Closer to You: 
Reviewing the Application, Design, and Evaluation of Ambient Displays

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ABSTRACT
This paper presents results from a recent literature review on ambient displays. While the main background of the authors is education and technology-enhanced learning, the review starts more generic with a broader view on ambient displays and their interactional, instructional, and informational characteristics. Beside depicting characteristics and classifying prototypical designs, the review also sheds light on the actual use of the covered ambient displays, their application context and addressed domains as well as the type of studies conducted, including the used methodologies and evaluation approaches to measure their effectiveness and impact. The review concludes with a discussion of the presented results emphasising the derived implications for the user when interacting with ambient displays.

Keywords: Ambient Displays, Design, Empirical Research, Evaluation, Literature Review

INTRODUCTION
Since the idea of ubiquitous computing with its subdomains pervasive and mobile computing has first appeared, the relation between people and computing devices and thus the impact of technology on the user has changed. Most notably the used human-computer interaction modalities changed with the latest technical developments. Starting from interacting electronically with the computer, over symbolic and graphical forms of interaction, right up to touch and gesture-based interaction – more and more human abilities were considered in interaction design. By gradually incorporating more skills and abilities the resulting principles made computation “more widely accessible to people without requiring extensive training, and to be more easily integrated into our daily lives by reducing the complexity of those interactions” (Dourish, 2001).

One of those interaction approaches, emerging from pervasive and mobile technologies situated and interacting close to the user,
utilises ambient media in the periphery of the user. Associated with a more tangible and social interaction corresponding systems make use “of the entire physical environment as an interface to digital information. Instead of various information sources competing against each other for a relatively small amount of real estate on the screen, information is moved off the screen into the physical environment” (Wisneski, Ishii, Dahley, Gorbet, Brave, Ullmer, & Yarin, 1998). Thereby the used ambient displays in the background are an addition to existing personal interfaces in the foreground, while the user attention can always move from one to the other or vice versa. Especially the ability to deliver contextualised and personalised information in authentic situations fosters ambient displays as an instrument for learning and thus moves this technology into the main research interest of the authors, i.e. technology-enhanced learning. Although the conducted review is adjusted to this research field accordingly, the derived principles and implications regarding the design and evaluation of ambient displays can be applied generically.

With respect to the learning context Ogata and Yano (2004) describe the main characteristics of the underlying concept of ubiquitous learning. Considering the discussed informational, interactional, and instructional aspects provides the theoretical foundation for this review. Thereby the informational aspect approaches the support and assistance of ubiquitous learning by enriching the experience with contextualised content and information. The interactional aspect then builds upon this conceptual idea focusing on novel interaction approaches that can facilitate the learning support. Finally the instructional aspect incorporates authentic and situated learning theories focusing on the knowledge construction within corresponding (supported) environments. Heading for a provisional conceptual framework, relevant research findings, models, design dimensions, and taxonomies have been examined. Based on the authors’ work on the use of ambient displays for learning proposed and explained by Börner, Kalz, and Specht (2011), the resulting framework allows the acquisition, channelling, as well as the delivery of information presented in context and framed in a learning process via ambient displays.

As one of the key concepts of informal learning support (Syvanen, Beale, Sharples, Ahonen, & Lonsdale, 2005) awareness is used as instrument to acquire information relevant (e.g. about tasks, concepts, or the workspace) for the learner within ubiquitous learning environments (Ogata, 2009). In order to present the acquired information in context a model introduced by Specht (2009) is utilised to carry on the conceptual framework. Within the model ambient information channels are used to deliver information and services but also to feed information back again. Thereby the information might be delivered using the receiver’s vision, hearing, haptic, olfaction or taste. In the presented framework ambient systems are then used for the delivery. Based on the comparison and discussion of existing ambient information systems by Pousman and Stasko (2006), the four design dimensions: information capacity, notification level, representational fidelity, and aesthetic emphasis are used to describe their design. The framing of the resulting ambient systems in a learning context complements the framework. Based on the revised taxonomy of educational objectives by Anderson and Krathwohl (2001) activities and objectives enabled by the systems are matched to the types of knowledge and the cognition processes involved. The taxonomy distinguishes factual, conceptual, procedural, and metacognitive knowledge and describes several consecutive cognitive process dimensions ranging from remembering over applying to creating. Incorporating this taxonomy, the framework results in the concept of ambient learning displays.

Beside depicting characteristics, design principles and guidelines, as well as classifying prototypical designs according to the presented conceptual design framework, the review also sheds light on the actual use of the covered ambient displays, their application context and addressed domains as well as the type of studies conducted, including the used methodologies.
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