Daniel Bühler

Universal, Intuitive, and Permanent Pictograms

A Human-Centered Design Process Grounded in Embodied Cognition, Semiotics, and Visual Perception

EBOOK INSIDE

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Finally, I would like to thank my brother, Denis Bühler, PhD, who has taught me most of what I should know and even more of what I should not.

Contents

List of Abbreviations, Acronyms, and Symbols

ANOVA	Analysis of variance
BES	Best-evidence synthesis
β	Probability of a Type II error
CMT	Conceptual metaphor theory
χ^2	Chi-squared
d	Cohen's *d*
df	Degrees of freedom
EC	Embodied cognition
η_p^2	Partial eta-squared
F	*F*-statistic
GUI	Graphical user interface
HCD	Human-centered design
HCI	Human–computer interaction
HITF	Human Inference Task Force
IQR	Interquartile range
IUUI	Intuitive Use of User Interfaces group
iStep	Intermediate step
M	Mean
Mdn	Median
n	Size of sample
n.t.	Not tested
NPR	Non-photorealistic rendering
p	Probability
PPS	Perceptual symbol systems theory
QUESI	Questionnaire for the subjective consequences of intuitive use
QUT	Queensland University of Technology group
R^2	Coefficient of determination
r	Pearson's *r*
RTD	Research through design
s	Seconds
SD	Standard deviation
STD	Semantic differential technique

τ	Kendall's τ
U	Mann-Whitney U
UCUI	Universal Cognitive User Interface
UIPP	Universal, intuitive, and permanent pictogram

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Step 1: Introduction, Goals, and Summary of the Process

Abstract

Following ISO 9241:210, the first step of a human-centered design process consists in the close examination of previous research, the identification of suitable theories, methods, and resources, and the planning of the process. All subsequent steps are based on this review. Consequently, this introductory chapter discusses existing theories and research, it describes the structure of the UIPP project, and it explains the project goals.

Let me begin with an example. A few years ago, a large German heating system manufacturer began distributing a newly developed heating system in Muslim countries. One function that could be activated via the system's user interface was economy mode. In this mode, the heating system saved energy, thus, it saved money. Economy mode was very popular in Europe. However, in Muslim countries, it was hardly used at all. The manufacturer discovered that Muslim users did not activate economy mode because the pictogram that needed to be touched in the graphical user interface to activate the mode represented a piggy bank. Users preferred not to touch the pictogram because, in Muslim countries, pigs are sometimes considered unclean. Subsequently, the manufacturer replaced the piggy bank with the visual representation of a leaf (M. Roßmann, personal communication, December 12, 2018, J. Zander, personal communication, March 13, 2019).

I suggest that three points are illustrated by the example. First, in the interaction of humans with computers and with each other via computers, graphical user interfaces (GUI) and visual representations are still ubiquitous. This holds although, in the field of human–computer interaction (HCI), today, GUIs and visual representations are sometimes considered to be outdated because of their long

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history and their restriction to a single sensory channel (e.g., Hurtienne and Israel 2007, p. 127; Ishii and Ullmer 1997, p. 240). Instead, the number of situations in which we encounter them seems to be still growing. Sometimes, scholars even consider visual representations the most important mode of communication and interaction today (Kress 2010; Marcus 2015, p. 59).

Second, the example shows that, in the course of recent technological developments, markets have become increasingly connected just as people's lives. Consequently, it is no longer sufficient to provide systems of interaction that are suitable for individual cultures, groups, and people. Instead, systems are required that allow for interaction between them, independent of culture, age, and capabilities (Bourges-Waldegg and Scrivener 1998, p. 288; Plocher et al. 2012, p. 162; Röse 2006, p. 253).

Third, pictograms and other visual representations are fast and easily recognized and learned (Nakamura and Zeng-Treitler 2012, pp. 535–536; Yamazaki and Taki 2010, pp. 71–72), they are often assumed to be universally and intuitively comprehensible (Massironi 2009, pp. 260–262; Mertens et al. 2011, p. 80). Sometimes, designers seem to hold on to these assumptions, although evidence has been gathered that suggests otherwise, showing that users interpret pictograms differently (Callahan 2005; Cho et al. 2007; Del Galdo and Nielsen 1996), sometimes in dangerous ways (Wogalter et al. 2006, p. 161).

In summary, I suggest, the example illustrates that visual representations are still relevant today. However, here is a lack of understanding of visual representations, there is a lack of research on universal and intuitive design (Marcus 2007, p. 376), and there is a lack of knowledge about how to apply scientific findings to design (Röse 2006, p. 253). This book tries to contribute to their remedy of all three.

Universal, Intuitive, and Permanent Pictogram Project: Two Main Goals

The project that I describe in this book started with the hypothesis that there is a good reason for the continuous use of pictograms and other visual representations in HCI. The reason is that they have the potential to be universally, intuitively, and permanently comprehensible (see Rogers 1989, p. 106). However, they appear to be sometimes arbitrarily, confusingly, or even wrongly designed, because their design is based on incorrect assumptions. Instead, I propose that they might be universally, intuitively, and permanently comprehensible if their design were grounded in scientific research and in empirical data.

The project was part of the Universal Cognitive User Interface project (UCUI). UCUI was a joint research project by numerous German research departments and companies, for example, Agilion GmbH, Chemnitz, InnoTec21 GmbH, Leipzig, Javox Solutions GmbH, Aachen, and XGraphic Ingenieurgesellschaft mbH, Aachen, led by Fraunhofer IKTS, Dresden, and Brandenburg University of Technology, Cottbus—Senftenberg. UCUI was funded by the German Federal

Ministry of Education and Research (Bundesministerium für Bildung und Forschung). The UCUI project aimed for the development of a user interface prototype that facilitates intuitive interaction of users with technical devices while protecting the user's privacy. The goal was to develop an interface system that adapts to the user, in other words, a user interface that does not require the user to adapt to the system. The project followed a universal approach (see Sect. "Definitions of Universality in HCI"). It aimed at users who are less familiar with technical devices or less able to use them. The prototype consisted of a single interface for a heating system with which the user interacted through speech, gestures, virtual keyboard, and pictograms (see, e.g., Jokisch and Huber 2018; Meyer et al. 2019).

Being a part of the UCUI project, the first goal of the project presented in this book was to design universally and intuitively comprehensible pictograms that might be integrated into the UCUI heating system user interface. In addition, the project aimed for permanently comprehensible pictogram prototypes. Let me explain. Modes of interaction that are learned might become intuitive through repeated use (see Sect. "Definitions of Intuitiveness in HCI"). For example, in general, we use language intuitively because we have learned it very early in childhood and because we use it constantly. Also, modes of interaction might become universal, for example, through globalization and standardization. English, for example, is becoming more and more widespread, and more and more people are learning the English language. However, modes of interaction are subject to change. Users transform modes of interaction according to their needs (Bezemer and Kress 2016; Kress 2003, 2010). For that reason, in the case of language, differences between uses of a language in distinct regions exist as much as between distinct user groups in one region. Also, there are differences in the use of a language between certain points in time. We are usually not able to comprehend our first language, as it was used in the Middle Ages. Consequently, even if a mode of interaction were universal and intuitive because of repeated use and standardization, it would transform over time, and future generations might no longer be able to comprehend the previously universal and intuitive mode. This holds for language, and it holds for visual representations, too (see Sect. "Historical and Contemporary Examples of Visual Representations"). For that reason, the project that I present aimed for interactions that are successful in the future, too. That is, it aimed for the design of pictograms that are permanently comprehensible. Thus, I call it the Universal, Intuitive, and Permanent Pictogram project (UIPP).

To be clear, I assume that neither pictograms nor any mode of interaction will ever be completely universal, intuitive, or permanent. Human beings, their physical and cognitive abilities, their bodies, and their personal and cultural experiences are far too complex, and technology is developing too fast to create a single set of pictograms or a mode of interaction that is suitable to everyone and will be forever (Heimgärtner 2013, pp. 67–68). In reality, designers might need to integrate "partially universal, general solutions and partially unique, local solutions to the design of UIs" (Marcus 2007, p. 356) in order for these to be suitable for specific users or user groups at specific times (Miller and Stanney 1997, p. 130). In addition, because of various limitations, constraints, and lacking resources, I assume, no project will be able to achieve such a high goal. For example, a general focus of universal design is on elderly people and people with disabilities (see Sect. "Definitions of Universality in HCI"). Since aging as well as certain disabilities might come with varying physical and cognitive abilities, research that focuses on elderly people and people with disabilities is extremely important. However, this was not a central focus of the UIPP project. Of course, this is a drawback. Nevertheless, the choice had to be made because of limited resources. I chose to focus on cross-cultural design instead of inclusive design because research on cross-cultural design is scarce, too (Hurtienne 2017, p. 16), and I hoped that focusing on similarities between people might provide a good basis for subsequent research on individual capabilities (Mansoor and Dowse 2004, p. 31). Consequently, the goal of the UIPP project was, to produce pictograms that are as universal, as intuitive, and as permanent as possible—considering the constraints on the project.

Besides designing universal, intuitive, and permanent pictograms, the project had a second main goal. Today, while various methods to evaluate designs exist, only few methods and technical processes for designing HCI can be found (Goonetilleke et al. 2001, p. 758). Instead, "the design outcome is highly dependent on the experience and expertise of the designer" (Löffler et al. 2013, p. 1). This is a challenge for less experienced designers, researchers, as much as businesses because they might lack the resources to access expert knowledge. Consequently, the second goal of the UIPP project was, to develop a technical process for the design of suitable pictograms that can be performed by other designers, researchers, and businesses, thus, enabling you, the readers, to adopt the process in your projects.

To achieve this, UIPP had two additional subgoals. In HCI, it is a desideratum to further strengthen the scientific bases to achieve more technical designs. In addition, it is a desideratum to strengthen the empirical bases to arrive at data-driven designs (Costa et al. 2014; Evers 1998, p. 4; Heimgärtner 2017, p. 192; Tan et al. 2017). For that reason, instead of focusing on artistic or designerly conventions (Cavanagh 2005, p. 301; Hurtienne et al. 2015, p. 236), the project aimed for scientifically underpinned processes and guidelines (Hurtienne et al. 2009, pp. 61–62). Furthermore, it aimed for comprehensive explanations of its empirical methods, its procedures, and their outcomes (Hurtienne 2017, p. 16). Consequently, in this book, I discuss in detail the theory, I ground the process in scientific research, and I present empirical data, that is, semiotics ("Step 2: Understanding Visual Representation(s)"), embodied cognition ("Step 3: Grounding, Deriving, and Evaluating Pictogram Contents"), visual perception and research through design ("Step 4: Developing a Design System and Producing the UIP Pictograms"), and empirical approaches in HCI ("Step 5: Evaluating the UIP Pictograms").

Furthermore, in contrast to many studies in HCI, UIPP includes all steps of the design process. As early as in 1998, Wood pointed out: "[W]hile there are some excellent sources of information on user interface design, none contains specific descriptions of how a designer transforms the information gathered about users and their work into an effective user interface design" (p. 10). The issue still exists. It is called the design gap (see Hurtienne et al. 2015, p. 240). In order to contribute to the closure of the design gap and to enable other designers, researchers, and business to perform the UIPP process, this project includes all steps, from theoretical underpinning, to requirements analysis, to design of prototypes, and to evaluation (see, e.g., Sect. "The Pictogram Design Production Process").

If these goals are achieved, I argue, not only will users profit, because their interaction will be more effective, and they will be able to interact successfully with people from all over the world. Researchers will profit, because the findings in this project will contribute to research on universal and intuitive design in HCI. Finally, businesses will profit, because they will be able to apply the technical process to design innovative products (Heß et al. 2013, p. 17), at low cost, to "achieve greater success and increased profitability through (…) global distribution and increased acceptance" (Marcus 2007, p. 376).

The UIPP Design Process and the Chapters of this Book

Shneiderman et al. (2017, pp. 137–141) described three viable approaches to the design of user interfaces and HCI: *participatory design*, *agile interaction design*, and *human-centered design*. Participatory design focuses on "the direct involvement of people in the collaborative design of the things and technologies they use. The arguments in favor [of this approach] suggest that more user involvement brings more accurate information" (p. 138). However, since only a limited number of users is involved, single users might have too much influence on the design of products that are developed for the public. Furthermore, direct user involvement comes with higher production times and higher costs. In contrast, the approach of agile interaction design aims at fast, flexible, and adaptive development in order to be able to react to fast-changing markets, technologies, and user preferences. For example, Apple introduces new devices every few months (Apple Inc. 2020). However, these rapid changes in the design of interfaces may lead to unwanted confusion in the users. Finally, the approach of human-centered design (HCD) focuses on the users by involving them during the process and taking their wishes into account. Here, instead of direct involvement, the user information is used to scrutinize the designer's assumptions. According to Shneiderman et al. (2017, p. 137), human-centered design leads to easily developed, maintained, and utilized designs. The process has been used successfully in many studies and projects (e.g., Fetzer et al. 2013; Heimgärtner 2013; Hurtienne et al. 2008, 2015; Salman et al. 2012; see Hartson and Pyla 2012, pp. 47–86; Sharp et al. 2019, pp. 37–67, too). Consequently, the UIPP project was structured as a human-centered design process, too.

The UIPP process was based on the ISO 9241:210 standard (International Organization for Standardization 2010) which is a framework for human-centered design. ISO 9241:210 does not define a specific process but mentions six HCD steps that can be adapted according to the goals and requirements of a specific project (International Organization for Standardization 2010, pp. 5–19) (see Fig. 1).

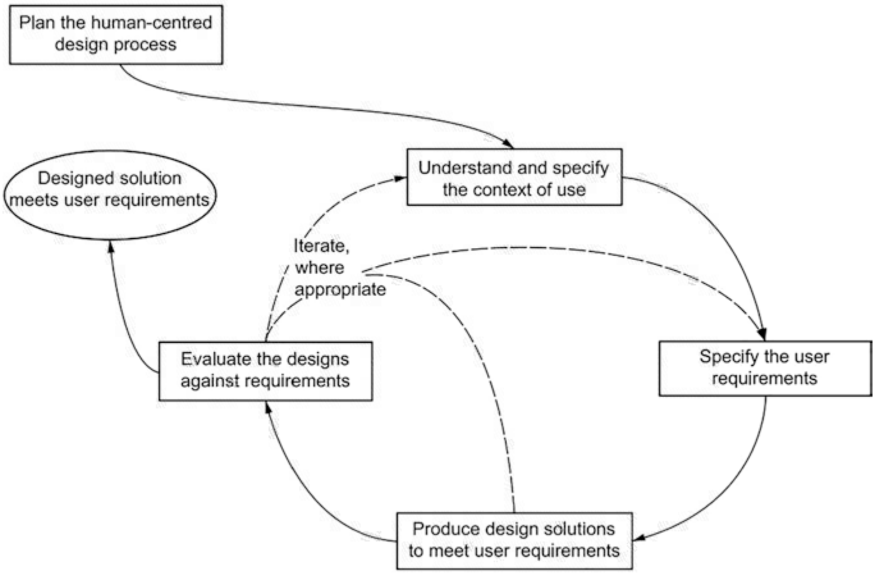

Fig. 1 The six steps in a human-centered design process, according to ISO 9241:210 (International Organization for Standardization 2010, p. 11)

In the following, I describe the HCD steps and I summarize their subsequent application in the UIPP project. The six HCD steps make up the six chapters in this book (see Fig. 2). Although the book presents a complete human-centered

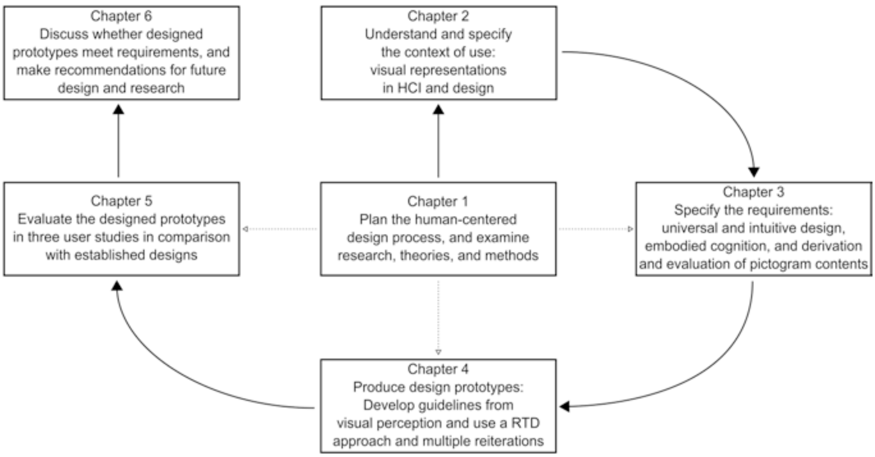

Fig. 2 The UIPP human-centered design process. Each chapter represents one step. Dotted arrows indicate iterations

design process, readers might want to study the chapters separately if they are interested in ideas for specific steps in their design projects:

1. Following ISO 9241:210 (International Organization for Standardization 2010, p. 9), the first step of a human-centered design project consists in the close examination of previous research, the identification of suitable theories, methods, and resources to achieve the goal of the project, and the planning of the project. The subsequent HCD steps are based on the reviews.
   While previous theories and research were examined throughout the UIPP project, in this introductory chapter ("Step 1: Introduction, Goals, and Summary of the Process"), I discuss previous research, and I describe the structure of the project and its goals.
2. In the second HCD step, the context of use, including the users and the user tasks and goals, need to be identified, described, and analyzed.
   Usually, this step consists in a close examination of the real situations in which existing products are used by actual users (e.g., Cooper et al. 2014, pp. 113–117). In UIPP, however, the context of use, the users, and their tasks were specified by the Universal Cognitive User Interface (UCUI) project. That is, the context of use is the universal use of pictograms in HCI, and the pictograms should be comprehensible to all users, independent of culture, age, and capabilities. If this is achieved, the pictograms should be suitable for the UCUI heating system interface, too. For that reason, in UIPP, instead of examining real situations in which users interact with existing pictograms, in Step 2 ("Understanding Visual Representation(s)"), I discuss universal characteristics of visual representations in HCI. That is, I describe in detail the central properties and relations, I discuss existing pictogram systems, and I propose a taxonomy. The goal was to achieve a general understanding of visual representations that might be the basis for the following steps in the process and for other design projects, too. For example, I argue, in order to yield suitable results when designing visual representations, one must always consider two central properties: the design and the reference relation.
3. According to ISO 9241:210, in Step 3 ("Grounding, Deriving, and Evaluating Pictogram Contents"), based on the context of use analysis, requirements for design are specified. Various ways to achieve this exist, for example, through analyses of existing designs, through interviews, and ethnographic observations (Shneiderman et al. 2017, pp. 144–148). Actual users of the designed systems should be involved in the process to provide information, to participate in the design process, and to evaluate the results.
   In UIPP, pictogram contents are considered requirements for pictogram design (as explained in "Step 2: Understanding Visual Representation(s)"). Consequently, following the examples by Hurtienne et al. (2008, p. 242) and Löffler et al. (2013, pp. 5–6), grounding, deriving, and evaluating pictogram contents is considered the HCD analysis of requirements, according to

ISO 9241:210. In Step 3 ("Grounding, Deriving, and Evaluating Pictogram Contents"), first, I present general requirements for universal and intuitive design. Then, I discuss the theory of embodied cognition, and I develop requirements for universal, intuitive, and permanent pictogram contents relying on the theory. Finally, I report two empirical online studies that were conducted to derive and evaluate pictogram contents based on these requirements. Users were involved throughout the UIPP process. In Step 3 ("Grounding, Deriving, and Evaluating Pictogram Contents"), they provided data for the derivation of pictogram content candidates, and they evaluated the candidates.

4. In Step 4 ("Developing a Design System and Producing the UIP Pictograms") of a HCD process, a design team produces prototypes based on previous findings and on existing guidelines. The design team should include people with various disciplinary backgrounds, skilled, for example, in human–computer interaction, user interface design, user research, technical support, and software engineering. According to ISO 9241:210, the designed prototypes should be refined continuously, for example, through iterative evaluations. Reiterations are useful because human–computer interactions are complex, and requirements can hardly be specified in their entirety at the beginning of a design process. Instead, many requirements will emerge only during the process.

   In Step 4, I describe the design production process. First, I suggest that the process of visual perception is universal, intuitive, and permanent. Consequently, I derived guidelines for universal, intuitive, and permanent content design from research on visual perception as part of the UIPP project. Then, I report a research through design (RTD) process that was used to produce the pictogram prototypes, following the previously derived guidelines and using the evaluated pictogram contents. All skills mentioned above were found in the UIPP design team, and several iterations were done during the production process.
5. According to ISO 9241:210, in the fifth step, the designed prototypes should be evaluated by real-world users. All requirements should be fulfilled, including requirements that emerge only during evaluation. While evaluations should be part of each HCD step in order to refine continuously the requirements for design, at the end of the project, the designed prototypes should be evaluated thoroughly.

   In UIPP, while several evaluation studies were conducted during the entire process, in Step 5 ("Evaluating the UIP Pictograms"), I report four user studies that evaluated in detail the produced UIP Pictograms by comparing them with established manufacturer pictograms. In these studies, three different approaches were used consisting of comprehension tests, direct comparisons, and subjective ratings to determine whether the UIPP prototypes are more suitable than the established pictograms and whether they might be considered universal, intuitive, and permanent. I contend that the evaluation was successful.

6. Finally, ISO 9241:210 suggests that the conformity of the designed prototypes with the requirements should be discussed, and recommendations regarding future designs and processes should be made.
   To that end, in Step 6 ("Conclusion, Implications, and Future Research"), the UIPP design process is summarized, drawbacks are discussed, and recommendations for design and for future studies are made. In conclusion, I propose a technical process for the design of suitable pictograms. See Fig. 2 for the complete UIPP human-centered design process.

Step 2: Understanding Visual Representation(s)

Abstract

In the second HCD step, the context of use, including the users and the user tasks and goals, needs to be identified, described, and analyzed. This step usually consists in a close examination of real situations in which existing products are used by actual users. Since the context of use in the UIPP project was specified by the Universal Cognitive User Interface project, this chapter discusses universal characteristics of visual representations in HCI. That is, it describes in detail central properties and relations, it discusses existing pictogram systems, and it proposes a taxonomy of visual representations. For example, it argues that always two central properties must be considered: the design and the reference relation. The goal of the chapter is to achieve a general understanding of visual representations that might be the basis for the following steps in the process as much as for other design projects.

Various Terms and Definitions

Research on visual representations is vast and variegated. This holds for HCI and for human science and practice in general. As Gittins (1986) said:

> Interest in the use of pictographic symbols is not confined to human-computer interface design. Considerable attention has been focused on iconic communication in human language, cognitive psychology, in signposting for public services, in equipment controls, as well as in graphic arts. (p. 520)

In line with the vast number of studies on visual representations, many, sometimes incoherent definitions and taxonomies exist, and several terms are in use for what I call *pictogram.* I suggest, this variety of definitions and taxonomies indicates a

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