Prior Knowledge in Inclusive Design: The Older, the More Intuitive?

Jörn Hurtienne
Engineering Design Centre
Department of Engineering
University of Cambridge
+44 1223 76961
jwh44@cam.ac.uk

Patrick Langdon
Engineering Design Centre
Department of Engineering
University of Cambridge
+44 1223 76961
pml24@eng.cam.ac.uk

ABSTRACT

Old age brings along reductions in sensory, cognitive, and motor abilities. Product development methodologies for Inclusive design have to adjust. While sensory and motor abilities are relatively straightforward to measure, cognitive abilities are more elusive. The paper discusses how different sources of prior knowledge can inspire inclusive design. Special emphasis is put on knowledge derived from basic and well-learned sensorimotor experiences. This is proposed to complement previous studies investigating the effects of tool knowledge on inclusiveness. Image schema theory as an account of sensorimotor knowledge is introduced and its universality, robustness, and multimodality are discussed. Current evidence for the usefulness of applying image schemas in user interface design is reviewed and implications for inclusive design research are derived. More specifically, a research program is developed that includes theoretical, empirical, as well as practical studies to promote the ideas developed in this paper.

Categories and Subject Descriptors
H5.2 [**User Interfaces**]: User Centered Design.

General Terms
Human Factors, Experimentation, Theory.

Keywords
Inclusive Design, Universal Design, Prior Experience, Interaction Design, Image Schemas, Cognitive Abilities.

1. INTRODUCTION

Research into inclusive design has investigated the relationship between the capabilities of the population at large – derived from statistical data sets, and properties and features of the design of products [1, 2, 3]. Products meeting the ideals of inclusive design aim to minimise the number of people who have difficulty with, or are excluded from use, or to control such exclusion by manipulation of product features [4,5]. The cognitive capabilities of older users are one of the primary areas of concern. Particular attention is given to the effect of memory on learning a products' use and the ability of individual users to transfer learning from prior experience [6].

This paper introduces a model continuum of prior knowledge sources and argues that previous approaches to designing technology around prior knowledge about tools can be complemented by other, more subconsciously applied sources of knowledge. Image schemas as a special form of sensorimotor knowledge are introduced. As the empirical evidence on the usefulness of the approach for inclusive design is rare, an agenda for further research is developed.

2. PRIOR KNOWLEDGE SOURCES

Prior knowledge is a critical factor of how easy the interaction with a new product is to learn [7]. If users can match their knowledge to what is presented at the user interface, the user interface will be easy to understand and be intuitive to use. To better understand the different sources prior knowledge can stem from, a continuum of knowledge sources has been proposed, shown in Figure 1 [8].

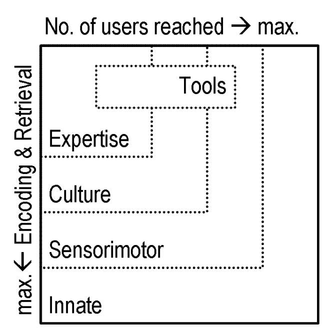

Fig. 1. Continuum of knowledge sources

The first and lowest level of the continuum consists of innate knowledge that is 'acquired' through the activation of genes or during the prenatal stage of development. Generally, this is what reflexes or instinctive behaviour draw upon. The sensorimotor level consists of general knowledge, which is acquired very early in childhood and is from then on used continuously through interaction with the world. Children learn for example to differentiate faces; they learn about gravitation; they build up concepts of speed and animation. Scientific notions like affordances [9], gestalt laws [10], and image schemas [11] (discussed below) reside at this level of knowledge.

The next level is about knowledge specific to the culture in which an individual lives. This knowledge can vary considerably between cultures and may influence how people approach technology. It touches, for instance, the realm of values (e.g. what constitutes a taboo), the styles of visual communication (cf. Japanese manga vs. American comics), but also concerns knowledge about daily matters like the usual means of transportation (e.g. buses, trains, or bicycles) or the prevalent form of energy supply (e.g. by a public power line or by burning wood for heating).

The most specific level of knowledge is expertise, i.e. specialist knowledge acquired in one's profession, for example as a mechanical engineer, an air traffic controller, or a physician – and in hobbies (e.g. modelling, online-gaming, or serving as a fire-fighter).

Across the sensorimotor, culture, and expertise levels of knowledge, knowledge about tools can be distinguished. Tools at the sensorimotor level are primitive tools like sticks for extending one's reach and stones used as weights. Tools at the culture level are those shared by many people, like ballpoint pens for writing, pocket lamps for lighting, or cell phones for communication. Tools at the expertise level are professional tools like computer aided design (CAD) tools, enterprise resource planning (ERP) systems, or machine tools.

2.1 Inclusive Design at the Tool Level

Tool knowledge from the cultural or expertise level is an important reference when designing user interface metaphors. Tools at the sensorimotor level are rarely or never used explicitly [12]. Previous research on prior experience in inclusive design also focused at the cultural or expertise level of tool knowledge. These often are pragmatic decisions, because all products make some reference to either products extant during previous generations or products from different companies or product families.

Products that help the user make a reference to the same function on another device with which they are familiar should outperform those that make no such association – or worse still, make a different reference. Knowledge at the tool level has been researched in terms of 'computer literacy' [13], 'technology familiarity' [14], or simply 'prior experience' [6, 7]. These studies show that prior knowledge about similar tools decreases the time and errors in interacting with a new product (e.g. microwave ovens, digital cameras, motor cars). But performance measures (times and errors) were also influenced by age, usage frequency, and general cognitive capability.

2.2 Promises of the Sensorimotor Level

Relying on prior tool knowledge at the cultural or expertise levels is one strategy for inclusive design. However, designers then need to determine what prior tool experience the target user group has. Data on tool usage quickly becomes outdated as technology develops – statistics on the distribution of tool knowledge in the population would quickly be loosing their usefulness. Also, designing for prior knowledge about specific tools, like mobile phones or desktop PCs, may exclude many users that are not familiar with these tools. Finally, just repeating how existing products look and feel gives no guidance for designing new functionality and can even hamper innovation [15].

As the continuum of knowledge sources in Figure 1 suggests, there are types of knowledge that may not have these problems and therefore could complement the previous approaches. Specifically, we would like to focus on knowledge residing on the sensorimotor level of the continuum. This type of knowledge comes with two promises:

- Lower level sensorimotor knowledge is so basic and fundamental, that it should be available to a large range of people of different backgrounds – much more than tool knowledge or knowledge from the expertise or cultural level.
- Sensorimotor knowledge is acquired early in life and is frequently encoded and retrieved in a large number of different situations. Thus, its application has become automated and subconscious. It therefore should be less sensitive against individual differences in cognitive abilities like working memory capacity and attentional demands as well as injuries [16, 17].

It is the universality and robustness against differing levels of cognitive abilities that makes general knowledge on the sensorimotor level the ideal complement to previous research on prior knowledge at the tool-level (culture or expertise) in inclusive design.

2.3 Image Schemas

Image schemas are a form of knowledge representation that encodes very basic and repeated sensorimotor experience [11]. The experience of vertically extended objects and of gravity, for instance, forms the image schema UP-DOWN. Other examples of image schemas include CONTAINER, BLOCKAGE, NEAR-FAR, and PATH (of a list of about 40 image schemas). They describe basic object properties (BRIGHT-DARK, BIG-SMALL), spatial relations (UP-DOWN, NEAR-FAR), or so-called force dynamics (BLOCKAGE, COMPULSION).

Many image schemas show experiential correlations with other sensorimotor experiences. For example, UP-DOWN correlates with quantity (the height of the water level correlates with the amount of water in a jar). NEAR-FAR correlates with similarity (similar objects or living things tend to occur together in space). These correlations are also encoded in memory and are re-used in the conceptualisation of abstract concepts, e.g. when talking about *rising inflation, sinking prices*, or *close colours*. In fact, most of these correlations have been first detected in language (about 250 of them are documented). The psychological reality of image schemas and their extensions to abstract concept has been validated by developmental research [18], by cognitive psychological experimentation [19, 20, 21, 22] and by neurocognitive findings [23].

3. IMAGE SCHEMAS IN DESIGN

Image schemas can be used in physical-to-physical mappings in user interfaces. This can be achieved by using simple principles of stimulus-response (or control-display) compatibility [24]. A highly successful application is Google Earth using the accelerometer and tilt sensors of the iPhone to navigate interactive 3D maps of the world. Maps are moved UP or LEFT by dragging a finger UP or LEFT on the screen. Zooming in is achieved by pinching the fingers as to stretch the surface of the map (BIG-

SMALL). Tilting the phone leads to views of mountains or streets of houses in 3D (ROTATION).

Yet the most promising features of using image schemas in user interface design are physical-to-abstract mappings. Experimental results show that vertical sliders and button arrangements labelled in agreement with MORE IS UP – LESS IS DOWN and GOOD IS UP – BAD IS DOWN mappings are operated faster and are more satisfying to use than the reverse mappings LESS IS UP – MORE IS DOWN and BAD IS UP – GOOD IS DOWN [8, 25]. Other research shows that under high cognitive workload the mapping SIMILAR IS NEAR – DIFFERENT IS FAR can explain results in user performance (times and errors) that can not be explained by previous design guidance like the proximity-compatibility principle of Wickens and Carswell [25, 26].

Lund [27] used physical-to-abstract mappings of image schemas to design a hierarchical collection of bookmarks in a virtual 3D space. This prototype was compared with an information-equivalent traditional hypertext prototype. The results show that the image-schematic mappings profoundly influenced what users thought about the interface in that the language of the users was influenced significantly b the image schemas present in the prototypes.

In two other studies [28, 29], image schemas were used during a context-of-use analysis of an invoice verification and posting software. The results were used to derive 29 image-schematic requirements for the re-design of the software. In the subsequent evaluation with users, the re-designed prototype was rated as significantly higher in hedonic and pragmatic quality compared to the users' current solution.

Taken together these examples show that there is value in regarding image schemas as a form of sensorimotor knowledge in user interface design. Using image schematic designs lead to more effective, efficient and satisfying interaction with technology and using them can lead to an improved design lifecycle [28, 29]. Thus the approach seems promising for inclusive design as well. However, it still needs to be shown that image schemas are as advantageous as they promise to be for user populations with widely varying cognitive abilities. Plus it needs to be shown directly, how image-schema inspired designs fare in comparison to current approaches using knowledge from other levels of the continuum.

4. A RESEARCH AGENDA

Image schemas are proposed to be universal, multimodal, and operating beneath consciousness. The universality predicts that user interface features designed with image schemas should be equally usable by members of different technology generations (cf. [31]). The multimodality predicts that also users with sensory impairments have image-schematic concepts. Blind users, for example, should have an understanding of what a CONTAINER is using haptic and acoustic cues. In fact, research has shown that the mental representations of blind people do not differ from those in sighted people, especially for spatial information (as opposed to purely visual information) [32, 33]. Most image schemas are abstractions of spatial relations [18], so image-schema based user interfaces should apply to blind users as well.

Finally, the subconscious application of image schemas predicts a certain robustness. Image-schematic designs should be less susceptible to variation in users' cognitive ability like working memory capacity, attentional resources, decision-making, etc. Similarly, cognitive losses should affect knowledge on the higher levels of the knowledge continuum earlier than image schemas that reside on a lower, earlier obtained and more strongly rehearsed level of knowledge.

Note that these predictions are different from those made for user interface features drawing on tool knowledge at the expertise or culture level. Research has shown that knowledge at the expertise/tool level is neither universal nor robust. Members of different technology generations perform differently and performance deteriorates with increasing age and decreasing ability [6, 7].

As these are interesting promises for the field of inclusive design and their empirical investigation is virtually non-existant, the following implications for inclusive design research arise:

(1) Theoretical: The aim should be to integrate the theory of image schemas with a model of assessment of the prior-knowledge demand of a product user interface at the expertise/tool level of knowledge. Simple models of cognition were already developed (cf. [34, 35]). As they are mostly inspired by information-processing approaches to cognition (e.g. [36]), they lack the subconscious, embodied, and sensorimotor accounts of knowledge that image schema theory can provide. An integrated theoretical framework would better account for the phenomena under study and would be a better guide to design than each of these theories alone.

(2) Empirical: Then the objective is to test the predictions of the integrated theoretical framework for different products and to verify their fitness for practical purpose. Studies should verify the claims made about the universality, multimodality, and robustness of image schemas, compared to other levels of prior knowledge. This means including participants of different ages and degrees of cognitive capability who interact with different versions of everyday technology (e.g. microwave ovens, digital cameras, or music players). The outcomes of the empirical studies will show whether the strong predictions of image schema theory can be confirmed, must be rejected, or need refinement considering moderating effects by other factors.

(3) Practical: Finally, the objective is to develop practical guidance for designers that results from the integrated theoretical framework and the empirical findings. This guidance could take the form of a design method. It will then be necessary to evaluate the usefulness of this guidance by applying it to a real-world design problem and assess its practicability.

These three objectives directly derive from the state of the art, because there is no common framework for inclusive design combining image schemas and general cognitive models of prior knowledge. Although data on the validity of image schemas in user interface design exist in general, it needs to be determined what their use for inclusive design is (see above). Ultimately, the growing demand for inclusive design makes it necessary to provide guidance to designers that is empirically validated.

5. CONCLUSIONS

A simple model of prior knowledge points out ways to analyse and design technology that have not been considered before. Current evidence shows that there is much potential in designing for more basic and subconscious forms of knowledge. Both, previous approaches to prior knowledge and the new approach can complement each other and can be integrated. More research needs to be undertaken on the theoretical, empirical, and practical level to make these ideas relevant for inclusive design. More generally, the results of such work will extend the knowledge, tools, and guidelines for engineering design and product development based on recent cognitive science findings.

6. ACKNOWLEDGMENTS

Work carried out under UK EPSRC funded Inclusive Design 3 project and EU Marie-Curie project INCLUDIS.

7. REFERENCES

1. Vanderheiden, G.C., Vanderheiden, K.: Guidelines for the design of consumer products to increase their accessibility to people with disabilities – working draft 1.7. Trace Research & Development Center, Madison, WI (1992)
2. Keates, S., Clarkson, P.J.: Countering Design Exclusion. An Introduction to Inclusive Design. Springer, London (2004)
3. Persad, U., Langdon, P.M., Clarkson, P.J.: Inclusive design evaluation and the capability-demand relationship. In: Clarkson, P.J., Langdon, P.M., Robinson, P. (eds.) Designing Accessible Technology, pp. 177–188. Springer, Berlin (2006)
4. Nicolle, C., Abascal. J. (eds.): Inclusive Design Guidelines for HCI. Taylor & Francis, London (2001)
5. Coleman, R.: Designing for our future selves. In: Preiser, W.F.E., Ostroff, E. (eds.) Universal Design Handbook, 4.1–4.25. MacGraw-Hill, New York (2001)
6. Langdon, P.M., Lewis, T., Clarkson, P.J.: The effects of prior experience on the use of consumer products. UAIS 6, 179-191 (2007)
7. Lewis, T., Langdon, P.M., Clarkson, P.J.: Prior experience of domestic microwave cooker interfaces: A user study. In: Langdon, P.M., Clarkson, P.J., Robinson, P. (eds.) Designing Inclusive Futures, pp. 95–106. Springer, London (2008)
8. Hurtienne, J., Blessing, L.: Design for Intuitive Use - Testing image schema theory for user interface design. In: Proc. ICED, P_386, pp. 1-12, Ecole Centrale, Paris (2007)
9. Gibson, J.J.: The ecological approach to visual perception. Houghton Mifflin, Boston, MA (1979)
10. Koffka, K.: Principles of gestalt psychology. Harcourt, Brace & Co., New York (1935)
11. Johnson, M.: The body in the mind: the bodily basis of meaning, imagination, and reason. University of Chicago Press, Chicago (1987)
12. Hurtienne, J., Blessing, L.: Metaphors as Tools for Intuitive Interaction with Technology. metaphorik.de 12, 21-52 (2007)
13. Wandke, H., Struve, D., Sengpiel, M. ALISA – Adaptive Lernumgebung zur Interaktiven Systemnutzung Älterer, https://www.psychologie.hu-berlin.de/prof/ingpsy/forschung/ALISA/index_alt_html.
14. Blackler, A.: Intuitive interaction with complex artefacts. Queensland University of Technology, Brisbane (2006)
15. Raskin, J.: Viewpoint: Intuitive equals familiar. CACM 37(9), 17-18 (1994)
16. Reber, A.S.: Implicit learning of artificial grammars. J. Verb. Learn. Verb. Behav. 6, 855-863 (1967)
17. Cleeremans, A.: Conscious and Unconscious Processes in Cognition. In: Smelser, N.J., Baltes, P.B. (eds.), International Encyclopedia of Social and Behavioral Sciences, pp. 2584-2589. Pergamon, Oxford (2001).
18. Mandler, J. M.: The foundations of mind: origins of conceptual thought. Oxford University Press, Oxford (2004)
19. Casasanto, D., Boroditsky, L.: Time in the mind: Using space to think about time. Cognition 106, 579-593 (2008)
20. Casasanto, D., Lozano, S.: Metaphor in the Mind and Hands. In: Sun, R., Miyake, N. (eds.), Proc. 28th Annual Conference of the Cognitive Science Society, pp. 142-147. Lawrence Erlbaum Associates, Hillsdale, NJ (2006)
21. Casasanto, D., Lozano, S.: Meaning and Motor Action. In: McNamara, D., Trafton, G. (eds.) Proc. 29th Annual Meeting of the Cognitive Science Society, pp. 149-154. Cognitive Science Society, Austin, TX (2007)
22. Gibbs, R.W.; The psychological status of image schemas. In Hampe, B. & Grady, J.E. (eds.) From perception to meaning: image schemas in cognitive linguistics, pp. 113-135. Mouton de Gruyter, Berlin; New York (2005)
23. Barsalou, L.W.: Perceptual symbol systems. BBS 22, 577-609 (1999)
24. Proctor, R.W., Vu, K.-P.L. Stimulus-response compatibility principles: data, theory, and application. CRC/Taylor & Francis, Boca Raton, FL (2006)
25. Hurtienne, J.: Image Schemas and Design for Intuitive Use. Technische Universität, Berlin (in prep.)
26. Wickens, C.D., Carswell, C.M.: The Proximity Compatibility Principle: Its Psychological Foundation and Relevance to Display Design. Human Factors 37, 473-494 (1995)
27. Lund, A.: Massification of the intangible: an investigation into embodied meaning and information visualization. Umeå universitet, Umeå (2003)
28. Hurtienne, J., Israel, J.H., Weber, K.: Cooking up real world business applications combining physicality, digitality, and image schemas. In Schmidt, A., Gellersen, H., v. d. Hoven, E., Mazalek, A., Holleis, P., Villar, N. (eds.), TEI'08, pp. 239-246. ACM, New York (2008)
29. Hurtienne, J., Weber, K., Blessing, L.: Prior Experience and Intuitive Use: Image Schemas in User Centred Design. In: Langdon, P.M., Clarkson, P.J., Robinson, P. (eds.) Designing Inclusive Futures, pp. 107–116. Springer, London (2008)
30. Pirhonen, A., Brewster, S., Holguin, C.: Gestural and Audio Metaphors as a Means of Control for Mobile Devices. CHI letters 4, 291-298 (2002)
31. Docampo, R.M.: Technology generations handling complex User Interfaces. Technische Universiteit, Eindhoven (2001)
32. Fleming, P., Ball, L.J., Collins, A.F., Ormerod, T.C. Spatial representation and processing in the congenitally blind. In: Ballesteros, S., Heller, M.A. (eds.) Touch, blindness, and neuroscience. UNED Press, Madrid (2004)
33. Knauff, M., May, E.: Mental Imagery, Reasoning, and Blindness. Quarterly J. of Exp. Psychology 59, 161–177 (2006)
34. Persad, U., Langdon, P.M., Clarkson, P.J.: A framework for analytical inclusive design evaluation. In: Proc. ICED, P_536, pp. 1-12. Ecole Centrale, Paris (2007)
35. Langdon, P., Keates, S., Clarkson, P. Developing cognitive capability scales for inclusive product design. In: Proc. ICED, P_1206, pp. 1-10. Stockholm (2003)
36. Card, S., Moran, T., & Newell, A.: The Psychology of Human-Computer Interaction. Lawrence Erlbaum, Hillsdale, NJ (1983)