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Narrowing the Gap of Cognitive and Physical Ergonomics in DHM Through Embodied Tool Use

Jessica LINDBLOM[a,1], Ari KOLBEINSSON[b] and Peter THORVALD[b]
[a] *University of Skövde, School of Informatics, 541 28 Skövde, Sweden*
[b] *University of Skövde, School of Engineering Science, 541 28 Skövde, Sweden*

Abstract. The fields of human factors and ergonomics are systemic by nature, focusing on studying complex interaction between human and technology. However, the levels of explanation have resulted in physical or cognitive ergonomics. Modern understandings of human cognition and technology-mediated interaction, such as embodied cognition, activity theory and user experience (UX) is used as a frame of reference to analyze and illustrate the usage of a digital human modeling (DHM) tool in practice. We try to narrow the gap between physical and cognitive ergonomics through embodied tool use. An identified core problem is to understand how 2D devices should properly interact within 3D objects and manikins in DHM. Some future work is presented, which could be beneficial for DHM, and, in the long run, promote a positive UX at work for various end-users of DHM tools in general.

Keywords. Ergonomics, Embodied Tool Use, DHM, User Experience

1. Introduction

The fields of human factors and ergonomics (HF/E) are systemic by nature, focusing on studying complex interaction between human and technology [1-3]. In spite of this, the common practice in HF/E is to split the human into 'neck up' and 'neck down', which has resulted in cognitive ergonomics and physical ergonomics [2]. Although this division makes it easier to study certain aspects of ergonomics, it runs the risk of not portraying the whole picture of the embodied human being situated in the world of technology [4]. Indeed, it should be acknowledged that both cognitive and physical ergonomics are dominant and well justified fields that have been successfully for a long time, but where the common practice is to mainly focus on performance-related aspects [4, 5]. However, it has been argued that one current challenge of HF/E is that that they are not aligned with the more modern approaches for studying human cognition and technology-mediated interaction, including embodied interaction and cognition, activity theory (AT), and user experience (UX) [4, 5]. Briefly stated, embodied cognition emphasizes that traditional cognitive science as well as HF/E has largely ignored the role and relevance of the lived body in human cognition, viewing the body more as a passive input and output device. Embodied cognition, on the other hand, argues that human cognition emerges via close couplings of brain, body and environment, stressing the active process

[1] Corresponding Author, Email: jessica.lindblom@his.se.

of bringing fourth the experience of being situated within the material and social world [6-14].

Recently, several initiatives have been performed to include embodied interaction and cognition into the equation of HF/E [1-5, 15]. One initiative is to include some aspects of embodied cognitive actions into digital human modeling (DHM) that merely models physical aspects of human bodies, focusing on anthropometry and physical strain on the body, which is also the case with most current DHM tools [2, 16, 17]. Another initiative is to study the use of DHM tools in practice from an embodied interaction and UX perspective. To the best of our knowledge, in the DHM domain, the combination of embodied cognition and interaction, tool use, and UX have received limited attention in practice and in theory/research. In addition, UX lacks proper theoretical frameworks, and we also want to contribute to this challenge, suggesting that embodied tool use would fit as hand in glove for addressing UX aspects within DHM.

In this paper, the focus is on the latter initiative, and the component of discussion is the digital DHM software called IPS IMMA [18]. This work is motivated from two overlapping perspectives. On the one hand, Dourish [14, 19] quests to investigate and analyze how human-technology interaction is embodied, studying how the visibility and availability of the interface is designed so it affords for a wider range of relevant engagements and embodied interactions. On the other hand, Grundgeiger et al. [20] argue that considering and improving users' experience (UX) is one of the fundamental aims of the ISO standards on human factors and human–computer interaction [21]. They point out that embodied interaction and cognition as well as tool use is a feasible approach for considering complementary views on *interaction* that cultivates a positive UX [20].

The next section briefly presents and discusses the underlying theoretical and methodological foundation for embodied tool use, and its relationship to UX. The discussion is illustrated with an illustrative example of the DHM tool IMMA from an end-user's perspective, focusing on activities and relevant embodied engagements that have an impact on UX. The paper ends with a short discussion.

2. Embodied Cognition and UX as Embodied Experience

The mainstream study of human cognition has since the inception of cognitive science in the mid-1950s mainly focused on studying individual's internal mental representations in form of symbol manipulation inside the head [6-14]. Cognition is viewed as information-processing of these more or less explicit internal symbolic representations, being the "internal content" of the external world, following the so-called computer metaphor of mind, and almost nothing outside "the skull" is taken into account. It presents a centralized view of cognition with the body only serving as some kind of input and output device, i.e. a physical interface between an internal program (cognitive processes) and an external world [6-14]. It should be pointed out that the information-processing view still dominates the fields of HF/E as well as traditional cognitive science.

Starting in the late 1970s, several lines of criticism arose about the fundamental assumptions of the computer metaphor of mind. It was argued, for example, that bodily and neurological aspects should be taken into account more seriously in explaining cognition. Another much discussed issue were if cognition should rely that much on mental representations and how the connection between the external world and the internal representations was realized. Some researcher started to study cognition as it unfolded in everyday life together with other people and various artefacts. The so-called 'turn to the wild' approach in cognitive science and human-computer interaction (HCI) questioned the nature of human cognition and how it should be studied [6-14, 22-23].

2.1. Various stances of embodied cognition

Since the 1980s, the cognitive sciences have (re-)introduced more elaborate views on cognition that are commonly referred to as dynamical, embodied, extended, distributed, and situated theories of cognition. A body of research now provides compelling empirical evidence and theoretical explanations that the human mind is the result of human's bodily interactions with a social and material environment within a broader unit of analysis "beyond the brain/skull" [6-14, 22-23]. Several characterizations of embodied cognition exist (see [10] for a review). Here we describe embodied cognition from three complementary stances, as a way to simplify, ranging from *sensori-motorness* and *situatedness* to *embeddedness*.

First, the *sensori-motorness* of embodied cognition commonly refers to structural couplings that usually are considered the core of embodied cognition [6], meaning the action-perceptions loops that span the agent-environment interaction unit [7, 9]. The claim is that knowledge and cognition is the result of an active and ongoing interpretation that emerges from biologically embodied structures of understanding, which makes it possible for us to "make sense" of our human being in the world [6, 9-13]. Most attention is placed on how the individual agent's physical body is mutually sensori-motor coupled to the material and social world, and how the agent continuously perceives feedback on its actions, which affects what is being perceived, and then the perceptions affect the actions, etc. A key aspect in embodied cognition is that the same dynamical processes which emerge through action-perception loops are also used in more advanced forms of cognition [6, 9-13]. The underlying assumption is that the acting and perceiving body as a whole organism is able to move and act in the world, manipulate objects, communicate, where these sensorimotor couplings are the pillar for human cognition. During the course of development and learning, an increasing ability to accomplish more advanced action-perception loops emerge via the growing ability to coordinate the lived body in relation to environmental constraints. As a result, stable patterns of behavior through which the body 'gets a grip' on the surroundings emerge [9, 11-12]. This implies that different kinds of bodies (morphology and structure) result in different kinds of cognition.

Second, the above stance of sensori-motorness enables us to be *situated in* the world, emphasizing the 'here and now' of a certain situation. This stance expands the unit of analysis to also consider what kind of social and material environment the embodied agent is situated within, i.e. to get a grasp of what is going on [7, 10-13]. This aspect of embodied cognition puts the sensorimotor coordination into a meaningful context, very often a social and material one [8-9]. Here the human needs to coordinate and collaborate her actions with other people and artefacts. A central focus is to describe and investigate what happens when cognition unfolds 'in the wild', studying how real humans enact their actions, and lot of ethnographic work has been performed that consider how complex patterns of collaboration emerge via distribution of cognitive processes between various kind of artefacts like calendars, cameras, pens, hammers, and other kinds of technology, and other humans, emphasizing the importance of studying practice as it occurs in real situations [11, 13, 15, 22-23]. It is highlighted that the social dimension of situatedness, i.e. other peers and caregivers, bootstrap the embodied agent into its particular niche and provide scaffolds for actions [22]. Moreover, this aspect also stresses that the cognitive system as a whole is able to perform cognitive phenomena at a systems level that cannot be explained by an individual person alone. Example of this is the distributed cognition approach by Hutchins [23] where ship navigation is considered as a distributed phenomenon spanning several people, the tools and artefacts used, which considers the possibilities and constraints that affect the work practice of navigation as a cognitively distributed phenomenon.

The last stance stresses the *socio-cultural embeddedness* of embodied cognition, which refers to the social and cultural norms and values that shape the individual agent's development into being a full-blown member of society. Much focus here is on learning and developmental processes of children and adults, including acquiring various competences and skills as well as language and other external symbol systems. The research is dominated by a focus on social and communicative aspects of being socially embodied and socially situated in the socio-cultural world. Another strand of research is focusing on the use of tools as well as the historical development of various kind of tools in order to enhance cognitive abilities, studying the material engagement of tools both for the individual, but also in society [22-23]. During the years, it has been stressed that embodied cognition is relational, i.e., although an act or gesture is carried out individually, the act itself is social in nature, and the human brain is considered as a mediating social organ [10-13]. When it comes to human language, it is argued that language has roots in sensori-motorness and many abstract concepts are metaphors of concrete actions; i.e., the expressions "grasping an idea" or "life is a journey" [10-13, 24].

Although we have disentangled various stances of embodied cognition, they should not be considered as distinct levels that could be investigated in isolation. These stances of embodied cognition are inseparably intertwined, as Johnson [24, p.155] phrases it "*in order to have human meaning, you need a human brain, operating in a living human body, continually interacting with a human environment that is at once physical, social, and cultural. Take away one of these three dimensions, and you lose the possibility of meaning*". This way of considering human cognition also have methodological implications. Propose that the unit of analysis for HF/E and DHM research should include all aspects of embodied cognition, future research needs to consider some critical reflections on how to conduct and to what extent to cover this broader scope on the embodied human mind. This argument holds both when implementing the digital twin manikins used for simulations in the DHM tools as well as when end-users use the DHM tools to make risk assessments digitally.

2.2. Embodied interaction and UX

When it comes to applying embodied cognition to human-technology interaction and HCI, the *embodied interaction* approach received increased attention when the phenomenological dimension of HCI was stressed in the late 1980s. The previous mentioned 'turn to the wild' in studying cognition, particularly the seminal work by Suchman [22] on situated actions when interacting with a photocopier machine and Hutchins's [23] work on distributed cognition in ship navigation, focuses primarily on the body as being situated and embedded in a particular context, not considering the sensori-motorness of embodiment, but include interaction with various kinds of technology. Building on these pillars, Dourish [14] claims that embodied interaction offers a new model or framework of interaction, which is suggested fundamental for the future development of human-technology interaction in the early 2000s. He stresses the need to develop more plausible interactive modes than the traditional graphical user interfaces, interactive modes which are physically and socially more similar to how tasks are performed in the real world. Dourish [14] emphasizes three elements in his work, in which embodiment is the key element in the analysis and design of interactive technology. He characterizes embodiment as meaning "grounded in everyday, mundane experience" [14, p. 125]. Another element is the focus on practice, which he describes as "everyday engagement with the world directed towards the accomplishment of practical tasks" [p. 125]. The third element is embodied practice that is the source of meaning: "we find the world meaningful primarily with respect to the ways in which we act within it" [p. 125].

Dourish's work [14-19] has been very influential in HCI, but he has been criticized for the lack of the actual body in his work. He does not merely consider physical embodiment, i.e. the physical instantiation of our living body. Instead, he focuses on the *participative status* of embodiment when describing interaction as an embodied phenomenon, which takes place in the real material and social world that affords form, substance and meaning to the interaction. Dourish argues that interaction should still be considered embodied, although there is no concrete contact between the human fingers and the computer mouse, because the interaction unfolds within a setting of specific knowledge, circumstances, and 'know how' that provides meaning and value. This 'background' should not be considered as a problem space to cope with. Instead, the background provides an essential and constitute component of the activity, we do not interact with an environment, were are *situated within* an environment.

Dourish's work [14-19] resulted in a focus on the aspects of social and tangible computing that contrasted the traditional desktop computing, as new modes of interacting with technology. This way of working resulted in a major misreading, namely that embodied interaction is only related to tangible computing, distinguishing between modes of interaction that are either 'embodied' or 'dis-embodied', explaining that embodiment cannot be 'turned off'. On the contrary, his intention was to compare and contrast between tangible computing and other forms of interactivity, suggesting that they should be analyze from the same point of view. This means that traditional desktop computing using mouse and keyboard is also embodied interaction [14, 19].

A lot of empirical studies of situated and embodied cognition has been conducted 'in the wild', which indicates that embodiment and situatedness requires a naturalistic environment to emerge. However, Rooksby [25] emphasizes that the 'in-the-wild' metaphor is not synonymous with applied research conducted outside the laboratory. He explains that Suchman's [22] work on situated action has been used as the ultimate ticket for leaving the contrived laboratory settings when studying cognition, is a total misconception of her work. Instead, Suchman introduced a new analytic model to study cognition where the relevant actions are driven by its context, reframing the issue of *interaction* per se in terms of sense-making practices [25]. Humans' sense-making practices may afford fewer degrees of freedom in a contrived laboratory setting, but still it is irrevocably a *situated activity* whether or not it is studied in 'the wild' or 'the laboratory'. It is quite ironic that Suchman's own work [23] was conducted in a laboratory setting. Consequently, there are no such claims that there are circumstances where human cognition is considered "dis-embodied" or "non-situated". Humans do not "think" differently in the laboratory, but the access to social and material scaffolds may be reduced. This aspect has been misinterpreted as "any human action that occurs in a laboratory is itself artificial" [25, p. 12]. Rooksby [25] argues that it is not a choice between 'artificial' or 'natural', rather it is possible to perform studies of embodied and situated activity that spans both the lab and the field [9]. To summarize, Grundgeiger et al. [20] claim that considering interaction as embodied, the intentionality of the user is emphasized, which is mediated via the structural couplings with the technical devices and the context of use (i.e., the social and material environment that the user and the tolls/devices are embedded within).

2.3. UX as embodied tool use

Turning to the UX perspective, some criticism has been raised towards the embodied interaction approach for being too vague in informing design and development of technology. More recently, Van Dijk et al. [26] present several approaches and principles for how to design for embodied engagements for a person's being-situated-in-the-hybrid world of digital and real world interaction. It is pointed out that describing cognition as embodied interaction implies that user's embodied actions constitute underlying intentions and motives, which means that these actions are fundamentally emotive and intentional [26]. Grundgeiger et al. [20] suggest several reasons why users' experience should be considered when interacting with technology in the workplace, and DHM tolls are no exception. Grundgeiger et al. [20] emphasize that *interaction* per se is as an ongoing experience, implying that interaction with technology always has an associated UX, which is ubiquitously present whether or not it is explicitly addressed by researchers or designers [20]. The UX does not only occur during interaction, but also the time before and after usage [21]. Moreover, it is not enough to ensure pragmatic qualities, e.g., error reduction, effective performance, and reduced cognitive load when humans are interacting with technology such as DHM tools in the workplace. Much more emphasis needs to be focused on hedonic qualities, e.g., satisfying humans' motives and psychological needs, including expectations, emotions, and wellbeing [5, 26-28].

Grundgeiger et al. [20] also consider interaction as tool use, and this claim is grounded in Activity theory (AT). AT [27-29] focuses on human tool use to manipulate, perceive and interact with the world in order to fulfill activities. What an activity is could be understood on an intuitive level, but in AT, the notion of "activity" is central, being characterized as a purposeful, transformative, and developing interaction between users and the world [27]. Hence, its focus is on understanding and describing human activity in context, i.e., stressing that the human mind can only be understood in the context of human interaction with the world, and that this interaction, i.e., *activity*, is socially and culturally determined [27-29]. This socio-cultural embeddedness is stressed by the co-operative nature of human activity. Hence, every *activity* consists of a set of intentionally performed goal-directed actions that could be described as an interaction between a user and an environment, e.g., professional ergonomists' workplace, with the aim of transforming the workplace through the use of mediating artefacts like DHM tools and additional artefacts. In so doing, individual users have to be perceived active actors who intentionally engage in tool-mediated interaction process [20, 27-29]. The tool mediates the relationship between the users and the environment to fulfill the activity, where both the users and the environment are affected by the mediating tool. The DHM tool could be considered as a mediating tool that foster new ways of working practice as well as the users is affected by learning additional functionality of the DHM tool. It should be stressed that a DHM tool is typically not an object of activity but rather a *mediating* tool, because the object of activity is the workplace and settings in which the DHM tool is used.

The three-level *hierarchical structure of activity* is the backbone of AT. The structure frames the activity into the levels of activity, action, and operation, which are related to motive, goal and condition, respectively [27-29]. The top layer is the *activity* itself, which is undertaken in order to fulfil some motive that corresponds to certain needs [27-29]. *Actions* refer to what must be done, and are conscious processes subordinated to activities, and they are directed at specific goals. These goals could be decomposed to sub-goals, sub-sub-goals, etc. Actions are similar to what usually is denoted as tasks within the HF/E literature. Actions are implemented through lower-level units called *operations* that describe how it can be done, defined by the prevailing conditions or circumstances under which they are carried out. Operations are routine processes that do not have their own goals, instead they provide an adjustment of actions to the ongoing situations. Operations are oriented toward the conditions under which the subject is trying to reach a goal, and humans are commonly not fully aware of their operations. Operations could be the result of an automatization of prior conscious actions, which over time may be transformed into a routine operation that may not require conscious control.

By combining the view of interaction as tool use from AT with the idea of interaction as fluent and intentional embodied ways of acting and being in the material and social world, implies that a transparent and useful tool amplifies the users' capabilities of bodily engagement in the material and social environment. This means that a positive UX is not only tied to a single entity in the interaction with a DHM tool in specific situations, or a moment of pleasure or joy when interacting with technology in general, but to the fulfillment of a successful embodied tool use of the activity.

Taking a UX perspective can be beneficial in the design and development of better DHM tools. Norros [4], Savioja et al. [5] as well as Hartson and Pyla [30] emphasize the need to include the intended end-users, i.e., the domains experts and professionals that will use the envisioned technology in accomplishing tasks in their daily work practice. In the case of DHM tool; ergonomists, several kinds of healthcare practitioners, and workstation designers in manufacturing are tentative primary user groups. In so doing, these domain experts are able to assess the potential and efficiency of the envisioned future technology. Considering UX early on can result in DHM tools that are usable, accepted, and support a positive UX [5, 30-31]. In addition, this way of involving und-users in the process can also support current work practices. It is widely acknowledged that professionals have to make workarounds to fill the gaps when technology rather hinders than supports the users' competence in their work practices, forcing them to pay attention to reducing the gaps in information flow, handling task interruptions, keeping various processes running smoothly, and enabling or recreating safety [20]. It should be emphasized that much work practice is based on tacit knowledge, originating in embodied and situated knowledge that sometimes is hard to articulate [32]. Neglecting various aspects of UX may cause poor interaction design and decreased interaction quality, which in turn may have a negative impact on acceptance of technology such as DHM tools to a wider group of end-users. This can be manifested in anxiety about digital and technical competence, reduced trust in data credibility, altered or even undermined professional autonomy and competence [20].

3. Illustrative example of the IMMA tool from an embodied tool use perspective

To illustrate these concepts and present how an embodied tool use approach could be used to study DHM tools in practice, we take a closer look at a tentative usage situation of the digital DHM software called IPS IMMA [18] where two professional ergonomists are going to evaluate and assess physical strain in the hand's grip for an assembly task for an operator virtually, even before the assembly task is implemented at the shop floor (Figure 1). IMMA digitally simulates a manikin of the operator's performance and the objects used in the assembly situation, and the forces for each joint are calculated. IMMA can perform these calculations with families of manikins that are created from ergonomics databases, thus highlighting the ergonomic attributes of a task for several kinds of operators [18].

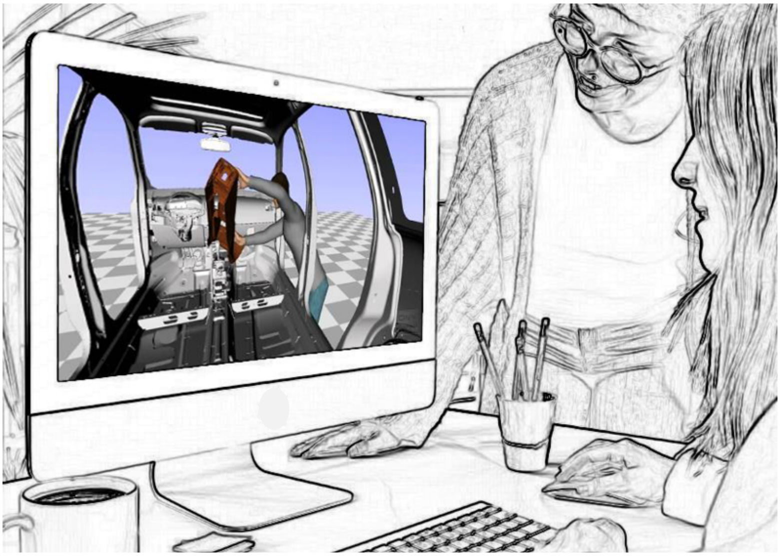

Figure 1. Illustration of the sensori-motorness, situatedness, and embeddedness of embodied interactions in relation to UX using the mediating IMMA tool in practice.

Referring to *embeddedness*, the ergonomists perform this task in a background of acquired embodied skills and situated knowledge of doing risk assessments in general, and for the particular manufacturing company. Beside the IMMA tool, multiple persons are involved in risk assessments of workstation design and work tasks that require collaboration between various specialists and company representatives. Moreover, additional tools and techniques should be included, e.g., legislation, company standards, additional risk assessment techniques based on field observation, interviews, and other manuals. The templates provided by the Swedish Work Environment Authority (SWEA) offer detailed instructions for the application of the assessment models denoted Key Indicator Methods Manual Handling Operations (KIM MHO) [33], which are commonly used, among others, in their current work practice. KIM I is about manual lifting and carrying [34], KIM II is about manual pushing and pulling of heavy objects [35], and KIM III deals with assessment of the probability of physical overload of repetitive work [36]. The available KIM assessment templates can be filled in directly on the screen at the SWEA's website and then a risk assessment score is calculated automatically (or be printed to be filled in and calculated manually). In the *activity* of doing risk assessments of manual operations in assembly for the particular company, all available digital and physical tools, and acquired skills and knowledge should be properly aligned with credible trade-offs in order to balance cost justification between competing financial and ergonomic goals as well as wellbeing at work.

From the stance of *situatedness*, the ergonomists perceive themselves from a first person point of view, in the unfolding social interaction when doing the risk assessment 'here and now' through the material and social constraints present at the current situation, which can be considered as a whole cognitive system. When the emergent participation in social and structural couplings evoke the experience of running smoothly and fluently, it can evoke the experience of a fluent interaction. This experience is bodily based, enable them to pay attention on the actual task (or actions), and the mediating IMMA tool could enable the structural coupling via acquired bodily skills to cope with the software and its input and output devices, which are not that easy to accomplish. Such a fluent interaction may promote a sense of competence that is likely to satisfy some of the emotional and psychological needs of the end-users.

The difference between *activities*, *actions* and *operations* in AT can be explained how to master the simulated movements of a manikin's various grips of a virtual object in manual assembly when learning to use the IMMA tool, being able to perform virtual risk assessments of manual assembly tasks, portraying the dynamic nature between these concepts. The overall motive here is to perform digital risk assessment by learning to use the IMMA tool, where manipulating the mouse, cursor and key board, the IMMA functions and 3D controls while using the IMMA tool is the fundamental activity in the very beginning. The focus on the hand-eye coordination of the structural couplings when creating the simulated manikin's basic grip points, grasp points, release points and viewpoints requires the full attention of the learner initially, perhaps on a non-complicated grasp for a 3D object. The new activity is then to conduct rather simple grips with the manikin's hand on typically object shapes, and these simple hand grips is now an *action* that is performed consciously since the learner is still a novice user of the IMMA tool, and soon, as a result of prolonged practice, moving the mouse, controlling the cursor, and using the controls become *operations* that are done without too much effort. Eventually, for the skilled super-user of IMMA, manipulating the manikin's various grips on several objects is no longer an *activity* in itself, but just an *action* as part of another activity, for example, virtually evaluating a new work station layout or designing a new assembly sequence for a new product component in order to increase operators wellbeing or the company's profit. Hence, the action of creating the simulated manikin's basic grip points, grasp points, release points and viewpoints has transform into routine operations, which does not require conscious control. An *activity* both mediates, and is mediated by, the physical and psychological *tools* used, as well as the social context of the activity. Viewing human activity as a three-layer systems provides the possibility for doing a combined analysis of motivational, goal-directed, and operational aspects of human activity in the socio-cultural and material environment, by interrelating the issues of "why", "what", and "how" within the AT framework [27-29].

However, it should be emphasized that working in a 3D environment using screen, mouse, cursor, and keyboard, as done in the IMMA tool, spans several *layers* of complex embodied interaction [37] (see Figure 2).

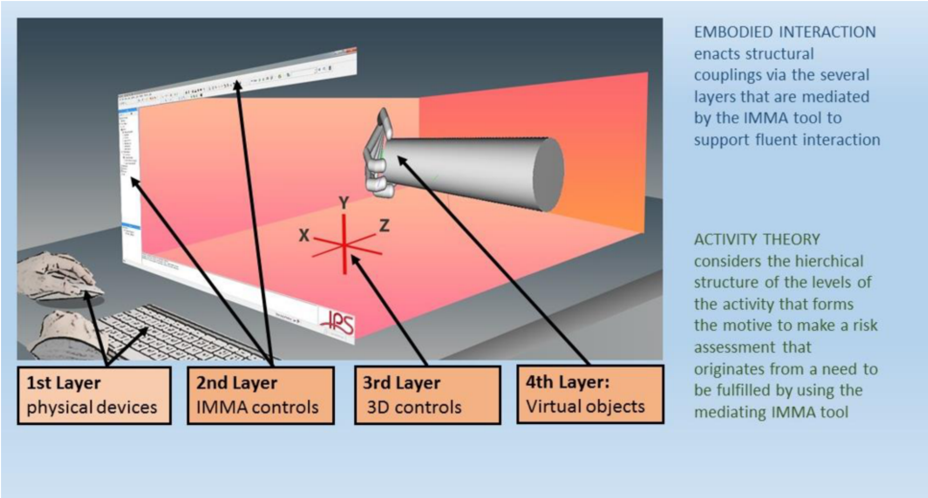

Figure 2. Illustration of the several layers of sensori-motorness in IMMA.

As Kolbeinsson [30] describes, the first layer is the real physical and social world, in which basic input/output devices like the screen, the keyboard and the mouse are physically situated. The second layer consists of the application controls, e.g., buttons and menus in the software interface as well as the mouse cursor, being two-dimensional in nature. The third layer represents the controls for manipulating the simulated three dimensional objects in IMMA software. These controls are three dimensional in nature, displaying a direct link to the manipulated object. The fourth layer is the three dimensional manikin's hand and the virtual objects themselves [37]. Hence, all the prevailing layers are made for the purpose for interacting with the fourth layer, the manikin hand's grip and the object it touches. Consequently, these various layers cover several forms of *sensori-motorness*. Every action performed via the hands that controls the keyboard and mouse, is intentional in itself, resulting in a bodily felt phenomenological experience. The IMMA tool will only achieve the anticipated outcome and functionality in the hands of a very skillful user. In order to accomplish this level of skill, the user needs to develop complex action-perception couplings that encompass complex hand manipulations of the input devices available – requiring well-acquired *handedness* skills as well as advanced sensorimotor coordination between what the hands do and what the user sees on the screen, which span several of the layers of interaction with the IMMA tool.

Upon closer analysis, it is revealed that manipulating the 3D world via 2D controls has a negative impact on the UX experience. The critical identified aspect is how to design the interface for the translation from the 3D entities of the interface to the 2D devices. In other words, the core problem is in understanding how a mouse cursor should interact within 3D objects and manikins in a 3D environment. As pointed out by Kolbeinsson [37], the lack of specific guidelines to handle this translation is surprisingly absent in theory and practice of interaction design, although the symptoms are addressed. Cooper et al. [38], for example, highlight three symptoms of the core problem: *drag thresholds* (translating a 2D dragging motion into 3D), *the picking problem* (picking objects at various depths in the simulated scene), and the *object rotation/viewpoint movement* problem [37]. However, Cooper et al. [38] mainly discuss these issues, but do not provide any concrete guidelines, tentative solutions how to overcome these issues or any underlying principles that may provide some support for tentative solutions. A tentative explanation to reduce the gap is found in the concept of body schema [10, 12] that clarifies *why* the translation between the 2D layer and the 3D layer causes negative UX. Body schema results in the accomplishment of movement, referring to the phenomenological aspect of having a *capacity to move* or to exist in the action of one's own body. The body schema supports intentional activity, accomplished by almost automatic sensori-motor processes, given that the attention mostly is focused on external objects, and not on the particular accomplishment of movement [10, 12]. The body schema concept explains the problem's underlying cognitive foundation that results in a confusion that occurs when the mismatch in the visual perception provided that appears to be three dimensional, and the interaction mode provided by the IMMA tool that is two dimensional. Hence, the experienced dimensionality of movement gap between on the one hand the 2nd layer, and on the other hand, the 3rd and 4th layers, is the tentative underlying cause to the core translation problem (for more details about body image and body schema and their interrelatedness, see [10,12]).

4. Discussion

This work is initial steps in viewing the IMMA tool from an embodied tool use perspective, being aligned with UX that is one fundamental part of the ISO standards [21]. The identified core problem in understanding how 2D devices should properly interact within 3D objects and manikins in a DMH tool that results in negative UX. More detailed analysis and actions taken how to reduce this gap in DHM tools to improve a positive UX will be conducted. We will focus on more detailed and systematic analysis of DHM tools like IMMA in theory and practice, and include additional aspects and concepts from embodied cognition. The development of an evaluation framework of embodied tool use from a UX perspective is planned. To conclude, we want to enhance the embodied experience of interacting with DHM tools and improving their UX, contributing to the well-being of ergonomists and other user groups of IMMA, and, in the long run, the operators of the factories of the future, to promote a positive UX at work.

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