Design Principles for Wearable Enhanced Embodied Learning of Movement

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Abstract. Human Computer Interaction (HCI) has seen increased interest in designing embodied experiences and interactions. This also includes the field of Wearable Enhanced Learning which marks the transition from the desktop age through the mobile age to the age of wearable, ubiquitous computing. Wearable enhanced learning relates to learning in a state of physical mobility supported by body-worn devices and sensors. While computer-mediated communication has been observed to enhance conscious experiences without self-reference leading to the sense of disembodiment, wearable technologies have the potential to enhance embodied experience with a strong self-reference. In fact, the affordances of wearable technologies to support embodied learning make wearable enhanced learning unique compared to other technology enhanced learning approaches. The concept of embodiment is based on the assumption that thoughts, feelings, and behaviours are grounded in movement and bodily interactions. Wearable Enhanced Embodied Learning is enabled by transmitting bodily information gathered by wearable sensors onto dynamic displays and making bodily information accessible to learners, in this way extending the learning experience. This paper draws on literature review in HCI and Embodiment research and collates a set of principles to inform the design of wearable enhanced embodied learning of movement.

Keywords: Wearable Enhanced Learning · Embodied learning · Learning design · Technology enhanced learning · Learning experience · Wearables

1 Introduction

"An overview of 20th century commercial products will show how design increasingly neglected our perceptual motor skills while burdening our cognitive abilities" [1: 8].

Embodiment establishes the body as the foundation of a human experience and calls for a higher appreciation of embodied experience. Embodiment can be defined as "an integrity of mind, body, and action accompanied by some awareness in the broader social context" [2: 27]. Wearable technologies has brought new possibilities to enhance embodied experience with a strong self-reference including (but not limited to) learning of movement (motor learning domain). This paper draws on literature review in HCI and Embodiment focused on the design of embodied (learning) experiences and

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collates a set of principles to inform the design of wearable enhanced embodied learning of movement, i.e. motor domain, beyond cognitive domain.

1.1 Wearable Enhanced Learning

Wearable Enhanced Learning (WELL) has emerged as one of the earmarks of the transition from the desktop age through the mobile age to the age of wearable, ubiquitous computing [3]. Wearable devices and sensors are body-worn and can be seamlessly integrated into daily activities and support learning while the learner is moving, e.g. running, exercising, interacting or engaging in everyday tasks [3]. With wearables allowing for the convergence of mobile technologies, body-worn and environmental sensors, augmented, virtual and mixed reality, internet of things and big data, wearable enhanced learning can be designed to provide rich contextual learning experiences. A number of research and development projects and publications have demonstrated how wearable computing can support learning of diverse groups, e.g. students, disabled and senior learners, and how different technologies, e.g. fitness trackers, smart clothing, smart glasses, can support individual learning processes, e.g. knowledge construction, inquiry-based learning, teamwork, worked-based learning and healthy ageing [4].

Wearable technologies have specific affordances which allow for new pedagogical approaches and new forms of learning, including embodied learning, and teaching, including embodied teaching [4, 31]. Some of the key affordances of wearable technologies include capturing data directly from the body of the learner, using the information from the context to support hands-free access to contextually relevant knowledge, provide in-situ contextual information and guidance, recording of information, communication streams integrated into daily routines, engaging immersive educational experience, unobtrusive and contextualised feedback, and allowing for greater efficiencies in learning [4, 5]. Embodied affordances of wearable technologies include the capability to enable the user to see through the eyes of a virtual body (first-person view) and the virtual body to react based on user actions, the capability to allow the user to act upon represented entities such as artefacts in augmented, virtual and mixed reality environments, which can be picked up, examined, manipulated, and rearranged by the user [6], and the capability to enhance embodied learning experience embedded or immersed in virtual environments [7]. In fact, the affordances of wearable technologies which support embodied learning make wearable enhanced learning unique compared to other technology enhanced learning approaches.

1.2 Embodied Learning

Human Computer Interaction (HCI) has only recently seen an increased interest in the design embodied user experiences. The complexity of human movement may have been one of the reasons accounting for the previous lack of focus on embodied experience in HCI [8]. A number of authors have pointed out the contemporary shift from technology-based to anthropological perspective in design in general as well as a shift away from technology-driven approach in embodied learning. Technology-driven approach has determined the design of embodied experiences by technological abilities, while human-centred, anthropological approaches have focused on human factors in designing computing systems in general and strived towards designing intuitive and engaging wearable applications in particular [1, 8]. For example, [10] have described a conceptual framework and architecture for wearable enhanced embodied learning in context of supporting healthy ageing through physical exercises embedded in a Massive Open Online Learning (MOOC) settings with integrated fitness trackers to ensure sustained physical activity through gamified and social learning in a community of senior learners. [11] described a technology-based framework to support embodied mathematics educational scavenger hunt games using wearable devices such as smart garments with Arduino-lilypads devices sewn on sweatshirts, smart watches and smart phones strapped to the forearms of the learners allowing learners to move freely and search for objects hidden in a physical space. [12] proposed a framework for creating embodied learning environments for STEAM (Science, Technology, Engineering, Math, Art and Design) domains. [13] examined the potential of smart textiles as part of an Internet of Things (IoT) ecosystem, to support embodied learning experiences. Publications on wearable enhanced embodied learning have built on a diversity of concepts of embodiment. Embodiment can be defined as the recognition of movement as part of the self [27]. The different perspectives on embodiment in designing learning experiences are outlined below.

Disembodiment. A number of authors have addressed the phenomenon of disembodiment in traditional pedagogies including technology-enhanced learning. For example, [13] views learning with wearable technologies as a welcome challenge to traditional pedagogies which presume learning as a “disembodied” activity. [14] point out that traditional computer-mediated communication may lead to disembodiment through enhancement of experiences without self-reference. Disembodiment can be experienced as a disconnection of thought and body in a virtual environment [15]. Wearable technologies, on the contrary, may enhance embodied experience, e.g. through gathering, transmitting and utilising bodily information for learning. The distinction between disembodied and embodied learning is considered by some authors as imposed by traditional curriculum designs and teaching methods which presuppose the learner as a passive recipient of knowledge [13].

Embodied Cognition. A number of authors build on the concept of embodied cognition by Merleau-Ponty and a perspective on thinking as an embodied event [16]. Human cognition is embodied in the sense of being interwoven with the body, i.e. perception, emotion and experiences are always embodied [13, 16] view embodied cognition as a natural view on learning and point out that traditional learning technologies, compared to wearable technologies, have not been able to support embodied cognition. Authors building on the concept of embodied cognition perceive thoughts, feelings and behaviours as grounded in bodily interaction with the environment and focus on designing for bodily interaction with the environment [17, 18].

Embodied Interaction. Embodied interaction is a perspective on the relationship between people and systems and asks the questions of how a system should be developed, explored and instantiated [20]. Embodied interaction can be defined as an inter-subjective and bodily activity [20]. Embodied interaction is implicitly embedded in wearable systems, as any system is designed to support some interactions and inhibit others [20]. Embodied interaction is applied as an approach by [1] to design a smart, proprioceptive wearable in context of healthcare. Authors building on the concept of embodied technologies emphasise that meaning is created during physical interactions and these interactions can be supported by wearable technologies [1].

Embodied Learning. Embodied learning can be defined as learning which uses physicality and tangible interactions of learners and with physical objects rather than with abstract concepts [19]. An embodied pedagogy therefore encompasses embodied learning and embodied teaching, with physical interactions between teachers and students playing the key role in the learning process [19]. Embodied learning involves the creation, manipulation, and sharing of meaning through engaged interaction with artefacts [20]. Activity Theory has been used as a theoretical framework for embodied learning, e.g. by [11, 21]. Embodied learning has been considered as an alternative to prevailing technological and cyber learning models which focus on the acquisition of information and neglect the diverse modes of learning including physical interactions with the real world [22]. Interactions with the real world require learners to acknowledge the complexity and ambiguity of human experience. [22] argues that an embodied learning approach re-introduces learners to the joy and depth of personal learning experience through physical presence and engagement.

Embodied Training. Embodied trainings aim at developing bodily memory aids to positively influence the learning process through body experiences [29]. Embodied trainings have been successfully applied in learning therapies for persons with reading and spelling problems. For example, the "syllable swinging" method, which requires learners to swing or dance the speech rhythm of words with their bodies, has shown improvements in reading and spelling through embodied syllable analysis. To support embodied training by wearable technologies, accelerometers can be used to recognise body interactions such as movements or gestures. The aim of wearable enhanced, embodied learning design described by [29] is to maintain the learners' learning curve, motivation and an enjoyable learning experience over a longer period of time.

Embodied Knowledge. Building on Bourdieu's theory of practice, embodied knowledge has been viewed as part of the habitus [9]. The development of embodied knowledge requires a transformation in strength, flexibility, mobility, and is expressed in transformations of kinaesthetic styles, daily habits, social interactions, personal practices and perceptions of the world [9]. These elements constitute the habitus, which has been defined as a constellation of cognitive structures implemented as practical knowledge to act in the social world through everyday movements of the body [9]. Habitus serves as an "internal compass" to guide the practices of a person and is expressed in the way a person stands, walks, talks or moves [9]. Embodied learning can be also viewed as a mode of non-discursive knowledge acquisition, wich results in the shifts the sensory experience and habits of everyday life [9]. It has been argued that the body registers fundamental categories of a world view acquired through education and socialisation, and expresses them in the form of reactions, gestures or postures [23]. Since embodied knowledge is obtained on an intuitive level, the vocabulary to express embodied experiences and the verbalisation of bodily experiences is necessary to bring embodied knowledge to a conscious level [8]. Designing for the development of embodied knowledge, e.g. through new movements, focus on technological mediation of the learning process [27].

2 Research Methods

The research approach of this paper follows the systemic design approach [24], applied to the domain of designing for wearable enhanced embodied learning. This type of design may be considered as a design of higher order systems encompassing multiple (technical and non-technical) subsystems [24]. Systemic design approach is used to describe, recommend and reconfigure complex systems, such wearable enhanced learning. The variety of concepts, perspectives and frameworks applied to designing embodied learning may be challenging for teams and projects working on prototypes and solutions in the area of wearable enhanced learning. The view on systems as networks of interconnected functions designed to achieve intended outcomes [24], calls for multi-/interdisciplinary approach to design learning experiences. Therefore, systemic design can give an orientation for advancing design practices for complex, multi-system and multi-stakeholder services [24].

The research method applied in this paper is a literature review based on secondary data from scientific and research publications [25] and aims at eliciting a set of design principles for wearable enhanced embodied learning through an iterative analysis process. The aim of the literature review presented in this paper is to enhance the understanding of design principles applied to designing embodied learning of and through movement in order to inform the design practice. The following research question has guided the literature review: *What are the key design principles applied for designing wearable enhanced embodied learning of movement?*

Literature sources were drawn from the relevant fields, including HCI, Embodiment, Technology Enhanced Learning, and included a wide range of publications published in scientific journals, conference and workshop proceedings and project reports. The search for relevant sources for literature review was based on a search string related to research studies and designs of embodied, wearable enhanced learning and included such key words as "wearable learning", "embodied learning" and "wearable embodied learning". Google Scholar, ResearchGate and ScienceDirect were the primary search engines and databases used to find and select relevant literature. The selection of sources focused on academic publications including empirical studies and conceptual papers describing designs of wearable enhanced and/or embodied learning, in order to allow for a broad coverage of the design practices in various applications fields. The selection of publications for the review was based on the thematic relevance and quality criteria for appraisal of academic publications [25]. Table 1 lists publications selected for the synthesis of design principles for wearable enhanced embodied learning of movement.

Table 1. Literature selected for the synthesis of design principles

Author (Year)	Context of analysis
Moen (2007)	Modern dance
Wilde (2008)	Performance
Downey (2010)	Capoeira
Hallam et al. (2014)	Ballet
Overhage (2015)	Parkinson's Disease
Mencarini et al. (2016)	Learning to climb
Hassib et al. (2016)	Biosensing
Smyrnaiou et al. (2016)	Learning Science through Theatre
Holz et al. (2017)	Reading and speaking

3 Design Principles

The findings from the literature review have been extracted as principles for designing wearable enhanced embodied learning of movement, focusing on the motor domain as opposed to the cognitive and affective domains. Extracted design practices and extracted design principles are summarised below.

Human-Centred, Kinaesthetic Perspective. A number of authors emphasise that embodied interaction should be designed not from a technological but from a human-centred and kinaesthetic point of view. For example [8], leaning on the methods and theories of modern dance described five aspects of human movement which can serve as orientation and aims for the design of embodied learning experiences: (a) *kinaesthetic awareness,* i.e. developing awareness of differences in movements and of own limitations and possibilities, aims at developing sensibility for knowledge within the body and trust in the bodily memory; (b) *phrasing* as a way of grouping movements, aims at recognising rhythms and phrases within the movements; (c) *forming* in the sense of creating forms or patterns to create meaning, aims at organising movements so that they make sense to the mover and others; (d) *relating,* i.e. relating to others' movement, aims at learning to know own movement patterns and expressions and at developing kinaesthetic empathy, e.g. when working in groups; (e) *abstracting,* i.e. abstracting the essence of a movement aims to explore and manipulate movements to find out what a given movement is about.

Whole-Body Interaction Design. Numerous authors emphasise the importance of the whole-body interaction design. For example, the Kinaesthetic Movement Interaction (KMI) approach, which focuses on whole body interaction design and the development of a kinaesthetic ability to sense and experience own movements, has been applied in the design of a wearable enhanced learning system by [8]. KMI calls for the design of free and expressive movement aimed at individual communication and/or interaction with the system [8]. It can be differentiated from partial body movement such as hand movement and the design of haptic interfaces and from full-body applications depending on screen-based output, such as video games, which tends to lock the user to a certain interaction direction, possibly limiting the variety of movements [8].

The interaction design principles for whole-body interaction design include: (a) *personal interaction space*: design of a three dimensional, user-defined interaction space with tangible interactions near the body and independency of visual or audio output; (b) *natural movements*: design of support free, explorative movements based on individual preferences; (c) *movement impulses*: design of movement-triggers to generate and stimulate movement, without defining “correct” or “incorrect” uses and abstaining from any “punishments”; (e) *movement as impression and expression*: design for a wide range of spontaneous movements, recognition of all kinds of movements and enhancement of the movement dialogue; (f) *movement as fun*: design for movement for the sake of movement [8]. These design principles can be used to create engaging, intuitive and enjoyable embodied interaction experiences. An example design is provided by [8], who designed a movement-based interaction prototype, called *BodyBug*, an electronic box on a wire which can be worn and used in personalised ways, e.g. as a piece of jewellery, dance partner, moving pet, computer game, electronic yo-yo or hula-hoop. Another examples is provided by [26] who described the design of a wearable musical interface for self-expression and body-centric experience called *hipDisk* and explored how the wearers of the *hipDisk* learned to use the wearable interface through own bodies. One of the insights from related research is that wearable interfaces enable to move beyond the reliance on linguistic support towards more open, dynamic and fluid forms of expression [26]. Example of embodied training by [29] and [30] show how physical exercises can support learners with reading and spelling difficulties through the use of whole-body movements and gestures as part of the learning therapy. [29] have developed a set of embodied training games called *Prosodiya* enhanced by wearable technologies such as fitness trackers to support learners with reading and spelling problems in developing the awareness of rhythmic structures of speech such as syllable emphasis. The swing movements of learners are recorded with accelerometers and gesture recognition, extracted and classified as patterns to enable automatic evaluation of learner movements. An integrated learner model models the knowledge level of the learners and individually adapts the type of exercise and the difficulty level during the course of the embodied training. [29] indicate a number of design principles for embodied training, e.g. systems must be adapted to the needs and behaviour of individual learners, the correct execution of gestures must be trained in detail, e.g. via a learning game.

Social Context of Movement. A number of authors emphasise the importance of including the social context of movement in design of embodied experiences. For example, the motivation to move may be closely linked to social settings which define which movements are appropriate in a given context [8]. Designs should therefore consider appropriate movement-triggers which include not only visual (e.g. other people’s movements and actions) and audio cues (e.g. music and sound), but also social aspects (e.g. social acceptance of movements in a specific context) [8]. An aspect related to the social context of movement is self-confidence, which can be described in relation to the fears and experiences of clumsiness and embarrassment resulting from own (lack of) movement, the level of movement skills and perceived or visible differences between skilled and less skilled movers [8]. On the design level, the negative experiences related to movement (e.g. fears) can be addressed by enhancing learning about own and others' movement patterns and understanding intentions to move in a specific way [8]. Designs should also focus on creating new socially accepted movements and encouraging user to perform these new movements [8]. A relevant design principle in this context is a sustained focus on how a movement should feel, rather than which (ideal) movement should be performed [8]. The social context of movement can be also included by the application of the apprenticeship approach, which allows learners to develop a specific lifestyle which is expressed as an attitude used to confront everyday challenges [9].

Meaningful Learning. The social context of movement is related to the perceived meaningfulness of a bodily activity and in consequence of the meaningfulness of learning. One of the design methods to enhance the perception of actions as meaningful is to convert these actions into first-person simulations [9]. Another design method is to enhance apprenticeship learning, which allows practitioners to develop a "sense of the game" for any system of bodily movements [9]. The apprenticeship approach to embodied learning through observing and imitating an expert enhances the acquisition of experiential knowledge and a specific lifestyle which is expressed in an attitude used to confront everyday challenges [9]. Meaningful learning can be also enhanced by means of a collaborative learning design. Based on constructivist principles and embedded in the approach to learning through theatrical plays, [34] consider embodied learning from the perspective of the development of skills such as creativity and critical thinking, active engagement with scientific topics and interdisciplinary connection of science with art. [34] recommend to design for learner cooperation, e.g. in context of meaning making of scientific concepts.

Learning Through Mimesis and Imitation. Drawing the concept of habitus by Bourdieu, the acquisition of embodied practice through bodily training can be seen as learning through mimesis, which (contrary to imitation) is related to identification and is acquired without intention or awareness, resulting in implicit knowledge (as opposed to explicit, declarative knowledge) [9]. Practical mimesis allows a set of corporeal schemes to be passed directly from practice to practice in the process of embodied socialisation [9]. Referring to Tomasello's perspective on imitation ("children are imitation machines"), [9] explores how imitation can be included in the embodied learning and teaching practice. For example, the correspondence problem, which emerges with matching a visual image of someone moving in a particular way with own motor control, can be addressed in design by a number of techniques such as scaffolding imitation, slowing down the movement, parsing the technique into smaller units, offering verbal help, physically adjusting student bodies, abstracting parts of a technique, creating movement drills to teach basic components [9].

Reducing Complexity. A number of authors argue for the simplification in the design of embodied experience. For example, [27] describe the design of a wearable garment in context of a ballet technique taught to adult beginners embedded in a phenomenological framework. A wearable, smart garment worn by an instructor and incorporating visual feedback is proposed as a supplement to the teacher-student relationship [27]. Embodied experience is enhanced through mirrored synchronous movements and management of chunking aimed at decreasing the complexity of the visual-motor sequencing of movement [27]. The system proposed by [27] lights up instructor's limbs, breaks basic movements down into starting and stopping positions and allows the student to focus on the key frames to see a movement as a chunk. Key design principles included visual simplification, using key frames to chunk movement, highlight important points and to establish dominant positions of movement, allowing learners to start and stop in correct moments and to measure learners performance against the ability to follow the instructor [27].

Augmented Communication. Design for wearable enhanced embodied learning should provide the involved actors (e.g. learners, teachers, peers) with augmented communication [31]. In their design of wearable enhanced learning in context of climbing, [31] consider augmented communication as a means to address both motor and emotional aspects of learning, for example designing for support of wearable devices when negative emotions appear during the learning process. Especially beginners may experience negative emotions, such as discomfort, clumsiness, stress, fear, panic. Negative emotions are often caused by the lack of motors skills, the novelty of the movement and the abandonment of the usual motor schemes [31]. With communication playing an important role in teaching, including the provision of coping strategies in case of negative emotions, an augmented communicative support is of particular relevance. Designing for augmented communication has to be based on clear understanding of the different forms of communication used in a given learning/teaching setting. For example, [31] observed the interpersonal communication in context of learning how to climb and arranged the different forms of communication along two dimensions ranging from functionality to emotionality, and from abstraction to concreteness, to define the design space for wearables as communication tools.

Design for Wellbeing. Design for wellbeing aims at empowering users, especially enabling people with disabilities to "influence their living conditions through active participation in the design of the assistive devices they use daily" [1, 28]. Embedded in the context of wearable rehabilitation technologies, [1] describes a prototype for proprioceptive wearable technology developed following the principles of design for well-being. The prototype which can assist in improving the quality of life for patients of Parkinson's Disease, which includes postural instability and equilibrium problems. The proposed prototype is a system monitoring the upper body posture and providing bodily feedback to guide the patient towards the desired posture [1]. The design of wearable systems for well-being focuses on improving the quality of life by helping users to make a transformation from an actual state to a desired state, without making users feel weak, incapable or invalid, e.g. by attracting attention to the disabilities [1]. Further design principles include comfort in wearing during every day activities (wearability) and the focus on look and feel (aesthetics) as important factors for the perception of quality of life [1]. The approach taken by [1] is a design inspired by gemstones and jewellery, which aims to achieve an unobtrusive yet aesthetic appeal to communicate a healthy lifestyle. This design approach allows to shift the focus from designing a medical device to designing an appealing high-tech, fashion accessory.

Acquiring, Sharing and Receiving Data. Design for wearable enhanced embodied learning should also consider user needs for acquiring, sharing and receiving data including bio-data [33]. A number of design have focused on exploiting wearables to extract bodily information to provide value for users [33]. [33] have conducted research to identify user needs related to the utility, connectivity, and feedback of the biometric and affective wearables. The results show that data most interesting for the users include learning about own *cognitive state,* especially in stressful situations such as conflicts and knowing about own high mental concentration peaks; *physiological data* such as heart rate, blood pressure, body temperature, breathing rate; and *emotional information*, including for happiness and anger [33]. Designs should account for these different types of information and provide diverse modalities of feedback, e.g. subtle, tactile, haptic, olfactory, air-based feedback [33]. Designs for embodied learning should be based on a deeper understanding of the context of sharing data, e.g. sharing of data with negative valence for relief and support from others, as well as consider ways of encouraging mutual sharing of information [33].

4 Limitations and Future Work

The literature review presented in this paper has a number of limitations. The selection of relevant literature is preliminary and limited in scope. The review has been conducted with focus on learning of and though movement and the selected literature is limited to motor learning or learning of skills in the motor domain. Thus, this literature review is not exhaustive and provides only a few examples of design practices and principles in context of wearable enhanced embodied learning. Future work should include a more comprehensive analysis, possibly a meta-study, with a broader focus and encompassing learning in psychomotor, cognitive and affective domains. Design principles for wearable enhanced embodied learning are expected to inspire and support designers in focusing on relevant aspects of embodiment in learning.

5 Conclusion

Designing for wearable enhanced embodied learning raises a number of design challenges, e.g. how to design for learning of and though movement, what kind of support the technology could provide, and how to balance individual user needs with constraints of available technologies. The literature review presented in this paper shows that the systemic design of wearable enhanced embodied learning draws on a number of approaches including interaction design, service design, experience design, learning design, information and visual design. The analysis of the current literature revealed that a substantial body of work already exists in the area of motor and cognitive learning, while the affective domain tends to be underrepresented in the current research and design practice. Based on the design principles described in this paper, further design considerations related to the design of wearable enhanced embodied learning can combine these design principles with taxonomies of learning objectives in the motor domain, such as the taxonomy by [32], which can be used to scaffold learning experiences at different levels of complexity. To conclude, designs for wearable enhanced embodied learning should consider a number of design principles including a human-centred and kinaesthetic perspective, consider whole body interaction design (as opposed to the focus on selected parts of the body), analyse and consider the social context of movement (e.g. which movements are socially acceptable and/or how to make new movements socially acceptable), enhancing meaningful learning (e.g. through the apprenticeship approach), enhance learning through mimesis and imitation, strive for reducing complexity (e.g. through chunking of movement and application of key frames), design for augmented communication (e.g. to support learners in coping with negative emotions), design for wellbeing (e.g. focusing on improving the quality of life not only though functional features but also on the level of aesthetic design).

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