

Daniel Bühler

Universal, Intuitive, and Permanent Pictograms

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

EBOOK INSIDE

 Springer

Universal, Intuitive, and Permanent Pictograms

Daniel Bühler

Universal, Intuitive, and Permanent Pictograms

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

Daniel Bühler
Berlin, Germany

ISBN 978-3-658-32309-7 ISBN 978-3-658-32310-3 (eBook)
<https://doi.org/10.1007/978-3-658-32310-3>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Fachmedien Wiesbaden GmbH, part of Springer Nature 2021

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Responsible Editor: Petra Steinmüller

This Springer imprint is published by the registered company Springer Fachmedien Wiesbaden GmbH part of Springer Nature.

The registered company address is: Abraham-Lincoln-Str. 46, 65189 Wiesbaden, Germany

Acknowledgments

I am grateful for the funding of the design production process by the German Federal Ministry of Education and Research (BMBF) and the VDI/VDE Innovation + Technology GmbH (VDI/VDE-IT) through the Universal Cognitive User Interface project (grant no. 16SV7305K) and for the partial funding of the evaluation studies by the Research Cluster Cognitive Systems at Brandenburg University of Technology Cottbus—Senftenberg.

I would like to thank Jutta and Walter Bühler, Matthias Dübner, Prof. Dr. rer. nat. Carsten Hartmann, Prof. Dr.-Ing. Fabian Hemmert, Prof. Dr.-Ing. Jörn Hurtienne, PD Dr. phil. Dr. rer. nat. habil. Peter Klimczak, Dr. rer. nat. Robert Lieck, Dr. med. Martha Loose, Maxi Matzanke, Prof. Dr. phil. Christer Petersen, Dr. rer. nat. Kati Nowack, Nils Schekorr, and all study participants for their contribution to the project.

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

Step 1: Introduction, Goals, and Summary of the Process	1
Step 2: Understanding Visual Representation(s)	11
Step 3: Grounding, Deriving, and Evaluating Pictogram Contents	33
Step 4: Developing a Design System and Producing the UIP Pictograms	127
Step 5: Evaluating the UIP Pictograms	187
Step 6: Conclusion, Implications, and Future Research	233
Appendix A	243
Appendix B	245
Appendix C	247
Appendix D	249
Appendix E	261
Appendix F	263
Appendix G	267
Appendix H	271
Appendix I	275
Appendix J	279
Appendix K	281
Appendix L	283

Appendix M	285
Appendix N	287
Appendix O	289
Appendix P	291
Appendix Q	293
Appendix R	295
Appendix S	299
Appendix T	301
Appendix U	303
Appendix V	305
References	307
Index	329

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

List of Figures

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

Fig. 1	The six steps in a human-centered design process, according to ISO 9241:210 (International Organization for Standardization 2010, p. 11)	6
Fig. 2	The UIPP human-centered design process. Each chapter represents one step. Dotted arrows indicate iterations	6

Step 2: Understanding Visual Representation(s)

Fig. 1	A diagram of the Peircean triad as applied to a print pictogram (Barr et al. 2003, p. 26)	14
Fig. 2	Adapted diagram of the Peircean triad as applied to a print pictogram adapted from (Barr et al. 2003, p. 26)	15
Fig. 3	Adapted diagram of the Peircean triad as applied to a print pictogram adapted from (Barr et al. 2003, p. 26)	16
Fig. 4	Like icon (Cresnar)	17
Fig. 5	Bliss symbol hand. (Blissymbolics Communication International 2019)	25
Fig. 6	a) Apple tabBar contacts (Apple Inc. 2019). b) SAP group (SAP SE). c) IBM group (IBM)	26
Fig. 7	a) Unicode thumbs up (Microsoft Windows 10 OS version) (Unicode Consortium 2019). b) ISO manual control activation. (Deutsches Institut für Normung and International Organization for Standardization 2008, p. 113)	26
Fig. 8	Heart icon (Cresnar)	29
Fig. 9	Detail of “A diagram of the Peircean triad as applied to a Print icon” (Barr et al. 2003, p. 30)	29
Fig. 10	Pictogram with the meaning dry mouth. Detail of “Examples of representation through semantic association: Metaphor” (Nakamura and Zeng-Treitler 2012, p. 546)	30
Fig. 11	The UIPP human-centered design process. Step 2 is completed. Dotted arrows indicate iterations.	31

Step 3: Grounding, Deriving, and Evaluating Pictogram Contents

Fig. 1 “Conceptual tool for applying intuitive interaction during the design process” (Blackler et al. 2014, p. 9). The spirals that are part of the tool represent iterations in the design process. 44

Fig. 2 “Continuum of knowledge in intuitive interaction” (Hurtienne and Blessing 2007, p. 2) 46

Fig. 3 The four basic kinds of sensorimotor knowledge according to RBI (Jacob et al. 2008, p. 3) 61

Fig. 4 Presentation of the meaning [*something*] is important. This is the English version of the presentation (see Study 1.2). In Study 1.1, the German translation was presented. 76

Fig. 5 Presentation of the stimulus for the meaning [*something*] is bad, negative and the content a sad, crying face. This is the English version of the presentation in Studies 2.2. to 2.4. In Study 2.1, the German translation was presented. 99

Fig. 6 The UIPP human-centered design process. Step 3 is completed. Dotted arrows indicate iterations. 125

Step 4: Developing a Design System and Producing the UIP Pictograms

Fig. 1 Judd et al. (2007, p. 5) presented the abovementioned three approaches to line drawings and argued that apparent ridges—their approach—yields the best results. However, other authors find that apparent ridges “exaggerate curvature in some cases and tend to be noisy” (Cole et al. 2008, p. 2) 142

Fig. 2 “When a transparent surface covers a contour in the object behind it, the contour of the transparent surface and the underlying contour cross to form an X-junction” (Cavanagh 2005, p. 304). On the right, no X-junction, thus, no transparency is visible. Other aspects of transparency, like refraction, are not important. 144

Fig. 3 Girshick et al. (2000, p. 50) gave an example of how principal direction line drawings can lead to easily recognizable pictogram contents. In the example, lines representing the object’s curvature from the bottom to the top would create confusion. However, the presented drawing remains ambiguous: It represents pears but could be interpreted as bells, too. This indicates the importance of considering further guidelines in the design process (e.g., G2, G9, and G12) 145

Fig. 4 Pictograms with the content sun and the meaning day. a) is a prototype designed using the presented guidelines, especially G2, 9–11, 17–19, 22–25. b) is an established pictogram by the manufacturer Bosch (Bosch Thermotechnik GmbH 2018, p. 24) 146

Fig. 5 “Example drawings of a fish, chair, and dump truck for a single observer. The average imagined size and preferred size across observers are shown for these same objects in the adjacent columns” (Konkle and Oliva 2011, p. 12) 146

Fig. 6	Examples from a set showing 12 viewpoints by Palmer et al. (1981, p. 139) who studied the phenomenon first. Best viewpoint is left	147
Fig. 7	A complex pictogram (a: file compression) that includes at least 8 distinguishable elements in contrast to a simpler pictogram (b: communications) that includes 3 elements (Curry et al. 1998, p. 1592)	148
Fig. 8	Pictogram with two similar lines that are interpreted as one continuous line.	149
Fig. 9	A UIPP prototype with the meaning <i>[warmth] goes wrong, is wrong</i> , designed using the described guidelines (see Section <i>Presentation of the Design System</i> , p. 255, too). The first frame is presented for 450 ms, the last for 650 ms. All other frames are presented for 350 ms	151
Fig. 10	UIPP design production process plan	163
Fig. 11	Presentation of established pictograms for the meaning <i>warmth</i> . . .	164
Fig. 12	Examples of sketches drawn for the meanings <i>[something] is good, positive, [something] is bad, negative, and [something] begins</i>	166
Fig. 13	Examples of prototypes for the pictogram <i>warmth</i> and the pictograms <i>[warmth] is increasing</i> and <i>[power] is increasing</i>	168
Fig. 14	Internal document by the design team regarding the curvy and irregular design of pictogram contents	169
Fig. 15	Screenshot during the design of the pictogram <i>[something] is bad, negative</i> , using the freeware software Inkscape (The Inkscape Project 2019)	170
Fig. 16	Examples of colored pictograms that were not further refined in favor of real-world shapes and animated pictograms	170
Fig. 17	Examples of refined and discussed prototypes in an internal document by the design team	172
Fig. 18	Internal document of the design team that discusses the animation of the compound pictogram <i>[something] goes wrong, is wrong</i>	173
Fig. 19	Basic pattern for pictogram design, according to IEC 80,416–1: 2008 (International Organization for Standardization 2007).	175
Fig. 20	Pictogram meaning: <i>coldness</i> . The represented content is <i>snowflake</i> . The reference relation is based on the semantic association type semantic narrowing	176
Fig. 21	Pictogram meaning: <i>day</i> . The represented content is <i>the shining sun</i> . The reference relation is based on the semantic association type semantic narrowing	176
Fig. 22	Pictogram meaning: <i>power</i> . The represented content is <i>a male arm with flexing biceps</i> . The reference relation is based on the semantic association type semantic narrowing.	177

Fig. 23 Pictogram meaning: *hand*. The represented content is *hand*. The pictogram was not derived in Chap. “Step 3: Grounding, Deriving, and Evaluating Pictogram Contents” However, it was designed as a part of the pictogram for *[something or someone] is busy*. The reference relation is iconic. 177

Fig. 24 Pictogram meaning: *night*. The represented content is *bright moon and stars*. The reference relation is based on the semantic association type semantic narrowing. 177

Fig. 25 Pictogram meaning: *person*. The represented content is *a person standing or sitting alone*. The reference relation is iconic 177

Fig. 26 Pictogram meaning: *warmth*. The represented content is *fire*. The reference relation is based on the semantic association type semantic narrowing 178

Fig. 27 Pictogram meaning: *[person] is absent, not here*. The represented content is an *empty space in the middle of people*. This is a conflation of the two contents *an empty seat in the middle of people* and *an empty space in the middle*. The reference relation is based on the semantic association type temporal decomposition. The first frame is presented for 1,000 ms, the second for 4,500 ms. The loop appears to be continuous 178

Fig. 28 Pictogram meaning: *[power] is bad, negative*. The represented content is *an angry, frowning face*. The reference relation is based on the semantic association types semantic narrowing and metaphor. The first frame is presented for 1,250 ms, the second for 1,150 ms. The loop appears to be continuous 178

Fig. 29 Pictogram meaning: *[warmth] begins*. The represented content is the rising sun. The reference relation is based on the semantic association types semantic narrowing, metaphor and temporal decomposition. Each frame is presented for 500 ms, except the last frame which is presented for 1500 ms. The loop is apparently repeated 179

Fig. 30 Pictogram meaning: *[warmth] is busy (Version A)*. The represented content is hands performing an action. The reference relation is based on the semantic association type semantic narrowing. Each frame is presented for 150 ms. The loop appears to be continuous 179

Fig. 31 Pictogram meaning: *[warmth] is busy (Version B)*. The represented content is a conflation of the contents *[something] is moving around fast and an action is performed over and over again*. The reference relation is based on the semantic association type semantic narrowing. Each frame is presented for 100 ms. The loop appears to be continuous 180

- Fig. 32 Pictogram meaning: *[warmth] is dangerous*. The represented content is *[something] is approaching very fast*. The reference relation is based on the semantic association type semantic narrowing. The first frame's presentation time is 80 ms. Presentation time decreases for each following frame by 5 ms. The last frame is presented for 30 ms. The loop is apparently repeated 180
- Fig. 33 Pictogram meaning: *[power] is decreasing*. The represented content is *the level of [something] is sinking*. The reference relation is based on the semantic association type semantic narrowing. All frames are presented for 600 ms except for the last frame which is empty. It is presented for 1,200 ms. The loop is apparently repeated. 181
- Fig. 34 Pictogram meaning: *[coldness] ends*. The represented content is *[something] becomes darker until it is black*. The reference relation is based on the semantic association types semantic narrowing and temporal decomposition. All frames are presented for 800 ms, except the last which is presented for 1,200 ms. The loop is apparently repeated. 181
- Fig. 35 Pictogram meaning: *[warmth] is everywhere*. The reference relation is based on the semantic association type contiguity. The represented content is *air*. Each frame is presented for 300 ms. The loop appears to be continuous 182
- Fig. 36 Pictogram meaning: *[coldness] is good, positive*. The represented content is *a smiling, laughing face*. The reference relation is based on the semantic association types semantic narrowing and metaphor. The first frame is presented for 1,250 ms, the second for 1,150 ms. The loop appears to be continuous 182
- Fig. 37 Pictogram meaning: *[person] is here, on-site*. The represented content is a conflation of the two contents *[someone] is arriving* and *[someone] is standing in front of oneself*. The reference relation is based on the semantic association type temporal decomposition. The first frame is presented for 800 ms, the following for 400 ms, and the last frame for 4,500 ms. The loop is apparently repeated. . . 182
- Fig. 38 Pictogram meaning: *[coldness] is important*. The represented content is *[something] is flashing*. The reference relation is based on the semantic association types contiguity. Each frame is presented for 500 ms. The loop appears to be continuous. 183
- Fig. 39 Pictogram meaning: *[warmth] is increasing*. The represented content is *[something] is growing upward*. The reference relation is based on the semantic association type semantic narrowing. All frames are presented for 800 ms, except for the last frame, which is presented for 1,200 ms. The loop is apparently repeated. 183
- Fig. 40 Pictogram meaning: several, a group of [people]. The represented content is [some people] standing together in a circle. The reference relation is iconic 183

Fig. 41	Pictogram meaning: <i>[power] goes wrong, is wrong</i> . The represented content is <i>[something] collapses</i> . The reference relation is based on the semantic association type semantic narrowing. The first frame is presented for 450 ms, the last for 650 ms. All other frames are presented for 350 ms. The loop is apparently repeated	184
Fig. 42	The UIPP human-centered design process. Step 4 is completed. Dotted arrows indicate iterations.	185
Step 5: Evaluating the UIP Pictograms		
Fig. 1	Pictogram meaning: <i>cold</i> (Bosch Thermotechnik GmbH 2018, p. 4). Used as an equivalent to <i>coldness</i>	189
Fig. 2	Pictogram meaning: <i>day</i> (Bosch Thermotechnik GmbH 2018, p. 24). Used as an equivalent to <i>day</i>	189
Fig. 3	Pictogram meaning: <i>energy</i> (Bosch Thermotechnik GmbH 2017, p. 20). Used as an equivalent to <i>power</i>	189
Fig. 4	Pictogram meaning: <i>manual operation</i> (German: Manuelle Bedienung) (Bosch Thermotechnik GmbH 2017, p. 13). Used as an equivalent to <i>hand</i>	190
Fig. 5	Pictogram meaning: <i>night</i> (German: <i>Nacht</i>) (Bosch Thermotechnik GmbH 2018, p. 24). Used as an equivalent to <i>night</i>	190
Fig. 6	Pictogram meaning: <i>end user</i> (German: <i>Endbenutzer</i>) (Bosch Thermotechnik GmbH 2018, p. 35). Used as an equivalent to <i>person</i>	190
Fig. 7	Pictogram meaning: <i>hot</i> (Bosch Thermotechnik GmbH 2018, p. 4). Used as an equivalent to <i>warmth</i>	191
Fig. 8	Pictogram meaning: <i>user away</i> (Bosch Thermotechnik GmbH 2018, p. 25). Used as an equivalent to <i>[person] is absent, not here</i>	191
Fig. 9	Pictogram meaning: <i>heating on</i> (Bosch Thermotechnik GmbH 2018, p. 10). Used as an equivalent to <i>[warmth] begins</i>	191
Fig. 10	Pictogram meaning: <i>heating generator in operation</i> (German: Wärmeezeuger in Betrieb) (Bosch Thermotechnik GmbH 2017, p. 7). Used as an equivalent to <i>[warmth] is busy</i>	192
Fig. 11	Pictogram meaning: <i>danger</i> (German: <i>Gefahr</i>) (Bosch Thermotechnik GmbH 2017, p. 2). Used as an equivalent to <i>[something] is dangerous</i>	192
Fig. 12	Pictogram meaning: <i>energy consumption</i> (Bosch Thermotechnik GmbH 2017, p. 38). Used as an equivalent to <i>[power] is decreasing</i> (Version A).	192
Fig. 13	Pictogram meaning: <i>battery status indicator</i> (in International Organization for Standardization and International Electrotechnical Commission 2007, p. 25, only a description is provided and not a meaning). Used as an equivalent to <i>[power] is decreasing</i> (Version B). The first three frames are presented for 600 ms, the last for 1,200 ms.	193

Fig. 14	Pictogram meaning: <i>cooling off</i> (Bosch Thermotechnik GmbH 2018, p. 10). Used as an equivalent to <i>[coldness] ends</i>	193
Fig. 15	Pictogram meaning: <i>everything okay with your system</i> (German: Alles okay mit Ihrem System) (Bosch Thermotechnik GmbH 2018, p. 33). Used as an equivalent to <i>[something] is good, positive</i>	193
Fig. 16	Pictogram meaning: <i>attention</i> (German: <i>Vorsicht</i>) (Bosch Thermotechnik GmbH 2017, p. 2). Used as an equivalent to <i>[something] is important</i>	194
Fig. 17	Pictogram meaning: <i>temperature up</i> (Bosch Thermotechnik GmbH 2018, p. 11). Used as an equivalent to <i>[warmth] is increasing</i>	194
Fig. 18	Pictogram meaning: <i>user at home</i> (Bosch Thermotechnik GmbH 2018, p. 25). Used as an equivalent to <i>[person] is here, on-site</i>	194
Fig. 19	Pictogram meaning: <i>multiple users or group</i> (Bosch Thermotechnik GmbH 2018, p. 35). Used as an equivalent to <i>several, a group of [people]</i>	195
Fig. 20	Pictogram meaning: <i>error or fault</i> (Bosch Thermotechnik GmbH 2017, p. 10). Used as an equivalent to <i>[something] goes wrong, is wrong</i>	195
Fig. 21	Study 3.1 presentation of the UIP Pictogram with the meaning <i>coldness</i>	197
Fig. 22	Percentage distributions of UIPPs and manufacturer pictograms regarding CRs	201
Fig. 23	Study 3.2 presentation of UIPPs and manufacturer pictograms for <i>several or a group of [people]</i>	206
Fig. 24	Chart of median ratings for direct comparison of perceived suitability of UIPPs and manufacturer pictogram	208
Fig. 25	Study 3.3 presentation of UIPPs and manufacturer pictograms, here, for UIPP <i>[warmth] begins</i>	213
Fig. 26	Pictogram meanings: <i>[warmth] is absent, not here</i> . The first frame is presented for 1000 ms, the second for 4500 ms	221
Fig. 27	Pictogram meanings: <i>[warmth] is bad or negative</i> . The first frame is presented for 1250 ms, the second for 1150 ms.	221
Fig. 28	Pictogram meanings: <i>[warmth] is decreasing</i> . All frames are presented for 600 ms except the last frame which is empty. It is presented for 1200 ms	221
Fig. 29	Pictogram meanings: <i>[warmth] is here or on-site</i> . The first frame is presented for 800 ms, the following for 400 ms, and the last frame for 4500 ms	222
Fig. 30	Pictogram meanings: <i>[warmth] goes wrong or is wrong</i> . The first frame is presented for 450 ms, the last for 650 ms. All other frames are presented for 350 ms	222

Fig. 31 Mean CRs in percent for pictograms with *warmth* vs. with *power* or *person* 223

Fig. 32 Mean RTs in seconds for pictograms with *warmth* vs. with *power* or *person* 224

Fig. 33 The UIPP human-centered design process. Step 5 is completed. Dotted arrows indicate iterations. 230

Step 6: Conclusion, Implications, and Future Research

Fig. 1 The UIPP technical design process. Dotted arrows indicate iterations 234

Appendices

Fig. C.1 Instructional page for Study 1.2. In Study 1.1 an identical German translation was presented 247

Fig. E.1 Instructional page for Study 2.2 to 2.4. In Study 2.1, an identical German translation was presented 261

Fig. K.1 Distribution of educational levels of participants (*n* = 101). None mentioned *no school leaving certificate*. 281

Fig. K.2 Distribution of use frequency of pictograms by participants (*n* = 101). 282

Fig. K.3 Distribution of use frequency of heating interfaces by participants (*n* = 101) for pictograms. 282

Fig. O.1 Presentation of Version A and B of UIPP [*warmth*] is busy 289

Fig. Q.1 Distribution of educational levels of participants (*n* = 95). None mentioned *no school leaving certificate*. 293

Fig. Q.2 Distribution of use frequency of pictograms by participants (*n* = 95). 294

Fig. Q.3 Distribution of use frequency of heating interfaces by participants (*n* = 95) for pictograms. 294

List of Tables

Step 2: Understanding Visual Representation(s)

Table 1	Poles and categories of design and reference relations, including examples of corresponding visual representations	28
---------	--	----

Step 3: Grounding, Deriving, and Evaluating Pictogram Contents

Table 1	Hofstede’s cultural dimension values per country and per dimension (1–100).	71
Table 2	Count of words collected as open-end responses per meaning in Austrian, German, and Swiss participant group	78
Table 3	Ranks and frequencies of lemmata and n-grams in the response data for the meaning <i>[something] is important</i> in German (Total word count: 3,046)	79
Table 4	Response categories including details coded for the meaning <i>[something] is important</i>	80
Table 5	Meanings, abbreviated categories, and content candidates (80) for German-speaking participant group.	83
Table 6	Count of words collected as open-end responses per meaning in North American (NA), South African (SA), and Australian (A) participants subgroups (Total: 78,923)	88
Table 7	Meanings, conflated and abbreviated categories, and content candidates (104) for English-speaking participant group	89
Table 8	Friedman tests and Matched-pairs Wilcoxon signed-ranks tests for content candidates and meanings in Austrian, German, and Swiss participant group.	102
Table 9	Friedman tests and Matched-pairs Wilcoxon signed-ranks tests for content candidates and meanings in Canadian and U.S. participant group	106
Table 10	Friedman tests and Matched-pairs Wilcoxon signed-ranks tests for content candidates and meanings in South African participant group	111
Table 11	Friedman tests and Matched-pairs Wilcoxon signed-ranks tests for content candidates and meanings in Australian participant group	115

Table 12	Comprehensive ranking of the highest-rated contents for all participant groups	120
Step 4: Developing a Design System and Producing the UIP Pictograms		
Table 1	Intermediate steps (iSteps) 1–4 in the design production process according to HCD	158
Table 2a	Report of the UIPP design production process	163
Table 2b	Report of the UIPP design production process	164
Table 2c	Report of the UIPP design production process	165
Table 2d	Report of the UIPP design production process	166
Table 2e	Report of the UIPP design production process	171
Table 2f	Report of the UIPP design production process	171
Table 2g	Report of the UIPP design production process	173
Step 5: Evaluating the UIP Pictograms		
Table 1	Median ratings for suitability (SU), intuitiveness (IU), un-ambiguity (UA), un-complexity (UC), innovativeness (IO), and familiarity (FA) per participant ($n=95$)	215
Table 2	Kendall's τ correlations for characteristics ratings for complete UIPP set ($n=95$)	217
Table 3	Kendall's τ Correlations for characteristics ratings for complete manufacturer set ($n=95$)	218
Table 4	Correct responses (CRs) in percent and response times (RTs) in seconds for UIP Pictograms with <i>warmth</i> vs. with <i>power</i> or <i>person</i>	223
Table 5	Median ratings for pictogram characteristics	224
Step 6: Conclusion, Implications, and Future Research		
Table 1	UIPP technical process for the design of suitable HCI pictograms	234
Appendices		
Table A.1	UCUI scenarios and derived UIPP meanings	243
Table B.1	English and German UIPP meanings derived from UCUI scenarios	245
Table D.1	Open-ended response data for the meaning [<i>something</i>] is important from German-speaking participant group	249
Table F.1	Median ratings per content candidate in Austrian, German, and Swiss participant group	263
Table G.1	Median ratings per content candidate in U.S. and Canadian participant group	267
Table H.1	Median ratings per content candidate in South African participant group	271
Table I.1	Median ratings per content candidate in Australian participant group	275

Table J.1	Guidelines and cited references, following best-evidence synthesis method	279
Table L.1	Correct responses (CRs) in percent for UIPPs and manufacturer pictograms ($n = 101$)	283
Table M.1	Aggregated and cleaned response times (RTs) in seconds for UIPPs and manufacturer pictograms ($n = 101$)	285
Table N.1	Pearson's Product Moment Correlations for Age with CRs and RTs.	287
Table P.1	Median ranks and IQRs of comparisons between UIPPs and manufacturer pictograms ($n = 101$)	291
Table R.1	Median ranks for suitability (SU), intuitiveness (IU), un-ambiguity (UA), un-complexity (UC), innovativeness (IO), and familiarity (FA) per UIPP and manufacturer pictogram ($n = 95$)	295
Table S.1	Median ranks for suitability (SU), intuitiveness (IU), un-ambiguity (UA), un-complexity (UC), innovativeness (IO), and familiarity (FA) per participants ($n = 95$)	299
Table T.1	One-sample Wilcoxon signed-rank tests for UIPP and manufacturer ratings (test value = 3)	301
Table U.1	Matched-pairs Wilcoxon signed-ranks test for UIPP and manufacturer ratings	303
Table V.1	Matched-pairs Wilcoxon signed-ranks test for UIPP and manufacturer ratings	305



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

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).

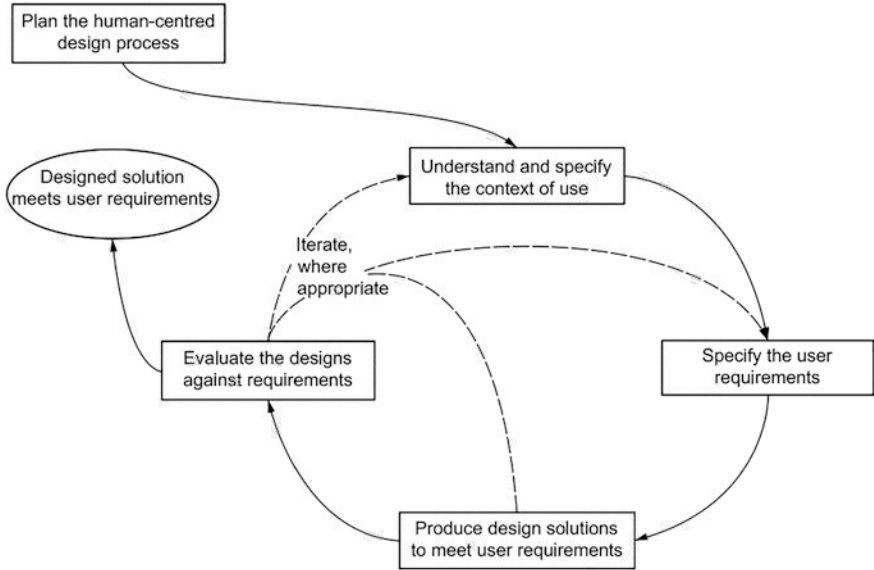


Fig. 1 The six steps in a human-centered design process, according to ISO 9241:210 (International Organization for Standardization 2010, p. 11)

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

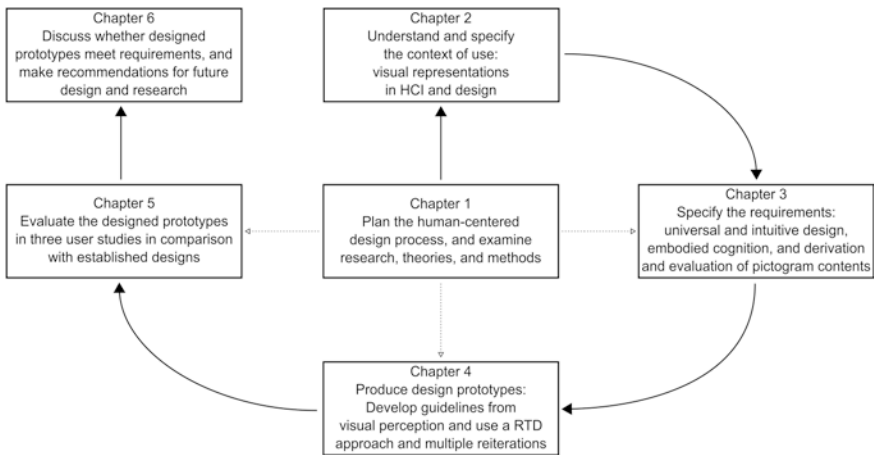


Fig. 2 The UIPP human-centered design process. Each chapter represents one step. Dotted arrows indicate iterations

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