Perception, Mobility and the Affordances of Portable Computers: An Historical Epistemology of Mobile Computing.

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ABSTRACT

The interaction between humans and portable technologies, as a part of the broader problem of technology use in Human-Computer Interaction, has received considerable research attention and has been approached from diverse angles. The concept of affordance, drawn from ideas in the psychology of perception, is one of these angles. Unfortunately, most of these theories of perception which premise technology affordances are understood from biological or physiological sense-modalities in essentialist theories of perception, and from relativist theories of perception in which 'seeing' for example is reconstructed as 'seeing as.' In short, they are ahistorical. Moreover, in the context of mobile computing, existing conceptualizations of technology affordances have overlooked or ignored human mobility which is an essential aspect of mobile computing. In this paper, the affordances of portable computers are examined from an historical perspective. Based on an historical epistemology of perception, in which perception is a mode of human action that is endowed with goal-orientation and teleological consciousness, mobile computing is analyzed to tease out the dynamic affordances of portable computers in mobile activities. The model which emerges from these discussions contributes to the understanding of affordances of portable computers and also provides practical guidelines for the design and integration of portable technologies in mobile activities.

Contents

1. INTRODUCTION

The concept of "affordance" (Gaver, 1991, 1996; Gibson, 1979; Norman, 1988; Zaff, 1995), drawn from the psychology of perception, is one of the predominant principles underlying current conceptualizations of the interaction between humans and artefacts. Gibson (1979) defines affordances as the opportunities for action for the observer provided by an environment. Gibson's definition mirrors what Ortega y Gasset (1941) describes as "facilities" and "frustrations" that are not properties of the world but properties that lay solely in our "interaction with the world" – our interaction with reality.

This sense of affordance is reflected in physical objects of human design such as portable computers – what they afford affects the fluidity or incoherence and clumsiness in our activities (Cook & Brown, 1999). Although the expositions of affordances by, most notably, Gibson and Gaver provide ideas on how we can understand the interactive possibilities of computers, they draw either from humans' physiological or biological structures in terms of their sense-modalities – vision, hearing, touch, smell and taste; or, at best, from relativist theories of perception in which "seeing" for example is reconstructed as "seeing as" (Wartofsky, 1973). As a corollary, conceptualizations of technology affordances (e.g. Gaver, 1991) only provide insights of the "sense-data" (e.g. Russell, 1997) of the physical and interface design properties of technologies. Narrowing this deficiency to the context of mobile computing, and coupling it with the negligence of human mobility in existing conceptualizations of technology affordances, they render the affordances of portable computers concept underdeveloped. In short, existing understanding of the affordances of portable computers is limited because, in the first place, the whole perceptual foundation of technology affordances is ahistorical and misleading; and second, human mobility, as an integral and fundamental aspect of human praxes, has been ignored, overlooked or taken for granted. This paper is aimed at addressing these shortcomings.

In my arguments that follow, I re-examine the idea of technology affordances (Gaver, 1991) in relation to the mobility of humans and their mobile computing actions. This re-examination is grounded on an empirical study of the integration of portable computers in a mobile activity. Mobility, in this re-examination, must be understood in terms of purposeful and sensational actions; contrary to movements in response to simple excitability or irritability that are intrinsic features of every living thing (Leont'ev, 1981; Orbeli, 1938). For this reason, I argue that purposeful mobility is a conscious action that can further consume conscious resources applied in mobile computing. And upon this premise, I analyse the affordances of portable computers drawing upon Marx Wartofsky's (1973) historical epistemology of perception.

A history- and mobility-based knowledge of the affordances of portable computers is necessary for understanding the dynamic affordances associated with portable computers in mobile activities. This approach is useful because by tackling mobility, historical perception and the interaction between humans and portable computers, it exudes a more holistic understanding of the relationship between perception, mobility and portable technology affordances.

Furthermore, this approach is useful because it provides guidelines for the design of portable technologies aimed at supporting, most notably, modern professionals whose work exhibit mobility in both location and interaction senses (Kakihara & Sørensen, 2002b). By proceeding beyond physiological sense-modalities and their associated sense-data, this approach transcends the conceptualization of affordances based on just the material and interfacial design properties of technology towards a conceptualization that accounts for the

holistic relationship between mobility, perception and the physical, interface and system design properties of portable technologies.

2. THEORETICAL FOUNDATIONS

2.1. Tool Mediation, Representation and Perception

In his discussion of the *Social Origins of Indirect (Mediated) Memory*, Vygotsky (1978, p.38) distinguished between elementary and higher mental functions in human beings. Elementary functions are completely genetic, and directly related to natural memory; therefore they are unmediated responses to environmental stimuli. However, "[natural] memory is not the only kind…even in the case of non-literate men and women" (p.39). Human beings are characterized by higher mental functions that represent development based on their extensions of biological memory.

> "They extend the operation of memory beyond the biological dimensions of the human nervous system and permit it to incorporate artificial, or self-generated stimuli, which we call *signs*. This merger, unique to human beings, signifies an entirely new form of behavior" (p.39).

The new form of behavior is inherently a reflection of development of higher mental functions. Leont'ev drew upon this idea in his treatment of the essence of mediation in this form of development:

> "Mediated memory, in turn, develops along two lines: (a) along that of a development and perfecting of methods of using aids, which continue to be in the form of stimuli acting from outside, and (b) along the line of a transition from external means to inner ones. Such a memory, based on a highly developed capacity for instrumental use of components of experience that are predominantly internal (inner 'symbolic aids'), constitutes the last and highest stage in its development." (Leont'ev, 1981, p.349).

Sign operations of human beings are therefore external phenomena that mediate their elementary stimulus-response functions; Signs and symbols are "second order" intermediating stimuli that ensure higher mental functioning (see Figure 1).

Figure 1: (a) The structure of the unmediated act (b) The structure of the mediated act: 'S' – Stimulus, 'R' – Response, and 'X' – Mediating Sign. [Source: Vygotsky (1978)].

In this formulation, Vygotsky emphasized the inseparability of mediating sign and activity: "This intermediate link is a second order stimulus (sign) that is drawn into the operation, here it fulfils a special function; … [the] term 'drawn into' indicates that an individual must be actively engaged in establishing such a link." (Vygotsky 1978, p.39).

The theory of Activity (Leont'ev, 1978, 1981) derives from this formulation: the stimulus-sign-response relationship is transformed into a subject-tool-object relationship by Engeström (1987) – the subject's *responses* to external object *stimuli* are mediated by tools and *signs* (psychological tools). The philosophical assumptions of Activity are founded on the following ontology: every human activity is conducted by a *subject* who pursues an *object* with a motive to transform the *object* into a product or *outcome*; the relationship between the subject and object is always mediated by some physical and psychological *tools*. It is

important to note that, psychologically, tools and signs are mutually interrelated and separate at the same time:

> "[a] most essential difference between sign and tool, and the basic real divergence of the two lines, is the different ways that they orient human behavior. The tool's function is to serve as the conductor of human influence on the object of activity; it is *externally* oriented; it must lead to changes in objects. … The sign, on the other hand, changes nothing in the object of a psychological operation. It is a means of internal activity aimed at mastering oneself; the sign is *internally* oriented. (…)
>
> The mastering of nature and the mastering of behavior are mutually interlinked, just as man's alteration of nature alters man's own nature." (p.55) (italics in original).

Perception in an activity therefore departs from a simplistic notion of natural, elementary and unmediated perception that is biological or physiological towards a complex idea of perception as a mode of action that is always mediated by cultural-historically-produced and -communicated tools and signs; that is, by "representations" (Wartofsky, 1973). This idea underlines the necessary *active* relationship between subject and tool, and points out the weakness in relying only on biological- or physiologically-based notions of perception to understand the efficacy of mediating tools and signs in human activity. In the words of Wartofsky,

> "… the very foundation of what is distinctively human in perception is its character as a socially and historically achieved, and changing mode of human action; and thereby invested with a cognitive, affective and teleological character which exemplifies it as a social, and not merely a biological or neurophysiological activity (1973, p.196).

Perception is necessarily a mode of human action that shares the essential characteristics of human actions such as intentionality, consciousness, historicity, goal-orientation, and as constituents of activity. We understand tools and signs as "representations" that mediate perceptual actions; that are artificial (socio-cultural); and that are produced and communicated by humans in their ontogenetic and phylogenetic means of existence. We also regard both tools and signs, in general, as artifacts that consist of both "signifying" and "signified" properties (Saussure, 1983), and in this regard, the perception of an artifact reflects the semiotic "variation in modes of representation that perception itself comes to be related to historical changes in other forms of human practice, and in particular, to social and technological practice" (Wartofsky, 1973). The signifier is the form which the artifact takes, its structure; and the signified is the concept it represents. According to Wartofsky, there are three modes of representation – genetic, reflexive and abstract.

The *genetic mode* of representation (structural) is the "fundamental activity of producing and reproducing the conditions of species existence, or survival" that is distinctively human due to our creation of artifacts. That is to say, the genetic mode of representation derives from humans' transformation of part of the environment into artificial extensions of our biological organs. Artifacts that exhibit genetic modes of representation are perceived as "primary artifacts." The *reflexive mode* of representation (functional) consists of "symbolic externalizations or objectifications of such modes of action – 'reflections' of them, according to some convention, and therefore understood as images of such forms of action – or if you like, pictures or models of them." (Wartofsky, 1973). To him, the signs that Vygotsky labels as "psychological tools" – e.g. language, theories, norms and modes of action – and that can be communicated in one or more sense-modalities are perceived as "secondary artifacts."

Vygotsky's notion of the external orientation of physical tools and the internal orientation of signs are reflected in Wartofsky's semiotic conceptualization of tools as structural representations (of "primary artifacts") and signs as functional representations (of "secondary artifacts"). In the case of "primary artifacts", their structural conceptualization is based on the idea that they are simply the environmental implements which are of interest or use in

production. In the case of "secondary artifacts", their functional conceptualization is founded on their functions as preservers and transmitters of "the acquired skills or modes of action or praxes by which this production is carried out" (Wartofsky, 1973).

Wartofsky conceptualized a third mode of representation based on "imaginative praxes" – "abstract." Imaginative praxes does not connote mere mental activity, although it is compatible with and sometimes derivative of it. Rather, imaginative praxes connotes actions that are detached from actual direct praxes and are exemplified in play, drama, rehearsals, enactments and modeling. The representations (of "tertiary artifacts") generated in imaginative praxes are abstractions of their use in actual praxes: they are

> "abstracted from their direct representational function … and suggest that they constitute a domain in which there is a free construction in the imagination of rules and operations different from those adopted for ordinary 'this-worldly' praxes. … That is to say, just as in dreams our imagery is derived from our ordinary perception, but transcends or violates the usual constraints, so too in imaginative praxes, the perceptual modes are derived from and related to a given historical mode of perception, but are no longer bound to it" (p.209).

Tools that exhibit abstract modes of representation are perceived as "tertiary artifacts." Through imaginative praxes, "possible worlds" are conceived and perceptual alternatives can be enacted, modeled and tested leading to their actualization. The essence of "tertiary artifacts" lies in the conscious teleology, goal-orientation and values that characterize the alternative imaginative perceptual modes behind their production and communication. It is important to note, here, that alternative imaginative perceptual modes possibly "[feed] back into actual praxes, as a representation of possibilities which go beyond present actualities." (Wartofsky, 1973, p.209). This assertion mirrors Leont'ev's exposition of the transformation of representations on the mental plane: "… they are generalized, verbalized, condensed, and most important, they become capable of further development which exceeds the boundaries of the possibilities of external activity." (Leont'ev, 1978).

The objective properties of technological tools symbolize shared, preserved and transmitted cultural-historical understandings that inform their users. They are material ("primary") in nature, with enabling and limiting properties into which are crystallized signs, methods and operations (Leont'ev, 1978), "psychological tools," (Vygotsky, 1978) or "functional representations" (Wartofsky, 1973); however, in most instances, an understanding of their production and exchange suggest that they are "tertiary artifacts" reflecting the abstraction and modeling underlying their "off-line" (Wartofsky, 1973) production.

The upshot of this review is that perception of an artifact is a mode of human action which is mediated by variations in modes of representations – structural, functional and abstract – and which is essentially aligned with the cultural-historical evolution of all forms of human activity.

Consequently, we will derive our understanding of the affordances of portable computers from this historical epistemology of perception; that is, we seek to ground the affordances of portable computers on the idea of perception as a mode of human action. Since these three modes of representation (structural, functional or abstract) of portable computers always mediate perceptual actions, the epistemological basis of this paper is that the perception of an artifact is dependent on its assumption of a primary, secondary or tertiary status in an activity. The assumption of any of these statuses is also a function of the totality of those actions (constituting an activity) which the individual's perception forms a part. We will draw upon the understanding of the modes of representation of portable computers to premise the historical epistemology of perception necessary for teasing out their affordances.

2.2. Technology Affordances

The concept of affordance was originally an illumination concerning the direct relationship between an organism and its environment. The crux of this concept is that the

affordances of an object of the environment, natural or artificial, lie in what it "offers the animal, what it provides or furnishes, either for good or ill" (Gibson, 1979, p.127). Affordances point to both the environment and the active individual, and are mostly realised in the interactions between organisms and environmental objects.

> "An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behaviour. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer" (*Ibid.*, p. 129).

The Gibsonian notion of affordance suggests the possible existence of affordances "independently of the individual organism in the sense that as long as the possibility of a particular activity exists for a particular species in an environment, then the affordance can be said to exist." (Bærentsen & Trettvik, 2002, p.52-53). However, this notion of affordance has been challenged, notably, by Gaver (1991; 1996) and Norman (1988; 1999). Their challenging ideas are inspired by the fact that some cultural-historical tools such as modern information and communication technologies (ICTs) exhibit sufficient complexity, and therefore, compared with simplified tools, passive sensitivity by the actor alone does not offer adequate perceptual information needed to appreciate other "hidden affordances" of the artifact. In other words, Gibson's idea of absolute reliance on immediate sensual information to determine the affordances of objects breaks down when applied to ICTs.

ICTs are information systems of cultural-historical origin which comprise complex assortments of technological components. Their cultural-historical value is manifested in the "objective meanings" (Leont'ev, 1978, 1981) inherent in their semiotic properties built and accumulated over time by previous generations of human users and contained in language and symbols. For any given ICT tool, given its artificial nature, its affordances are determined through social-cultural factors and through the activity which it is mediating. Therefore, to Gaver (see also Draper, 1986; 1991), "Affordances are not passively perceived, but explored" during an action with the tool on an object. And hence, "[m]aking affordance perceptible is one approach to designing easily-used systems."

While Gaver's critique is sound in terms of his idea of the inseparability of perception and action, he appears to draw upon "relativist theories of perception" (see Wartofsky, 1973) in which perception is deemed as a variable process of interaction, "whose variability depends on acknowledged variation in context, use, background-knowledge or framework" (Wartofsky, 1973). Furthermore, Gaver himself, quite paradoxically, agreed with Gibson that "[affordances] per se are independent of perception. They exist whether the perceiver cares about them or not, whether they are perceived or not, and even whether there is perceptual information for them or not" (1991, p.80).

Based on Vygotsky (1978), Wartofsky (1973) and Leont'ev (1978), who argue for the inseparability of activity-consciousness and actions, I propose that we must understand affordance as always intrinsic in the "personal sense" made of a tool (an artificial representation, physical or psychological) by an actor *during* its use in an activity. Note that "personal sense" inherently entails the person's perception, consciousness and motive. In the supportive words of Bærentsen and Trettvik (2002), "unless we understand what motivates people to use something, we cannot even begin to understand why they succeed or fail to realize it." (p.59). This is important. Therefore, the affordances of portable technologies, including their ease of use and perceived ease of use, in an activity must necessarily remain a function of perception; that is, it must be conceptualized as a function of perceptual actions. Perception mirrors "activity-consciousness" (Leont'ev, 1978) that represents a continuous imaging and personal sense-making of one's interaction with an artifact.

2.3. Modalities of Human Mobility

The modalities of mobility which human beings exhibit are very diverse: they can be conceptualized from the slightest movement of the individual to distant travels into space. In-between these two extremes, there is an uncountable number of variations of human mobility that are possible, depending on the motives and needs of the individual.

Perhaps the closest anyone has come to theorizing human mobility can be seen in the work of Kistoffersen and Ljungberg (2000) who functionally characterized human mobility in terms of three modalities. Modality, according to their definition, is the description of the "fundamental patterns of motion" of humans as they move around – *traveling, visiting* and *wandering*. Traveling is the process of movement from one point to another in which the distance between those two points is such that a vehicle is required to convey the person in the process. Visiting demands some form of traveling but its essential component is the prolonged time a person spends at one location to perform some function before moving to another location. A wanderer is a person whose movements exhibit "extensive local mobility in a building or local area" (Kristoffersen & Ljungberg, 2000, p.142). He or she does some limited travels and visits in a localized environment. Other authors (e.g. Lyytinen & Yoo, 2002) also conceptualize the fundamental patterns of motion in terms of *micro-mobility*, *local mobility* and *remote mobility*. Micro-mobility denotes the basic movements of a person's body parts – head, hands, feet, shoulders, etc. However, local mobility and remote mobility respectively mirror Kristoffersen and Ljungberg's notions of wandering and traveling. This categorization enhances the understanding of human mobility, and hence an appreciation of the particular modalities their movements exhibit over time in an activity.

Against the backdrop of these theoretical foundations, it is interesting to explain how activity-based human mobility conditions perception and hence the affordances of mediating portable artifacts. We draw these explanations from an empirical example of mobile computing in a mobile activity.

3. MOBILE COMPUTING IN A MOBILE ACTIVITY

3.1. Research Setting

This empirical example is an embodiment of the key parameters whose relationship we seek to properly understand – perception, activity-based human mobility, tool mediation, and mobile computing. The artifact in question is the Compaq iPAQ H3970 personal digital assistant (PDA) produced by Hewlett-Packard® and running a Microsoft® Windows® CE 3.0 operating system. This technology was adopted and deployed in a work-integrated learning project sanctioned by the United Kingdom (UK) National Health Service (NHS), sponsored by the European Union (EU), and enforced by the EU Working Time Directive (EUWTD). The directive illegalized the 72 weekly hours spent at work by junior doctors in UK hospitals, and stipulated a maximum 48 weekly hours for these doctors. Although this legislation was passed some years ago, the EU authorities had decided to fully enforce it in August 2004. As a result, immediate pressure mounted on the authorities of the NHS to address the looming crisis that would be caused by man-hour shortages in surgical wards. And as a means to tackle this problem, the NHS Changing Workforce Programme at the Department of Health instituted 19 pilot training projects to train new professionals to assume some of the functions that were erstwhile performed by junior doctors. One of these projects/professionals – the Perioperative Specialist Practioner (PSP) – would be trained in peri-surgical skills which would predominantly consist of integrated care for surgical patients before and after an operation.

The training was designed in such a manner that the each PSP would train as part of a resident surgical team in their hospital. The mobile nature of surgical teams' work

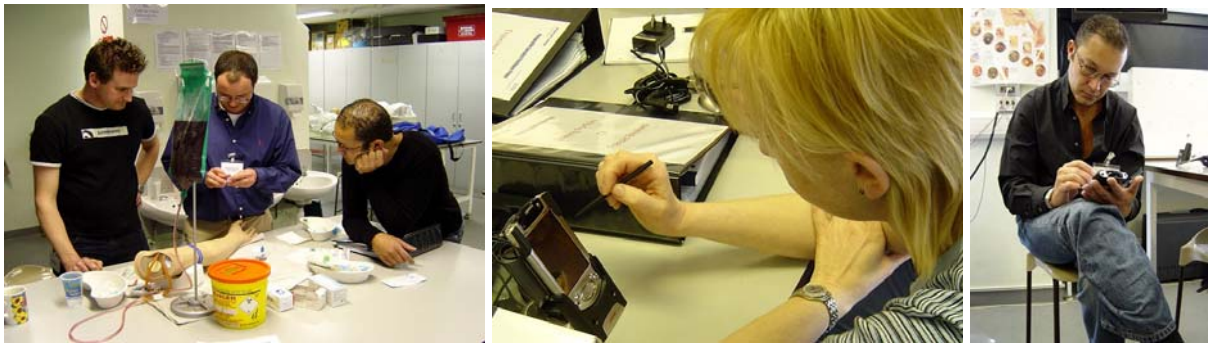
automatically suggested that the PSPs' learning would be mobile; in other words, their fundamental patterns of motion exhibited local mobility or wandering within their hospitals. For example, a PSP's typical schedule of a day at work involved wandering from one ward to another, one surgical patient to another to examine their conditions. This was witnessed in the following statement by one of them: "my work is so MOBILE …." Furthermore, it was designed that their time spent in their hospitals was interspersed by one-week classroom based modules in the training centre in London. Thus, after every six weeks spent in the hospital, all the PSPs would travel to London and stay for a week before returning to their various hospitals.

3.2. Mobile Computational Support

The project was monitored, coordinated and controlled by its authorities who were based in London; and the PDAs were officially adopted and deployed to enhance the project managers' remote monitoring, coordination and controlling efforts from his location in London. Mobile computational support was built around two main schemes or applications: On the one hand, an Actions Log or database that would hold recorded details of the PSP's encounters with patients on the wards was to be developed by each PSP. They were to select items from a predefined "pick list" by tapping a stylus directly on the PDA screen. On the other hand, there was also a learning Reflective Journal which consisted of a set of templates with headings such as "thoughts and feelings" and "what worked and what didn't?" These were intentionally open-ended questions which would allow the PSPs to frame the answers as they wished. Answers to these questions were to be typed at the end of each learning day using a foldable keyboard which was also provided by the project authorities.

It was envisioned that the PDAs would provide learning support to the PSPs through the accumulation of relevant learning resources – medical literature, drug calculators and formulary – which could be available to the PSPs anytime, anywhere during their learning maneuvers. It was also envisioned that when a PDA is inscribed with theoretical medical information and used in practical learning environments, the learner could intermittently refer to this information to shape his or her sense-making from the practical clinical actions (see Figure 2).

Figure 2: The left frame shows three PSPs in a simulated clinical setting. The middle frame shows a PSP documenting activities and reflections with her PDA outside the clinical setting. The right frame depicts the attention needed for mobile computing.



3.3. Data Collection Methods

Data from this project was collected through an action research strategy in which I actively collaborated with the PSPs and the authorities of the project. In addition, I was a direct observer in many of the London-based modules and led the training of the PSPs on

how to use the PDAs. Furthermore, I assumed the role of a 24-hour 'helpdesk' support to them – they could call me on the phone anytime for help if they encountered any problems with the use of the PDAs during their training. My role therefore oriented towards a facilitator, an active participant, and a "clinician" (Schein, 1987). I have to stress that I was strictly an action researcher not a consultant: I accepted the invitation to participate in the project as an action researcher not to gain monetary rewards, but to use the opportunity as a means to obtain as much in-depth information as possible. Judging my role with Baskerville's (1999) five key parameters for distinguishing between an action researcher and a consultant – motivation, commitment, approach, foundation for recommendations, and essence of organisational understanding – I was an action researcher. Offering myself as a facilitator for the adoption of technology and implementation of technology decisions in the project was a welcome gesture to the practitioner not only in cost-saving terms; but also on the grounds of my resolution of most of the emerging problems with the PDA use. This role was very significant because it eased my access to information and facilitated the process of data collection at all levels of the project set-up from the outset to its conclusion.

I held several meetings, conversations and interviews with the project manager and trainees throughout the project. Although, these meetings were far fewer in number compared, for example, with the number of interviews, they were a reliable and rich source of information on the motives behind the adoption and deployment of the PDAs.

In open-ended interviews, the trainees were asked questions leading to discussions of their experiences with their various hospital surgical teams. The objective was to induce and entice them to elaborate because when they did, their languages and social cues reveal attitudes, morals, beliefs, and opinions and feelings (Kendall & Kendall, 1993). Furthermore, open-ended interviews were most suitable for gathering information on questions of 'how' because they are explorative in nature.

I also conducted formal interviews, both face-to-face and over the phone. During my visits to the hospitals of the trainees, the face-to-face formal interviews were largely interspersed with informal interviews or conversations as part of my problem-solving role in the project. I also held several informal conversations with them anytime they returned to London for their modules – beside the tea table, in the classroom before a session, in the canteen, and during the official three-hour "PDA session" of every module.

The project manager instituted an official "PDA session" to allow the application designers and I to interact with the trainees and solicit their problems and concerns about the PDAs use in their learning activities. I always used these opportunities to throw open questions to the PSPs for discussion. These sessions also presented an environment where their personal experiences were shared among themselves, revealing critical information that could not be discussed in a formal interview.

The project manager also instituted another three-hour session in every module called "How things went,." This session, the first of every London module, was designed to solicit feedback and experiences from the trainees in relation to their learning experiences over the previous six weeks spent in their individual hospitals. "How things went" were always very emotional and presented the PSPs with the official opportunity to pour out their feelings and frustrations. Although it was the project leader himself who moderated the "How things went" sessions, I was always present as an observer and took notes of the proceedings.

Over the period, I also exchanged several e-mails with all members of the project. However, most of these e-mails consisted of exchanges with the trainees on the experiences with technology use. E-mailing was an option that I provided them to reach me if I could not be reached on the phone. The a-contextual nature of e-mail text, its associated asynchronous interaction, and its unobtrusive nature ensured that interaction was convenient for me and the trainee at any time.

3.4. PDA Implementation and Use

Each PSP was given his or her package – PDA, foldable keyboard, Microsoft® ActiveSync® software compact disc, users manual, charger and cradle – in the first module. They were given a three-hour training and induction session to familiarize with the PDA and learn to use its basic functions. Initially, when the custom applications had not yet been developed, the framework of the Reflective Journals and Actions Logging sheet were transformed from the pre-designed desktop Word® and Excel® files into a Pocket Word® and Excel® files via synchronization with ActiveSync®. The PSPs were taken through a short tutorial about the use of the files for Actions Logging and reflections documentation. Each was given a manual with explanations on how to develop the clinical activity database.

The PSPs found the standard applications very useful. They marveled and were fascinated by their usefulness, and as far as these were concerned, the PDA was a wonderful technology to them. However, it was almost impossible for them to log actions during history taking exercises with real patients. It was also nearly impractical to log observed activities during their wandering or local mobility around their hospital wards. They further complained of how irritating it was when they scrolled the Actions Logging spreadsheet left-right and up-down. They preferred to use the paper-based logging spreadsheet because of this problem.

Two and half months into the project, a new custom application – abcDB® – was developed and introduced to the PSPs. It was a database application that integrated both Actions Logs and Reflective Journals, and it was designed to help overcome the frustrations which the PSPs experienced with the pocket-based Word® and Excel® files. Unlike these files, abcDB® was seen as a better application because it contained text boxes, check boxes, radio buttons and drop-down menus that would do away with, most importantly, the left-right and up-down scrolling and facilitate actions logging and reflections writing. This application was installed on their PDAs, and they were taken through a three-hour orientation session where a step-by-step process of using the application was demonstrated by the application's developers. In addition, each of them was given a detailed user-guide as a supplement. The orientation session proceeded quite smoothly with very few questions from the PSPs. They all seemed to have understood the instructor and could navigate through the pages of the application and perform their writing and logging tasks without any perceived difficulty.

On their return to their various hospitals, however, reports of severe problems with the application began pouring in immediately.

> *"As you would expect, I am finding the new system even worse than the old...I do not use my PDA AT ALL!! I rely on paper and to be honest I find it much easier and quicker. You can have it back if you would prefer."* – Naomi, a PSP.

> *"It's not complicated, it's just too time-consuming. I just can't use it. If I could use it per patient, then that would be fine, but per activity, it's out of question. It's too time-consuming so I'm just not going to use it. To do each patient, I reckon it would take something like half-an-hour to input the data which would be mad. It's just not feasible to do it like that."* – Ruth, a PSP.

> *"Assuming I have to deal with 5 patients, the slowness of the application's response implies that I have to spend about 10 minutes with each patient … it's not realistic in a clinical setting"* – David, a PSP.

In the end, abcDB® was virtually unusable in the mobile clinical learning setting and had become extremely problematic for two reasons. First, there was a basic design flaw in which the users had to input one patient's personal details anytime a different action was to be

performed by the PSP on a patient. The PSPs' views had not been sought in the design of the application and therefore their particular practical needs were not incorporated into its design. The application's design was not reflecting the clinical reality in which the PSPs found themselves working and learning daily.

Second, there was a systemic problem with the application which manifested in its slow running. The purpose of the deployment of the PDA demanded the use of a database application that would allow an accumulation of PSP clinical actions as they were logged in daily. While the generic applications, such as contacts and calendar, responded very quickly to commands, it took an average of eight seconds for a command in abcDB® to execute on the PDA. Incidentally, this database software ran too slowly on the PDAs – and this was not detected beforehand. This also made the use of abcDB® very problematic because, again, it was too time-consuming and not practical in the clinical setting to wait for eight seconds for every command to execute. Quite simply, the use of a slowly responding application which contained too many pages was a burdensome process; disrupting the actual clinical actions of the PSPs.

These problems together made the use of the application very unwieldy and clumsy since its use was not simplified enough to stay as an action alongside the skills learning clinical actions they were performing. The magnitude of problems associated with abcDB® was alarming. The developers were informed of these reported problems but they could not fashion out an immediate solution. Feedback on the efficacy of the application was expected to be sought from the PSPs when they returned to London for the then-impending module; but the frequency of complains from the PSPs and the strength in their dismissal of the application caused its immediate abandonment by the project manager. He was immediately compelled to employ a learning technologist, approximately three weeks after the introduction of abcDB®, to develop a new and better application to replace it.

The learning technologist gathered the feedback on the PSPs' experiences with abcDB® use as an input into his new design. For this new application – HanDBase® – it was agreed by all members of the project that reflections writing would thenceforth be officially paper-based. But PSPs were still given the option to type their reflections in the earlier Pocket Word® templates if they found that more convenient. Thus, HanDBase® was an application to be developed solely for clinical actions logging purposes.

The learning technologist had to design the new application to surmount the problems which the abcDB® presented. Apart from the lengthy consultation of PSPs for their views on how the new application should look, the development process also included its beta-testing in the clinical setting by three PSPs. The feedback from the testing was encouraging: the application was easier to navigate because of its fewer pages, it was many times faster than abcDB®, and it better reflected the nature and structure of their clinical actions. To them, the redesign was much better.

However, during the beta-test, there was still the lurking problem of actions logging on-the-move or during its realistic use in the clinical setting. The testing PSPs reported that they did not have time to enter data contemporaneously. They rather logged their clinical activities at the end of the day in contravention of the contemporaneous actions logging rule. While one of them indicated that he could potentially enter data contemporaneously in the future, the general impression was that using the application was "another thing to do" in addition to their usual clinical actions round their hospitals.

The few rough edges of the application identified by the PSPs during the testing period were dealt with and the application was ready to be rolled out to them. The first step was another three-hour orientation session that was notably facilitated by the three PSPs who had earlier undertaken the testing. Their support, in addition to the PSPs' improved familiarity with the PDAs, and the fewer pages of the new application in totality ensured that the PSPs

were more properly trained to use the application for actions logging. They therefore left the training centre in London for their hospitals with the expectation that they could effectively use the PDA to log their clinical actions when they were being done.

During the evaluation of the application six weeks later, all the PSPs agreed that the new application and the installed software had caused significant improvements in their use of the PDA compared with the days of abcDB®. The application was many times faster than abcDB®, but it was still not usable contemporaneously with the performance of clinical actions and with patients' history taking. Based on this, it was decided by mutual consent that the PDA be officially abandoned for the second time. And HanDBase® was removed from all the PDAs. From that period, all information management tasks reverted to the use of pen and paper. Although the PSPs still had the option to use the initial Pocket Word® and Excel® files for reflections writing or activity logging or both, the official output of their portfolios was the huge paper-based files which were originally meant to be replaced by the PDAs.

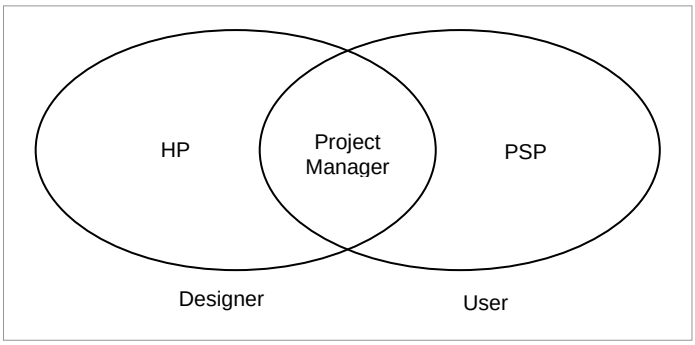
In this study, I discerned that in spite of each next application coming out as better than the one it succeeded, all the three applications failed to function as they were intended to. While poor systems design and lack of consultations with the users account to some extent for the PSPs' frustrations with the technology's usage and for the project manager's frustrations with the technology's inability to function remotely on his behalf, the dominant and more determining reasons emanate from the nature of actions which they were performing in the hospitals and which they were supposed to document. These actions were mobile, being conducted in remote locations and were subjected more to the authorities of hospital surgical consultants. I also discerned that the representational gap between technology design (abstract representations) and their utility in an activity (functional representations) could be traced to both the factory design of the PDA and the in-house development of custom applications. In the case of the factory designers, their design and marketing gimmicks backed by the success of PDAs in entirely different contexts influenced the project manager to integrate those PDAs into the project. That is, the manager's adoption of the technology was influenced by his imagination that its abstract representations could help to serve his remote controlling and coordinating functions in the project. In the case of the in-house designers, their designs were essentially further inscriptions of the manager's controlling and coordinating functions into the PDAs. As it turned out, there was a large representational gap between the promissory or abstract state of the off-the-shelf PDAs and the functions they exuded when they were put into use in the project.

In order to understand why all the three technology applications failed in the project, an analysis that exudes how activity-based mobility conditioned various representations and perceptions of the technology is necessary. This analysis leads to a discussion of the affordances of portable computers.

4. REPRESENTATIONS, PERCEPTION AND AFFORDANCES OF THE PDA

It is important to clarify, first, what is meant by designer and user in our subsequent analysis. From the PDA's production to consumption in the case, we can discern Hewlett Packard® (HP) as original designers; the project authorities led by the project manager as both designer and user, and the PSP as user (see Figure 2).

Figure 3: Conceptualisation of Designer and User



The project manager is designer because after acquiring the technology, he inscribed his rules, his controlling and coordinating functions, by sanctioning the design of the three applications. He is also user because his intention was to use the technology and his inscribed rules to control and coordinate the remote actions of the PSPs. Conceptually, when we subsequently refer to user, we will mean both project manager and the PSP. This conceptualization is grounded on the fact that the motives to monitor, control, and coordinate the PSPs' remote actions and for them to document their actions were shared by both project manager and PSPs. It was shared because the accreditation of the outcome of this learning exercise was dependent on the accreditation authorities' satisfaction that certain specific actions were performed by the PSPs during their training, and this would serve the interests of both project team and PSPs. This shared motive and outcome is the reference point for defining the functional representations conveyed by the technology. Similarly, when we refer to designer, we will mean both HP and the project manager as far as their "off-line" imaginations that premised the design of abstract representations are concerned. However, in instances where my discussions of user exclusively refer to the PSPs, especially in analyzing the role of their mobility in shaping representations, I adopt 'PSPs' to clarify the distinction.

4.1. Representations and Filtration

The ideal PDA, at the beginning of the project, was a simple extrapolation of the ideal functionalities of desktop computers. The designer's conception and the user's expectation of the functionalities of the PDA reflect a portable prototype of a desktop computer inputted with miniature versions of desktop computer applications. In the project, these envisioned functionalities or abstract representations were reflexive of such historical modes of action as control, monitoring, coordination, personal organization, learning support, mobile computing, and support from portable artifacts. However, anecdotal evidence from technology failures suggests that abstract representations or ideals undergo filtration and reconstruction during their use in certain contexts. Such pieces of evidence point out that either only a small aspect of the designer's intended use manifest or technology is reconstructed and used in fashions that are not even envisioned by the designer (see Ciborra, 2000). I have addressed the issue of reconstruction in an earlier paper where reconstruction was analyzed as the determinant of the flexibility of mobile computing. Reconstruction is intrinsically compatible with filtration in terms of process. Filtration is the process in which some or all of envisioned abstract representations that characterize an artifact manifest as or are transformed into functional representations. Filtration results in the actual functional representations seen from the user's own perspective in actual praxes; and in the context of the PSP project, they induce interest in questions like, what were the filters, and how did they filter the abstract representations into functional representations?

To illustrate, the filters were the "conditions" (Leont'ev, 1978) or "social variables" (Bijker, 2001), that is, the external factors that shaped the PSPs' actions – including perception and mobility. Note that the PDA was mediating a learning activity that consisted

of several goal-oriented clinical actions and human mobility. However, the PSPs computing actions with the PDAs were conditioned by the goal-oriented clinical actions that further dictated the various modes of the PSPs' mobility – micro, local and remote. In short, these other actions – mainly, clinical actions and mobility – were the filters that transformed the designer's abstract representations into the user's functional representations.

To understand *how* filtration of the abstract representations manifested, we must be mindful of the fact that the actions of a computer-mediated mobile activity are constituted by three main sub-actions – the 'true' actions, computing actions, and purposeful human mobility. 'True' actions are those that are directed towards the transformation of the object of activity, and do not necessarily require computing support for goals to be achieved. In this sense, computing actions may be deemed as 'false,' irrelevant or unwanted by the authorities who wield power and control over that activity. In the project, the clinical actions were 'true' in the sense that they did not necessarily require computations. It has to be added that these sub-actions are not mutually exclusive; they represent a mere analytical categorization, and in reality they may be intrinsically intertwined and interdependent. For example, when computing actions are mobile, they are necessarily dependent on human mobility; and the achievement of the goals of 'true' actions may be dependent on computing actions.

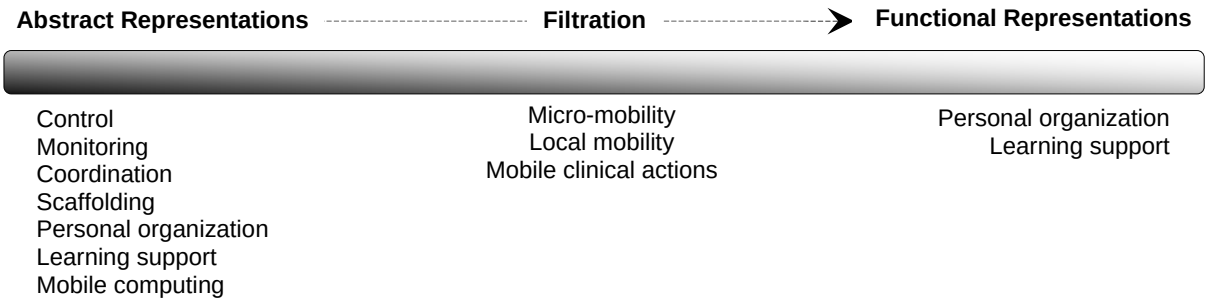
In the project, the clinical actions of examining patients and taking their histories, blood taking, putting up intravenous infusions, and venipuncturing all dictated the PSP's bodily movements that exemplify micro-mobility. Then the ward-to-ward movements as part of the surgical team's duties in conformity with the requirements of the training, as well as other administrative tasks dictated their local mobility or wandering around their hospitals. Lastly, their to-and-fro movements between London and their hospitals depicted their traveling or remote mobility. Since all these modes of their mobility were inherently conscious and purposeful, they translated into conditioning social variables of the concomitant mobile computing actions that also required consciousness as well as the perception of the PSP.

The mobile computing actions – actions logging and reflections writing, as well as those computations that used the standard applications – were envisaged to rely on the abstract representations of the PDA to be deemed successful by the user. In fact, the adoption and deployment of the PDAs by the project manager, in addition to his instructions that were inscribed (Hanseth & Monteiro, 1997) via the three applications into the PDA indicated his motive to control, coordinate, monitor and scaffold (Salomom & Perkins, 1998) the PSPs' learning from his remote location in London. These motives are abstract representations that were appropriated by the project manager in his imagination of the PSPs' mobile computing actions.

However, in the actual clinical praxes, all the three applications were deemed as failures not necessarily because of their poor designs, but mainly because the PDA was simply "unusable in the clinical setting." The clinical setting was dominated by the 'true' actions as well as micro-, local and remote mobility that did not enable the PSPs to perform mobile computing actions. Their micro-mobility – bodily movements during times with patients – would not allow them to log actions into the PDA. In their local mobility or wandering around the hospitals as part of surgical teams, they would not dare pull out their PDAs from their pockets to log in their actions because that was not considered by their immediate surgical authorities to be part of the 'true' clinical actions. It was only during their traveling or remote mobility that they were able to perform computing actions with the PDA, but we must remember that remote mobility was not constitutive of the clinical actions that the project manager was motivated to control, monitor, and scaffold. Ultimately, activity logging and reflections writing could only be done outside the domain of clinical actions, and this nullified the abstract representations – remote control, coordination, monitoring and scaffolding through the PDA. The PSPs could also use the PDAs comfortably for personal

organization through the standard applications, but this was also not considered as crucial for the training project nor as justification for the adoption and deployment of the PDAs. In effect, the micro-mobile and locally-mobile clinical actions filtered the abstract representations by nullifying the abstract (designer's functional) representations, leaving the remnants such as personal organization, and learning support as the functional representations.

Figure 4: Filtration of the PDA's Abstract Representations



4.2. Perception and Affordances of the PDA

Having analyzed how the variations in modes of representation of the PDA were filtered by the mobile clinical actions and human mobility, we have to apply this to understand how the PSP perceived the PDA. Since "the specific feature of perception as a mode of action is that it is mediated by representation" (Wartofsky, 1973), it is important to premise our examination of the user's perception of the PDA on the analysis of representations and filtration in the previous section.

To begin with, let us examine the structural representations of the artifact's promissory state. In that state, it has not yet been deployed in an activity and thus the structural representations are mere images that are internalized as sense-data through, mostly, vision, sound and feel. To Wartofsky, this form of imaging is *genetic* in the sense that it conforms with essentialist theories of perception that proclaim perception as a phenomenon that relies on biological and physiological sensory-motor apparatuses – "animal perception" (Leont'ev, 1978). Leont'ev labels the same idea as "image-consciousness" that refers to direct sensory-imaging of static or passive objects, in contrast with "activity-consciousness" that refers to one's interaction with those images.

"Activity-consciousness" relies on the goal-oriented interactions between the perceiver and the artifact; it translates into the *reflexive* mode of representation that is functional and reflects historical human praxes. In this mode, the erstwhile images are more than mere structures; in contrast, they represent historical human praxes such as control, monitoring, coordination, learning support, personal organization and scaffolding; that is to say, they are functional. Perception therefore becomes historical rather than biological, and therefore, in the project, the user's perception of the PDA must be understood from this historical and hence functional perspective. The user's perception of the PDA was mediated by the functional representations, that is, by the historical human actions they transmitted or communicated and were perceived at the same time by him or her. Since it is filtration that engenders functional representations, perception of the PDA became dependent on the filtration of abstract representations; that is, on the PSPs' various modes of mobility and the clinical actions that conditioned their mobile computing actions. In a generic sense, therefore, if representations of a portable computer turn out to be functional, in other words, if they preserve and transmit historical human actions, then the user will perceive a secondary

artifact, and mobile computing would ensure the manifestation of those historical human actions. To wit, the affordances of portable computers are in their functional representations that mediate users' perception of them (the computers) as secondary.

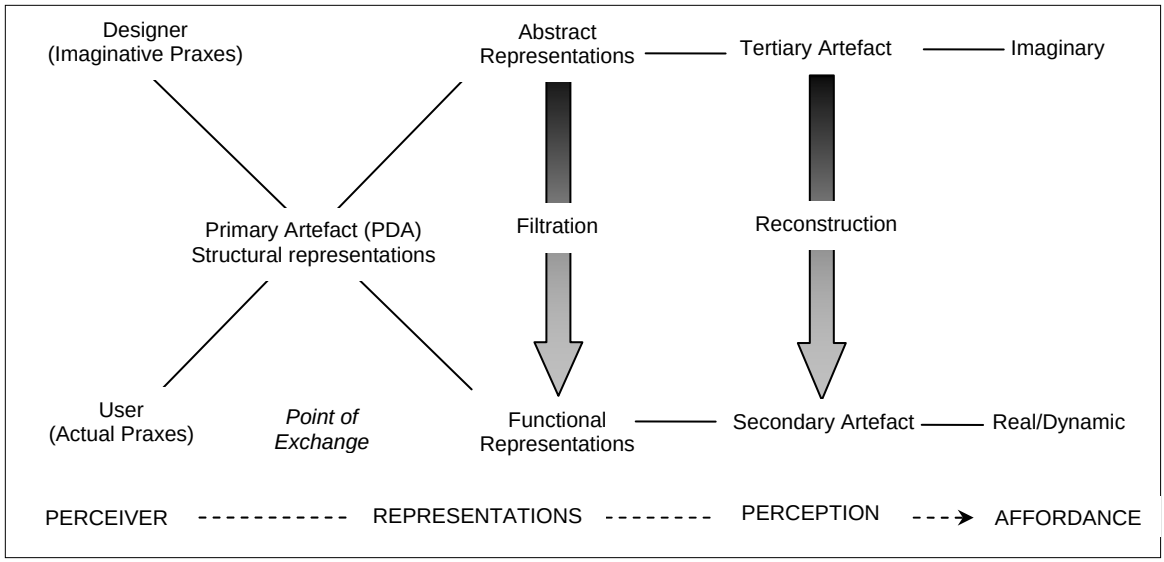
5. Discussion

The PDA is a product of hardware and software designers who aim at producing artifacts to facilitate and enhance human activities. These designers draw upon historical human praxes to develop models aimed at eventually producing artifacts that come as close as possible to actuality. Without doubt, the PDA's hardware and software result from this process. The designers produce these artifacts for society – individuals and organizations – and not for themselves; and this clarifies the fact that PDAs are designed as commodities for exchange and not as products for self-utility (Marx, 1909). The exchange values of commodities coerce their producers to rely on simulations and models of actual human behavior and expectations to deliver their commodities. That is not all: they also follow up with marketing and publicity gimmicks backed by the successful utility of these artifacts in entirely different contexts.

The adoption of the artifact through exchange signifies that the producer's promise and the consumer's expectation have coincided; but it must be noted that, at the point of exchange, the artifact is only promissory in its utility to the consumer. In its promissory state, it is perceived as a primary artifact that is mediated by structural representations of historical human praxes. These representations are the design properties that are externalized by the producer as real objects and internalized (perceived) as sense-data by the user. Here, we are talking mainly about sense-data such as the size of the PDA (through visual and tactile senses), and Graphical User Interface items (through visual and aural senses).

From this exchange point, there is a separation in the modes of representation of the artifact; and perception becomes dependent on the perspective one adopts – designer or user. Obviously, we are interested in understanding the affordances of the artifact and hence in the user's perspective. But this understanding will not be complete unless we fully empathize with the designer's praxes and its resulting representations (see Figure 5).

Figure 5: Representations, Perception and Affordances.



The designer's praxis is imaginative and "off-line"; that is to say, the production of technological artifacts is a mimetic re-enactment of actual historical human praxes. It relies

on imagination to produce tertiary artifacts that communicate abstract representations. Such is the characterization of the PDA: it is inputted with codified operations that mimic historical forms of human actions and operations, however, this inputting relies largely on models and simulations of actual social-historical praxes but are far removed from them.

From the user's perspective, the mode of representation differs from the abstraction that characterizes the tertiary artifact of the designer's viewpoint. The user's praxis is "on-line" and active; that is, the use of a portable computer must achieve real or actual enactments of historical human praxes.

Abstract representations are resultants of the designer's imaginative construction of things that are capable of preserving and communicating historical and time-honored modes of action. This means that the designer's software and applications inputted into a portable computer, and which are reflexive of historical modes of human actions, are functional from his or her point of view. However, from the user's perspective, such 'functional' representations may be abstract beforehand, during or after the use of the artifact depending on the social variables that condition the use of the artifact and associated filtration processes.

The affordance of a portable computer is therefore a direct function of the user's perception of it as a secondary artifact that exudes functional representations of historical human praxes. Since the notion of functional representations implicitly connotes an active interaction (activity-consciousness) between the user and the portable computer; that is to say, since it connotes mobile computing, we must understand affordances of portable computers as non-static and non-passive, but as active and functional phenomena. The active and functional connotation of affordances is in harmony with Ortega y Gasset's (1941) "facilities" and "frustrations" which is shown in his analogy of human-machine interactions. That facilities and frustrations are not properties of the world but properties that lay solely in our "interaction with the world" literally strengthens my claim that affordances of portable computers must not be understood in terms of their static design properties. Rather, they are fluid, dynamic and directly responsive to the functional representations which mediate the user's perception when they are in use.

This understanding of affordances of portable computers therefore underlines the historical epistemology of mobile computing. In other words, affordances of mobile computers are being seen in this historical paradigm not as a constant attribute of artifacts but as a variable whose variability is tied in with the variations of functional representations that mediate the perception of portable computers within mobile computing actions. The continuous variation of perception is seen in its shaping by functional representations and its reshaping of those representations as demanded by particular actions; and herein also lays the continuous construction and reconstruction of artifacts as their representations are conditioned by social variables – particular modes of human mobility and 'true' actions – in an activity. Therefore, the affordance of a portable computer is defined by how social variables filter its abstract representations into functional representations to suit particular demands of emergent human praxes. Filtration and reconstruction are mimeses of humans' production and reproduction of conditions of species existence or survival by means of the creation and manipulation of artifacts. Against this backdrop, the production and reproduction of functional representations vis-à-vis the construction and reconstruction of secondary artifacts reflect the historical essence of the perception of portable computers, and hence of the historical epistemology of mobile computing.

5.1. Implications

The discussions suggest that an understanding of the filters (social variables such as mobility and mobile actions) and the filtration processes (how such social variables filter abstract representations into functional representations) in a mobile activity are essential for

understanding how a portable computer user perceives that artifact, and hence its affordances. Most of the concepts – representations, artifacts, historicity of perception, and perception as action – in themselves are not new; and my discussions clearly show that they are borrowed from Wartofsky. However, the application of these concepts to develop the concept of affordances; and the elucidation of the influential role of mobility and mobile actions in shaping representations, perception and affordances of portable computers are deemed to be distinctive.

Theoretically, the dynamism of affordances introduces a new perspective for analyzing the utility of portable computers in mobile work. By elucidating the crucial roles of perception-as-action and the mediating role of filters and filtration processes in shaping the affordances of mobile computers, I have brought greater understanding to an issue that is not well addressed in existing literature. To the relativist theory of perception in which "seeing" is reconstructed as "seeing as," I will evoke Wartofsky's (1973) answer "If I see you, it's because I want to hit you" and Weick's (1979) dictum "believing is seeing" to endorse my arguments for an historical epistemology of perception, and hence for an historical epistemology of mobile computing. My arguments resonate with Sørensen *et. al*. (2002) who talk about the necessity for mobile artifacts to be designed to exhibit "functional diversity" in the services derivable from them so that they can fit specific types of business needs. They are also in harmony with Mathiassen and Sørensen (2002) who argue for the judgment of organizational technology to be based on their "information services."

The model (Figure 5) embodies the key elements and processes useful for analyzing the utility of portable computers that are deployed to support mobile activities. The integration of mobility, historicity of perception, and interaction between mobile workers and portable computers draws our attention to the fact that the utility of mobile computers in an activity cannot be properly judged with existing conceptualizations of technology affordances (Gaver, 1991). My elucidation of the role of functional representations that ground our understanding of the historicity of perception has implications for how researchers should approach their analysis of mobile computing in a mobile activity, especially on the different representations associated with portable computers and their roles in shaping users' perceptions of them. This implies that to understand the affordances of a portable computer in any mobile activity, the motives driving the activity which that portable computer is mediating should be the unit of analysis instead of the computer per se. It is in the motives driving an activity that we can understand the filters of abstract representations and filtration processes; and it is in the totality of actions constituting the activity that we can understand the filters, potential filters and the filtration processes that engender functional representations.

An historical epistemology of mobile computing also has practical implications in terms of the design of portable computers and their integration into mobile activities. The potential filters and filtration processes that differentiate abstract representations from their functional equivalents are aspects of the model upon which designers can draw requirements for the design of portable computer applications. Although it is obvious that the factory or standard production of portable computers is ever going to remain "off-line," the difference between designers' representations (abstract) and users' representations (functional) should be an issue of concern to both designers and those who champion the integration of portable technologies in mobile activities. For the designer, a wide difference between these representations suggests that their "off-line" imaginative praxes (modeling) is suspect. For the managers who champion the adoption and deployment of such technologies, a wide difference between these representations would suggest that the functions which they intend the technology to perform on their behalf are not being achieved. Thinking of in-house customization of standard technology as we witnessed in the project, these filters and filtration processes become even more important for in-house designers. These designers have to understand

those filters and filtration processes in their requirements elicitation efforts before they can produce designs that exude the optimal number of functional representations at any time. Stated differently, in-house designers must orient towards the achievement of designs in which the difference between their abstract representations and users' functional representations are minimal at any time.

The importance of the time factor is derived from the variations of functional representations that are intrinsically linked with the variability of affordances. The notion of representations is a cognitive phenomenon that is responsive to changing motives of and conditions (social variables) in a mobile activity. The motives driving an activity determine the functional representations; and the conditions are necessarily parameters of different spatial and temporal contexts that are important definers of the undulating mobile work terrain that filter representations. Thus, for the same application designed into a portable computer and being used in a mobile activity, it can exude maximum affordances according to a particular motive and in one mobile condition; but based on a different motive and in another condition, it may give off zero affordance. This implies that the design of portable computer applications must aim for applications that exhibit the necessary malleability that will ensure their adaptability to changing mobile work conditions of mobile workers who will use those applications.

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