0 and 1023. Taking this into account, it is necessary to know the characteristics of the equipment used, the characteristics of the sensors and their transfer function in order to reformat the signals.
   - *Filtration.* Each sensor has its bandwidth and eliminating frequencies outside that band is critical to greatly improving the signal. For this, low pass, high pass and/or band pass filters may be used, depending on the sensor used and the noise it picks up. If there is main noise and is within the sensor bandwidth, a filter notch is used to delete it. In the case of acquisition of physiological signals, motion artifacts are also often found. Their disposal is not easy, and it is often necessary to repeat the collection again.
   - *Resampling.* The sensors used are not always acquiring the same sampling frequency as the signals can be preventive of different equipment. In this sense, provided that the Nyquist principle is guaranteed, it is possible and desirable to resample all signals to the same sampling frequency. This way we can work with signal fusion algorithms or even greatly reduce the disk space occupied by the data.
   - *Synchronization.* Another important aspect involves signal synchronization. This process is usually required when working, for example, with protocols involving evoked potentials. In this case, delays in the application of stimuli (images, sounds, mechanical stimulation and others) can produce considerable delays in acquired signals. Several factors can delay the signal such as the sensor itself, the entire signal acquisition chain and the computer and monitor used. Synchronization mechanisms or signals may be required which may ultimately allow the delayed signals to be added during the process. Screen synchronization using a light sensor, sound synchronization using a microphone or even using an opto-coupler isolation synchronous to cable connection.
   - *Standardization.* The normalization process is mostly used when we intend to process data from different participants, as usually the variability from individual to individual is considerable.

4) Signal recognition and classification

This is a high-level procedure where a knowledge background is required to convert signals into information. This knowledge, often from the medical forum or specialists, allows decisions to be made. There are also some algorithms that make use of a large knowledge base to make decisions. However, in both cases, it is important to reinforce that errors in earlier stages may compromise decision-making and, in particular in health, may have serious consequences for patients.

- *Artifacts/noise (rejection).* When the noise level is very high, or the artifacts cannot be bypassed or even if the sensor malfunctions, it is necessary to make the decision to eliminate the collection. However, a survey of what went wrong must be done and find out where the fault is in order to be resolved.
- *Normal pattern or phenotype.* The fact that a population exhibits a dominant pattern does not mean that deviant patterns are also not normal as they may correspond to different phenotypes of the study population. Usually this type of information is already known to those who design the experimental protocol.
- *Pathological patterns.* However, there are deviating patterns that are related to pathologies. There may be similar patterns in different pathologies and as is well-known in medicine that most health decision-making is done using various complementary means of diagnosis.
- *Emotional patterns.* Emotional patterns are an area of knowledge where research has intensified in recent years. Emotional patterns are not easy to identify. It starts with the problem of defining what is an emotion. There are various approaches and definitions to the study of emotions, and some take into account how they were elicited (Scherer, 2005). In this chapter, emotion is approached as changes in physiological signals as a response to a stimulus. The difficulty in finding specific patterns in physiological signals has to do with the variability from subject to subject and the subjectivity that each one manifests according to their experience and their own emotional and physical state at the time of the experience.

## 18.7 CONCLUSIONS

In this work, we presented an integrated model to evaluate the UX, based in the user emotional reactions and behavior decisions, using virtual reality and biosensors technologies. This model was inspired by our previous experiences in the creation of VEs in different studies. To improve the locomotion in a VE, we evaluated the usability of the locomotion in place solution (Teixeira; Vilar; Duarte; Noriega; Rebelo and Moreira, 2013) and proposed a new strategy, the walk-in-place, to be used in human behavior research (Galrão, Rebelo and Noriega, 2020).

In the development of VEs, we developed a simulator for safety warnings behavior compliance evaluation (Almeida, Rebelo and Noriega, 2016). We study the behavior of older people, mainly with the concern to evaluate if they are able to explore and read information inside a VE (Reis, Duarte and Rebelo, 2015). We developed studies to evaluate the sense of presence in VEs (Duarte, Rebelo, Teixeira, Vilar, Teles and Noriega, 2013), and the evaluation of cybersickness (Almeida, Rebelo, Noriega and Vilar, 2017), to verify the quality of the VEs to be used in the human behavior situations. In the context of package design, we developed VEs to evaluate the human interactions with different types of packages (Ayanoglu, Duarte, Noriega, Teles and Rebelo, 2014). In the research area of behavior compliance, we study the design of warnings (Duarte, Rebelo, Teles and Wogalter, 2014) and safety directional signs in an emergency situation, using VEs (Vilar, Rebelo, Noriega, Teles and Mayhorn, 2013).

In the area of VE and biosensors, we develop VE to study job interview anxiety, using EDA (Borges, Vilar, Noriega, Ramos and Rebelo, 2016) and we used the heartbeat rate to study the relationship between VE and emotions (Oliveira, Noriega, Rebelo, Heidrich, 2018). To study the emotions appraisal in a touristic VE prototype, we used a face reading toll (Trindade, Rebelo and Noriega, 2019).

Given the previous experience and the common difficulties to evaluate UX with the traditional methodologies that use subjective data that can be affected by the user context, we proposed this model as an orientation guideline to create VEs to be used with biosensors. The model is composed of five elements that interact with each other in a systemic way. The analysis of the situation is the first step and aims at understanding the interaction situation and the identification of the main problems. The situation context allows the definition of the objectives for the model creation, using the previous information. The immersive virtual reality simulator involves the VR environment and the possibilities of interactions, in function of the previous steps. The biosensors, involving the equipment to measure the emotional reactions, need to be considered in all previous elements. Finally, the user interacts with the VR, where it is possible to measure the emotional reactions, with the biosensors and the participant decisions within the VE.

This model can be used by students or researchers who can begin to study user experience in a highly controlled and ecological context, using a VE with biosensors.

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