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Cognitive, Physical, Sensory, and Functional Affordances in Interaction Design

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…they may indeed look, but not perceive, and may indeed listen, but not understand
Mark 4.12 (NRSV)

Abstract

In reaction to Norman's [1999] essay on misuse of the term affordance in human-computer interaction literature, this article is a concept paper affirming the importance of this powerful concept, reinforcing Norman's distinctions of terminology, and expanding on the usefulness of the concepts in terms of their application to interaction design and evaluation. We define and use four complementary types of affordance in the context of interaction design and evaluation: cognitive affordance, physical affordance, sensory affordance, and functional affordance. The terms cognitive affordance (Norman's perceived affordance) and physical affordance (Norman's real affordance) refer to parallel and equally important usability concepts for interaction design, to which sensory affordance plays a supporting role. We argue that the concept of physical affordance carries a mandatory component of utility or purposeful action (functional affordance). Finally, we provide guidelines to help designers think about how these four kinds of affordance work together naturally in contextualized HCI design or evaluation.

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1. Introduction

Reacting to his urge to speak up while lurking among CHI-Web discussants over-using and misusing the term affordance, Don Norman was compelled to explain the concept of affordance in his essay [1999], 'Affordance, conventions, and design'. We[1] agree with most of what Norman said, but feel there is more to be said about the concept of affordance, especially to the end of making it a useful and applicable concept for usability designers and practitioners. Since Norman encouraged it in his opening paragraph: 'Hope it doesn't stop the discussion again' [Norman, 1999], we decided to add to the discussion, affirming the importance of this powerful concept, reinforcing Norman's distinctions of terminology, and adding some of our own ideas about applying affordance to interaction design and evaluation.

1.1. The importance of semantics and terminology

This is a concept paper, not a methodology paper or a report of an empirical study. The epistemological cycle in the science of human-computer interaction (HCI), as in most disciplines, alternates empirical observation with theory formulation to explain and predict the observed. Norman's stages of action model [1986] is a practical example of HCI theory, in that it explains and predicts what users do while interacting with systems (from refrigerators to computers) to accomplish goals in a work domain. It is our intention here to develop more fully some key concepts as a contribution to that kind of HCI theory.

In essence this paper is about semantics and terminology to express semantics. HCI is a relatively young field and the terminology we require for discussing, analyzing, and applying

[1] Although this is a single-author paper, most of it is written in first person plural to acknowledge much help from many HCI colleagues at Virginia Tech.

our concepts with a common understanding is incomplete. The terms we use for concepts are not inherently important, but the semantics behind the terminology commands our attention. In response to, 'It's just semantics,' we heartily agree with Allen and Buie [2002, p. 21] who proclaim: 'Let us say it outright: There is no such thing as *just* semantics. . . . In communication, nothing is more important than semantics.' Allen and Buie [2002, p. 18] are dead on: 'This isn't just nit-picking—a rich and evocative word like *intuitive* is wasted as long as it sits in a fog of uncertain associations.' This statement was never more true than it is for the term affordance, as Norman's essay [1999] attests. Shared meanings and representations (through common language) are an absolute must in science, art, and everything in-between.

1.2. Gibson on affordance

Norman begins by referring to Gibson's earlier definitions of afford and affordance [1977; 1979], as well as to discussions he and Gibson have had about these concepts. Setting a paraphrase of Gibson [1979, p. 127] within an HCI design context, affordance as an attribute of an interaction design feature is what that feature offers the user, what it provides or furnishes. Here Gibson is talking about physical properties, what Norman calls real affordances. Gibson gives an example of how a horizontal, flat, and rigid surface affords support for an animal. In his ecological view, affordance is reckoned with respect to the user, in this case the animal, who is part of the affordance relationship. Thus, as Norman [1999] points out, Gibson sees an affordance as a physical relationship between an actor (e.g., user) and physical artefacts in the world reflecting possible actions on those artefacts. Such an affordance does not have to be visible, known, or even desirable.

1.3. Norman on affordance

In his article, Norman [1999] takes issue with a common and growing misuse (or perhaps uninformed use) of the term affordance. In simple terms, much of the difficulty stems from confusion between what Norman calls real affordance and perceived affordance. To Norman [1999], the unqualified term affordance refers to real affordance, which is about physical characteristics of a device or interface that allow its operation, as described by Gibson in the previous section. However, in many HCI and usability discussions the term is also used without qualification to refer to what Norman calls perceived affordance, which is about characteristics in the appearance of a device that give clues for its proper operation. Since the two concepts are very different, perhaps orthogonal, Norman admonishes his readers not to misuse the terms and, in particular, not to use the term affordance alone to refer to his concept of perceived affordance and, perhaps, not to use these terms at all without understanding the difference.

1.4. Seeking a balance for interaction designers

In these admonishments [1999], Norman focuses mainly on real affordance. We believe that what Norman calls perceived affordance has an equally important role, perhaps even a starring role, in interaction design. We know that Norman believes this, too. In his book Design of Everyday Things [Norman, 1990], sometimes called the DOET book – formerly Psychology of Everyday Things [Norman, 1988], known as the POET book – Norman describes his struggles with refrigerators, British water taps, and other physical devices and says much about perceived affordances in the context of problems that users of these devices have in determining how to operate them. Norman feels that DOET might have played a part in the confusion of terms because, as he says [1999], 'I was really talking about perceived affordances, which are not at all the same as real ones'. However, in the course of emphasizing the difference in his more recent article, we feel that the importance of perceived affordances became somewhat lost, leaving researchers and practitioners in a quandary about how we can legitimately refer to this important usability concept. In hopes of a remedy we offer a perspective on the concept of affordance that has been working for us. We would like to strike a balance and we think Norman would approve.

1.5. Objectives

We think it is healthy when an article like Norman's leads to a follow-up discussion, especially about a topic essential to interaction design. In that spirit, this is not a critique or rebuttal. Rather, Norman has called for understanding of these concepts, and has highlighted the problem of inadequate terminology. We wish to respond to that call by suggesting terminology for four kinds of affordance without violating Norman's or Gibson's basic precepts but, in fact, amplifying and extending them in a useful way. Like Norman, we would like to see these concepts understood and properly distinguished in their use by researchers and practitioners alike. In the process, we would also like to give Norman credit for a broader contribution in his stages-of-action model [Norman, 1986] than perhaps he may have given himself.

We have named the different kinds of affordances for the role they play in supporting users during interaction, reflecting user processes and the kinds of actions users make in task performance. Norman's perceived affordance becomes cognitive affordance, helping users with their cognitive actions. Norman's real affordance becomes physical affordance, helping users with their physical actions. We add a third kind of affordance that also plays an important role in interaction design and evaluation, sensory affordance, helping users with their sensory actions. A fourth kind, functional affordance, ties usage to usefulness. We offer guidelines for considering these kinds of affordance together in a design context.

2. Related work

2.1. Calibrating terminology

Since Norman brought the term affordance into common usage in the HCI domain with his book Design of Everyday Things [Norman, 1990], the term has appeared many times in the literature. For example, an interesting recent treatment by Thimbleby shows how key aspects can be formalised as mathematical symmetry [2002].

In this section, we show the relationships among others' use of the terminology and ours. In so doing, we give a preview of our definitions and usage, along with a rationale for our particular choices.

Beyond Gibson and Norman, McGrenere & Ho [2000] and Gaver [1991] have influenced our thinking about affordances. McGrenere & Ho [2000] give credit to Gibson for originating the concept of affordance in psychology and to Norman for introducing this important concept into human-computer interaction. McGrenere & Ho also target current misuse and confusion of terms, noting the need to clarify the concepts for effective communication among researchers and practitioners and make a connection to usability design. Gaver [1991] sees affordances in design as a way of focusing on strengths and weaknesses of technologies with respect to the possibilities they offer to people who use them. Gaver also summarizes his view of the Gibson and Norman contributions. He extends the concepts by showing how complex actions can be described in terms of groups of affordances, sequential in time and/or nested in space, showing how affordances can be revealed over time, with successive user actions, for example, in the multiple actions of a hierarchical drop-down menu. That McGrenere and Ho [2000] also needed to calibrate their terminology against Gaver's further demonstrates the difficulty of discussing these concepts without access to a richer, more consistent vocabulary. Table 1 shows how various authors use the terminology, compared to usage in this paper.

Table 1. Comparison of affordance terminology

Hartson	**Physical affordance**	**Cognitive affordance**	**Sensory affordance**
Gibson	Affordance	Perceptual information about an affordance	Implied
Norman	Real affordance	Perceived affordance	Implied
McGrenere & Ho	Affordance	Perceptual information about an affordance	Indirectly included in perceptibility of an affordance
Gaver	Affordance, also perceptible affordance	Perceptual information about an affordance, also apparent affordance	Indirectly included in perceptibility of an affordance

In most of the related literature, design of cognitive affordance (whatever it is called in a given paper) is acknowledged to be about design for the cognitive part of usability, ease-of-use in the form of learnability for new and intermittent users (who need the most help in knowing how to do something). But the concept gets confused because a cognitive affordance is variously called a perceived affordance, an apparent affordance, or perceptual information about an affordance.

What McGrenere & Ho and Gaver simply call an affordance and what Norman calls a real affordance is, by and large, what we call a physical affordance, offered by artefacts that can be acted upon or physically manipulated for a particular purpose. All authors who write about affordances give their own definitions of the concept, but almost no one, including Norman [1986] (who, to be fair, intended to focus on the cognitive side) and McGrenere & Ho [2000] (e.g., in their Section 6.2), mentions design of physical affordances. Design of physical affordances is about design for the physical action part of usability, ease-of-use in the form of high performance and productivity for experienced and power users as well as to help disabled users achieve maximum efficiency in physical actions. McGrenere & Ho come close to recognizing this role of physical affordance in design in the discussion about their Figure 4, which relates cognitive affordance and physical affordance to design improvement.

Most other authors, including those in Table 1, include sensory affordance only implicitly and/or lumped in with cognitive affordance rather than featuring it as an separate explicit concept. Thus, when these authors talk about perceiving affordances, including Gaver's and McGrenere & Ho's phrase 'perceptibility of an affordance', they are referring (in our terms) to a combination of sensing (e.g., seeing) and understanding physical affordances through sensory affordances and cognitive affordances. Gaver refers to this same mix of affordances when he says, 'People perceive the environment directly in terms of its potential for action'. As we explain in the next section, our use of the term 'sense' has a markedly narrower orientation on sensory inputs such as seeing and hearing.

2.2. Level setting

Why maintain separate terms and concepts when they are to be integrated in design, anyway? The answer is simply that the differences among these concepts requires that each type of affordance must be identified for what it is and considered on its own terms in analysis and design. Each type of affordance plays a different role, uses different mechanisms, corresponds to different kinds of user actions, exhibits different characteristics, has different requirements for design, and implies different things in evaluation and diagnosis.

In this section we articulate a rationale for boundaries in the particular use of psychological terminology in the context of affordances, guided by a motivation to clearly bring out issues of HCI design and analysis. The concepts of sensing, perception, and cognition all have a large scope in their broadest interpretation, too broad for isolating the HCI design factors of affordances. In the general context of psychology, these concepts are more intertwined than orthogonal. To avoid this intertwining we use, for example, the term 'sensing' instead of 'perception' in most places, because perception usually embraces significant cognition [Hochberg, 1964]. Our motivation for attempting a degree of arbitrary compartmentalization, via reasonable operational definitions that work on a practical level for design, is that the HCI design issues we wish to associate with these levels of user actions <u>are</u> mostly orthogonal.

While overlapping and borderline cases are interesting to psychologists, HCI designers want to avoid marginal design and ensure that designs work for wide-ranging user characteristics. An abstraction that separates the types of user actions (e.g., sensing from cognition) removes the overlap. As an illustration, consider text legibility, which at a low level is about identifying shapes in displayed text as letters in the alphabet, but not about the meanings of these letters as grouped into words and sentences. Text legibility is an area where user perception, sensing, and cognition can overlap. To make out text that is just barely or almost barely discernable, users can augment or mediate sensing with cognition, using inference and the context of words in a message to fill in the blanks. Context can make some candidate letters more likely than other. Users can recognize words in their own language more easily than words in another language or in nonsense letter combinations.

In contrast, HCI design in this context requires solutions resolved on the side of pure sensing. Simply put, a label in a user interface that cannot be fully discerned by the relevant user population, without reliance on cognitive augmentation, is a failed HCI design. Thus, we wish to define sensing at a level of abstraction that eliminates these cases of borderline user performance so that HCI designers can achieve legibility, for example, beyond question for the target user community. We desire an understanding of affordance that will guide the HCI designer to attack a text legibility problem by adjusting the font size, for example, not by adjusting the wording to make it easier to deduce text displayed in a tiny font.

In our abstraction, a user's sensory experience can include gestalt aspects of object appearance and perceptual organisation [Arnheim, 1954; Koffka, 1935], such as figure/ground relationships, and might sometimes include some judgment and lexical and syntactic interpretation in the broadest spatial or auditory sense (e.g., what is this thing I am seeing?), but does not get into semantic interpretation (e.g., what does it mean?). In the context of signal processing and communications theory, this kind of sensing would be about whether messages are received correctly, but not about whether they are understood.

A discussion of HCI design without the kind of abstraction we propose can degenerate to hair splitting about levels of human information processing that distract from the practical design issues, further putting off practitioners who may already believe that concepts like affordance are just fodder for academic exercises.

3. Our proposal

To pursue the objectives of Section 1.5, specifically in the context of interaction design and evaluation for computer-based systems, we propose (the essence of the value-added in this article):

1. to clarify and define the terms cognitive affordance and physical affordance to refer to parallel and equally important usability concepts for interaction design,
2. that the concept of physical affordance carries a mandatory component of utility or purpose, which we call functional affordance, and that statements about physical affordance must include a reference to that purpose,
3. to add the concept of sensory affordance, supporting cognitive affordance and physical affordance in design, and
4. that cognitive, physical, sensory, and functional affordance be connected and considered together in any HCI design or evaluation context.

3.1. Cognitive and physical affordance – an alliance in design

The relevant part of what my dictionary says about 'to afford' is that it means to yield, to give, or to furnish. In design, an affordance gives or provides something that helps a user do something. For example, the study window in my house affords me a fine view of the forest; the window helps me see that nice view. Norman's stages-of-action model [1986] describes the typical course of interaction between a human user and a computer or any kind of machine. During interaction, a user performs cognitive, physical, and sensory actions and requires affordances to help with each. In our work on the User Action Framework [Andre, Hartson, Belz, & McCreary, 2001; Andre, Belz, McCreary, & Hartson, 2000; Hartson, Andre, Williges, & van Rens, 1999], based on Norman's model, we have also found a need for all four kinds of affordance in the context of interaction design and usability. It is in that context that we offer these definitions.

A cognitive affordance is a design feature that helps, aids, supports, facilitates, or enables thinking and/or knowing about something. As a simple example, clear and precise words in a button label could be a cognitive affordance enabling users to understand the meaning of the button in terms of the functionality behind the button and the consequences of clicking on it. A physical affordance is a design feature that helps, aids, supports, facilitates, or enables physically doing something. Adequate size and easy-to-access location could be physical affordance features of an interface button design enabling users to click easily on the button. Since physical affordance occurs with physical objects, I am treating active interface objects on the screen, for example, as real physical objects, since they can be on the receiving end of real physical actions by users. As many in the literature have pointed out, it is clear that a button on a screen cannot be pressed. Restricting the discussion to clicking on buttons easily dispatches this difficulty.

Norman [1999, p. 41] says that symbols and constraints are not affordances and that wording in the label on a button, for example, is symbolic communication. We agree, but under our definition, communication is exactly what makes good wording effective as a cognitive affordance: something to help the user in knowing (e.g., knowing what to click on). We see symbols, constraints, and conventions as essential underlying mechanisms that make cognitive affordances work, as Norman says, as 'powerful tools for the designer'. As Norman further says, the only way we know for sure if users share designers' perceptions of these symbols and conventions is by usability data. Thus, and we think this is a point that

Norman particularly had in mind in his article, if a designer claims to have 'added an affordance' to the interaction design, that in itself says nothing about usability.

In the DOET [Norman, 1990] tradition, we illustrate with a simple and ubiquitous non-computer device, a device for opening doors. The hardware store carries both round doorknobs and lever type door handles. The visual design of both kinds conveys a cognitive affordance helping users think or know about usage through the implied message their appearance gives to users: 'This is what you use to open the door'. The doorknob and lever handle each suggests, in its own way, the grasping and rotating required for operation. Again, we agree with Norman in noting that the message implied is based on convention and there is nothing intrinsic in the appearance of a doorknob that necessarily conveys this information. On another planet, it could seem mysterious and confusing, but for us a doorknob is an excellent cognitive affordance because almost all users do share the same easily recognized cultural convention.

Door operation devices also provide physical affordance, to help users do the opening and closing – some better than others. For example, many users prefer the lever type to a round knob because the lever is easier to use with slippery hands or by an elbow when the hands are full. The push bar on double doors in another example of a physical affordance helpful to door users with full hands.

Sometimes the physical affordance to help a user open a door is provided by the door itself; people can open some swinging doors by just pushing on the door. In such cases designers often help users by installing, for example, a brass plate to show that one should push and where to push. Even though this plate might help avoid handprints on the door, it is a cognitive affordance and not a real physical affordance, because it adds nothing to the door itself to help the user in the physical part of the pushing action. Sometimes the word ‘Push’ is engraved in the plate to augment the clarity of meaning of the plate as a cognitive affordance.

Similarly, sometimes the user of a swinging door must open it by pulling. The door itself does not usually offer sufficient physical affordance for the pulling action, so a pull handle is added. A pull handle offers both cognitive and physical affordance, providing a physical means for pulling as well as a visual indication that pulling is required.

Norman discusses many such everyday devices in his DOET book [1990] and makes it clear that, when he speaks of knowing how to operate a device, he is referring to cognitive (perceived, in his terminology) affordance, characterizing a view of cognitive affordance that we share [Norman, 1999, p. 39]: ‘When you first see something you have never seen before, how do you know what to do? The answer, I decided, was that the required information was in the world: the appearance of the device could provide the critical clues required for its proper operation’. However, when Norman later says that affordances play a relatively minor role in the world of screen-based systems [1999, p.39], he clearly is talking about physical affordances (and the statement is true only if one is not concerned with design factors for physical actions, such as those involving Fitts’ law [MacKenzie, 1992], physical disabilities, or the physical characteristics of interaction devices). And we think Norman would agree that cognitive affordances play an enormously important role in interaction design; cognitive affordances are one of the most significant user-centred design features in present-day interactive systems, screen-based or otherwise. They are the key to answering Norman’s question: ‘How do you know what to do?’ And, yes, the design of cognitive affordances can depend greatly on cultural conventions as a common base for communicating the meaning of visual cues from designer to user.

Continuing in the DOET tradition of non-computer examples, we have known many different kinds of wine bottle openers, possessing a range of effectiveness. Although most people understand how to use the kinds of openers shown in Figure 1, their design could offer better physical affordance, to help the user in doing the physical task for which they were intended. Because of somewhat crude mechanical operation, they often manage to crumble the cork, leaving bits unappetizingly bobbing in the newly liberated libation.

Figure 1. Ordinary cork pullers with acceptable cognitive affordance

In contrast a colleague, Roger Ehrich, recently gave me the marvelously efficient and reliably effective cork puller shown in Figure 2.

Figure 2. A cork puller with good physical affordance but non-obvious cognitive affordance

The problem with this device, though, is that its proper use was initially anything but obvious to me. For the sake of science, we have been increasing the frequency of informal user-based tests and find that an average of more than nine out of ten wine-drinking guests who have not seen this design before cannot determine how to use it in a reasonably short time. This device offers excellent physical affordance to help in doing the task, making it a good design for an experienced user such as a wine steward. However, it does not offer good cognitive affordance for helping intermittent and first-time users know or learn how to use it.

The secret to operation lies in shifting between modes in a classic case of moded design: there are two states, and in each state user actions and inputs have meanings and outcomes that are different from those of the other state (see Chapter 11 of Thimbleby [1990]). The thick piece of metal connecting the T-handle to the threaded shaft, at the left of Figure 2, is what makes this opener different from most others. By swiveling, it functions as a kind of 'gear shift' that changes the way the threads are engaged, lending the modality to the design.

Figure 3 shows the T-handle moved to the top of the threaded shaft and the shifting mechanism in the centre has locked the T-handle to a fixed position on the threaded shaft. When the T-handle is rotated in this cork engagement mode, the threaded shaft turns and the corkscrew at the bottom dives deftly into the cork.

Figure 3. T-handle locked to threaded shaft in the cork engagement mode

Then the shifting mechanism is swiveled, unlocking the T-handle from the shaft, putting the device in lifting mode. When the T-handle is now turned (in the same direction as before), the shaft does not turn but the T-handle moves along the threads on the shaft, lifting the cork, as in Figure 4.

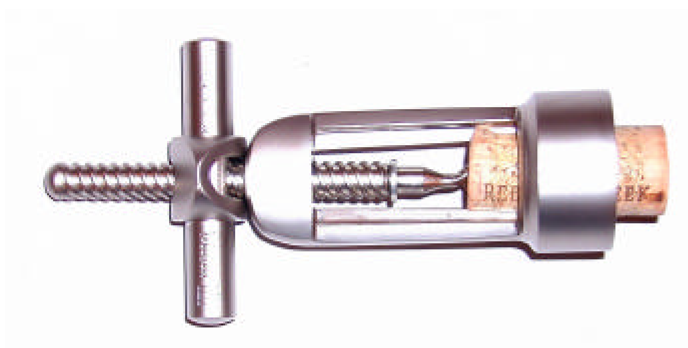


Figure 4. T-handle moving on the shaft threads in lifting mode

3.2. Functional affordance – design for purposeful action

The second part of our proposal is to bring Gibson's ecological view into contextualized HCI design by including a purpose in the definition of each physical affordance. Putting the user and purpose of the affordance into the picture harmonizes nicely with our interaction- and user-oriented view in which <u>an affordance helps or aids the user in doing something</u>.

As Norman points out [1999, p. 40], his own definition of (physical) affordance means that all interface designs afford clicking anywhere on the screen, whether a button is there or not, except where the pointer is constrained from being in certain parts of the screen (a hypothetical condition that Norman introduced to make his point). But that kind of clicking is without reference to a purpose and without the requirement that any useful reaction by the system will come of it. But, of course, we need more than that in a task-oriented context of interaction design, where user actions are goal-oriented and purposeful. A user doesn't click on the screen just because it's possible. A user clicks to accomplish a goal, to achieve a purpose (e.g. clicking on a user interface object, or artefact, to select it for manipulation or clicking on a button labeled 'Sort' to invoke a sorting operation). So, if designers or users say this button affords clicking, we would understand this to mean the button is sensitive to clicking in the sense that the system will usefully respond to clicking. But even this interpretation does not go far enough to meet our proposed requirement to associate purpose with physical affordance. It is more useful to be specific about the purposeful response and say that the button affords clicking to initiate, for example, the Sort function. A blank space on the screen next to the button, or another button elsewhere on the screen, does not provide that same kind of physical affordance. Adding the purpose for a physical affordance adds sense and a goal orientation to a design discussion.

The study window in my house affords me a fine view of the forest, but I have to participate by looking through the window to accrue the benefit of seeing that view. Gibson implicitly included reference to purposeful enablement: a horizontal, flat, rigid surface affords an animal to stand, walk, or run. Gibson is indeed talking here about purposeful activity, as he is in the discussion [1979], for example, about how objects (artefacts) afford manipulation (e.g. a pole that can be used by a chimpanzee as a rake to reach a banana).

In Norman's DOET world of non-computer devices, a purpose for a physical affordance is always implied. The doorknob is a cognitive and physical affordance for operating the door. The physical affordance offered by a doorknob does not mean merely that the doorknob can be grasped and turned. It means that the doorknob can be grasped and turned in order to operate (e.g. invoke the function or mechanism of opening) the door; the user is enabled to operate the door. In turn, the door itself is a functional affordance that, when invoked, allows passage. In this interaction design view, a physical affordance gives access to functionality, the *purpose* of the physical affordance used to access it.

McGrenere & Ho [2000] also refer to the concept of application functionality usefulness, something they call 'affordances in software'. In an external view it is easy to see a system function as an affordance because it helps the user do something in the work domain. This again demonstrates the need for a richer vocabulary, and conceptual framework, to take the discussion of affordances beyond user interfaces to the larger context of overall system design. We use the term *functional affordance* to denote this kind of higher-level user enablement in the work domain.

As McGrenere & Ho [2000] point out, requiring purposeful action as a component of physical affordance nicely substantiates the dual concepts of usability and usefulness [Landauer, 1995]. Usefulness stems from the utility of functional outcomes of user actions. In contrast, usability stems from the effectiveness of cognitive affordances for understanding how to use physical affordances, from the physical ease of using the physical affordances, and from the sensing of these via sensory affordances.

In sum, the addition of purpose to the description of a physical affordance is an obvious extension, but it should be made explicit, to avoid the ambiguities Norman has described. This extension to the concept of physical affordance might possibly go beyond what either Gibson or Norman had in mind, but we think it makes sense and is not difficult to justify in the domain of design.

3.3. Sensory affordance – a supporting role

The third part of our proposal is to include the concept of sensory affordance. A sensory affordance is a design feature that helps, aids, supports, facilitates, or enables the user in sensing (e.g., seeing, hearing, feeling) something. Sensory affordance includes design features or devices associated with visual, auditory, haptic/tactile, or other sensations. Cognitive affordance and physical affordance are stars of interaction design but sensory affordance plays a critical supporting role. In short, sensory affordance can be thought of as an attribute of cognitive affordance or physical affordance; users must be able to sense cognitive affordances and physical affordances in order for them to aid the user's cognitive and physical actions. Sensing cognitive affordances is essential for their understanding, and sensing physical affordances is essential for acting upon them. Sensory affordance issues of user interface artefacts include noticeability, discernability, legibility (in the case of text), and audibility (in the case of sound). In the concept of sensory affordance, as we explained in Section 2.2, we have deliberately included only the physical act of sensing and not any of the cognitive aspects that are often associated with the term perception.

3.4. Contextualized design as nexus of affordance roles

The fourth part of our proposal is to connect all four kinds of affordance in a design context. To put Gibson's ecological view in HCI terms, affordances have a relational ontology: their existence as an affordance is relative to the environment of users and usage. In HCI, the user's environment is the work context plus the interaction design. To accomplish work goals, the user must sense, understand, and use affordances within an interaction design. Gaver [1991] says that affordances are a powerful approach for thinking about technology because the effectiveness of an affordance depends on the attributes of both the artefact and the user. The concept of affordance is an instrument for focusing on links in design among the user, the actions, and the artefacts. The user's path from sensing to cognition to action shows how each affordance role is involved in both learning about (ease of learning) and using (ease of use) artefacts. The idea is to include both user and artefact attributes in affordance designs as part of the complementarity that Gaver describes, between actor and acted-upon environment. Gaver's ecological perspective offers a succinct approach to artefact design through an immediate connection between cognitive and physical affordances.

In Gestalt psychology [Koffka, 1935], well before Gibson or Norman, we see the connection of cognitive affordance to physical affordance and its purpose [Gibson, 1979, p. 138]. The meaning or value or use of a thing can be seen and understood through that object (at least if an effective design or cultural convention supports it), just as one can see its size or colour. Similarly, we design human-computer interaction for the user to understand the operation and purpose of a physical affordance through sensing (via sensory affordances) and understanding associated cognitive affordances.

Norman [1999, p. 41] says, 'Affordances (*meaning physical affordances*) specify the range of possible activities, but affordances are of little use if they aren't visible to the users', meaning 'visible' in both the sensory (detectable or observable) and cognitive sense (understandable). Physical affordance is associated with the 'operability' characteristics of user interface artefacts. Cognitive affordance is associated with semantics or meaning of user interface artefacts. Sensory affordance is associated with the 'sense-ability' characteristics of user interface artefacts, especially of physical affordances and cognitive affordances. In the domain of human-computer interaction, as in the domain of everyday physical devices, design is what connects physical affordances to the cognitive affordances that 'advertise' them and explain how to use, when to use, and whether to use each physical affordance. Design is also what connects sensory affordances to cognitive and physical affordances, so they can be seen or heard or felt (and eventually tasted or smelled) to be used. Table 1 contains a summary of these affordance types and their roles in interaction design.

Table 1. Summary of affordance types

Affordance Type	**Description**	**Example**
Cognitive affordance	Design feature that helps users in knowing something	A button label that helps users know what will happen if they click on it
Physical affordance	Design feature that helps users in doing a physical action in the interface	A button that is large enough so that users can click on it accurately
Sensory affordance	Design feature that helps users sense something (especially cognitive affordances and physical affordances)	A label font size large enough to read easily
Functional affordance	Design feature that helps users accomplish work (i.e., the usefulness of a system function)	The internal system ability to sort a series of numbers (invoked by users clicking on the Sort button)

3.4.1 A positive association of affordance roles as structured HCI design guidance

A design methodology based solely on affordance concepts cannot substitute for an effective design methodology set in a complete development life cycle [Hix & Hartson, 1993; Mayhew, 1999; Rosson & Carroll, 2002]. However, we do offer some guidelines to urge designers to think about how these four kinds of affordance work together naturally in the design of a user interface (or other) artefact.

McGrenere & Ho (Section 6.4 of [2000]) also allude to the possibility of affordances as a framework for design. But they, too, fall short of prescribing a design methodology based on affordances. It is plausible to codify and integrate affordance concepts so that they can be brought to bear systematically in interaction design, but the resulting approach would have to be evaluated in a summative study before one could make claims about the efficacy of this approach as a 'method'. Nonetheless, it is incumbent on HCI theory to find useful application to HCI design and analysis.

In the case of affordances, the theory offers a way to tie the different kinds of affordance to the HCI (or any human-machine interaction) design process in an organised way. HCI design must address (at least) two components, tasks and artefacts [Carroll, Kellogg, & Rosson, 1991]. For developing the work flow of an application, task analysis is useful to inventory the tasks, and usage scenarios [Rosson & Carroll, 2002] are necessary to guide design. Affordance theory can guide design of HCI artefacts. Each kind of affordance plays a different role in the design of different attributes of the same artefact, including design of appearance, content, and manipulation characteristics to match users' needs, respectively, in the sensory, cognitive, and physical actions they make as they progress through the cycle of actions during task performance. As Gaver [1991, p.81] says, thinking of affordances in terms of design roles 'allows us to consider affordances as properties that can be designed and analysed in their own terms.' Additionally, even though the four affordance roles must be considered together in an integrated view of artefact design, these words from Gaver speak to the need to distinguish individually identifiable affordance roles.

As an example of how the concepts might guide designers, suppose the need arises in an interaction design for a button to give the user access to a certain application feature or functionality. The designer would do well to begin by asking if the intended functionality, the functional affordance, is appropriate and useful to the user. Further interaction design questions are moot until this is resolved positively.

The designer is then guided to support cognitive affordance in the button design, to advertise the purpose of the button by ensuring, for example, that its meaning (in terms of a task-oriented view of its underlying functionality) is clearly, unambiguously, and completely expressed in the label wording, to help the user know when it is appropriate to click on the button while performing a task. Then, the designer is asked to consider sensory affordance in support of cognitive affordance in the button design, requiring an appropriate label font size and colour contrast, for example, to help the user discern the label text to read it.

The designer is next led to consider how physical affordance is to be supported in the button design. For example, the designer should ensure that the button is large enough to click on it easily to accomplish a step in a task. Designers should try to locate the button near other artefacts used in the same and related tasks, to minimize mouse movement between task actions. Finally, the designer is guided to consider sensory affordance in support of physical affordance in the button design by ensuring that the user notices the button, so it can be clicked. For example, the button must be a colour, size, and shape that make it noticeable and must be located in the screen layout so that it is near enough to the user's focus of attention. If the artefact is a feedback message, it also requires attention to sensory affordance (e.g., to notice the feedback), cognitive affordance (e.g., to understand what the message says about a system outcome), and physical affordance (e.g., to click on a button to dismiss the message box).

In sum, the concept of affordance does not offer a complete prescriptive approach to interaction design but does suggest the value of considering all four affordance roles together in design of an interaction artefact by asking (not necessarily always in this order):

1. Is the functionality to which this interaction or artefact gives access useful in achieving user goals through task performance (functional affordance, or purpose of physical affordance)?
2. Does the design include clear, understandable cues about how to use the artefact (cognitive affordance), or about system outcomes if the artefact is a feedback message?
3. Can users easily sense the visual (or other) cues about artefact operation (sensory affordance in support of cognitive affordance)?
4. Is the artefact easy to manipulate by all users in the target user classes (physical affordance)?
5. Can users easily sense the artefact for manipulation (sensory affordance in support of physical affordance)?

Considering one affordance role but ignoring another is likely to result in a flawed design. For example, if the wording for a feedback message is carefully crafted to be clear, complete, and helpful (good cognitive affordance), but users do not notice the message because it is displayed out of the users' focus of attention (poor sensory affordance) or users cannot read it because the font is too small, the net design is ineffective. A powerful drag and drop mechanism may offer a good physical affordance for opening files, but lack of a sufficient cognitive affordance to show how it works could mean that most users won't use it.

An example of a way that cognitive affordance and physical affordance work together in interaction design can also be seen in the context of designing constraints for error avoidance. 'Graying out' menu items or button labels to show that inappropriate choices are unavailable at a given point within a task is a simple, but effective, error avoidance design technique. This kind of cognitive affordance presents to the user a logical constraint, showing visually that this choice can be eliminated from possibilities being considered at this point. In that sense, the grayed-out label is a cognitive affordance on its own, quite different from the cognitive affordance offered by the label when it is not grayed out.

If cognitive and physical affordances are connected in the design, a grayed-out button or menu choice also indicates a physical constraint in that the physical affordance usually offered by the menu item or button to access corresponding functionality is disabled so that a persistent user who clicks on the grayed-out choice anyway cannot cause harm. Because these two aspects of graying-out work together so well, many people think of them as a single concept, but the connection of these dual aspects is evident to the user interface programmer, who usually must make separate commands or declarations for the cognitive and the physical parts – to gray out the displayed label appearance and to disable the artefact behaviour so it will not respond to a click.

3.4.2 False cognitive affordances misinform and mislead

Because of the power of cognitive affordances to influence users, designers must be aware of their responsibility to use them with caution. When cognitive affordances don't telegraph physical affordances or, worse, when cognitive affordances falsely telegraph physical affordances, users encounter errors. Gibson calls this 'misinformation in affordances'; for example, as conveyed by a glass door that appears to be an opening but doesn't afford passage. Draper and Barton [1993] call these 'affordance bugs'.

Sometimes a door has both a push plate and a pull handle as cognitive affordances in its design. The user sees this combination of cognitive affordances as an indication that either pushing or pulling can operate this as a swinging door. When the door is installed or constrained so that it can swing in only one direction, however, the push plate and pull handle introduce misinformation in the cognitive affordances that interfere with the design as a connection to physical affordances. We know of a door with a push plate and a pull handle that was installed or latched so that it could only be pushed. A 'Push' sign had been added, perhaps to counter the false cognitive affordance of the pull handle. The label, however, was not always enough to overcome the power of the pull handle as a cognitive affordance; we observed some people still grab the handle and attempt to pull the door open.

Another example of a false cognitive affordance showed up in a letter recently received from an insurance company. There was a form at the bottom to fill out and return, with this line appearing just above the form:

- Do not detach -

Because that dashed line looked so much like the usual ‘Cut on this line to detach’ cognitive affordance, I almost did detach the form before realizing that the information above, identifying me as a customer, would be lost if I did.

Examples of false cognitive affordances in user interfaces abound. A common example is seen in Web page links that look like buttons, but don’t behave like buttons. The gray background to the links in the top menu bar of a digital library Web site, Figure 5, makes them seem like buttons. A user might click on the background, assuming it is a button, and not get any result. Because the ‘button’ is actually just a hyperlink, it requires clicking exactly on the text.

Figure 5. False cognitive affordances in a menu bar with links that look like buttons

Below-the-fold issues on Web pages can be compounded by having a horizontal line on a page that happens to fall at the bottom of a screen. Users see the line (as a false cognitive affordance) and assume that it is the bottom of the page, and so do not scroll, missing possibly vital information below.

Sometimes a false cognitive affordance arises from deliberate abuse of a shared convention to deceive the user. Some designers of pop-up advertisements ‘booby trap’ the ‘X’ box in the upper right hand corner of the pop-up window, making it a link to launch one or more new pop-ups when users click on the ‘X’, trapping users into seeing more pop-up ads when their intention clearly was to close the window.

McGrenere & Ho [2000] make a point that the case in their Figure 2 labeled ‘false affordances’ is problematic because ‘it is not the affordance that is false; rather, it is the information that is false' [McGrenere & Ho, 2000, p. 5]. Affordance roles can help clarify this kind of discussion by allowing us to say that a cognitive affordance (the information McGrenere and Ho refer to) can be considered false when it indicates something about a physical affordance that doesn't exist or indicates something incorrect about a physical affordance that does exist.

As another example, I have a radio with a slider switch for selecting between stereo and monaural FM reception, sketched in Figure 6a. The names for the switch positions (Stereo, Mono) are a good match to the user's model, but the arrows showing which way to slide the switch are unnecessary and introduce confusion when combined with the labels.

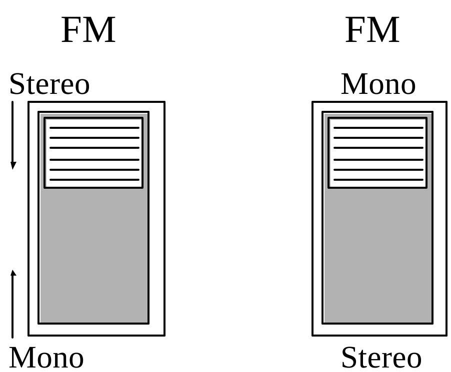


Figure 6. Radio switch with mixed affordances
a. existing design b. better design

The design has mixed cognitive affordances: the names of the modes at the top and bottom of the switch are such a strong cognitive affordance for the user that they conflict with the arrows. The arrows in Figure 6a call for moving the switch up to get monaural reception and down to get stereo. At first glance, however, it looks as though the up position is for stereo (toward the 'stereo' label) and down is for monaural, but the arrows make the meaning exactly the opposite. The names alone, as shown in Figure 6b, are the more normal and natural way to label the switch.

4. The user's role in evaluation and redesign – a trail of user-made artefacts

It is not uncommon to see modifications to designs made by users: trails of user-created artefacts blazed in the wake of spontaneous formative evaluation, boldly taking the original designers to task (and back to a task view). A most common example of trails (literally) of user-made artefacts is seen in the paths worn by people as they walk. Sidewalk designers usually like to make the sidewalk patterns aesthetic – regular, symmetric, and rectilinear. However, the most efficient paths for people getting from one place to the other are often less tidy but more direct. The wear patterns in the grass show where people need or want to walk and, thus, where the sidewalks should have been located. The rare and creative sidewalk designer will wait until seeing the worn paths, employing the user-made artefacts as clues about user needs to drive the design.

As Gaver says, when affordances suggest actions different from the way something is designed, errors are common and signs are necessary. The signs are artefacts, added because the designs themselves did not carry sufficient cognitive affordance. We have all seen the cobbled design modifications to everyday things, such as padding added to prevent bruised knuckles, a better grip taped on, an explanation written on, an important feature highlighted with a circle or a bright colour, a feature (e.g., instructions) moved to a location where it is more likely to be seen. Users add words or pictures to mechanisms to explain how to operate them, enhancing cognitive affordance. Users attach yellow Post-It™ notes to computer monitors and keyboards. A farmer has a larger handle welded onto a tractor implement, enhancing physical affordance of the factory-made handle and its inadequate leverage. A homeowner replaces the street number sign on her house with a larger one, enhancing sensory affordance. Such user-made artefacts are a variation on the 'user-derived interfaces' theme of Good, Whiteside, Wixon, and Jones [1984], through which designers, after observing users perform tasks in their own way, modified interaction designs so that the design would have worked for those users.

Figure 7, a photo of a glass door in a convenience store, shows an example of a user-added cognitive affordance. The glass and stainless steel design is elegant: the perfectly symmetric layout and virtually unnoticeable hinges contribute to the uncluttered aesthetic appearance, but these same attributes work against cognitive affordance for its operation.

Figure 7. Glass door with a user-added cognitive affordance (arrow) indicating proper operation

The storeowner noticed many people unsure about which side of the stainless steel bar to push or pull to open the door, often trying the wrong side first. To help his customers with what should have been an easy task in the first place, he glued a bright yellow cardboard arrow to the glass, pointing out the correct place to operate the door.

In this case, the glass had such a strong sensory effect that, although the arrow did add cognitive affordance, it was still a bit difficult to process visually because it looks as though it is 'floating' on the glass.

These trails of often inelegant but usually effective artefacts added by frustrated users leave a record of affordance improvements that designers should consider for all their users. Perhaps if designers of the everyday things that Norman discusses [1990] had included usability testing in the field, they would have had the data they needed to accomplish this goal. In the software world, most applications have only very limited capabilities for users to set their preferences. Wouldn't it be much nicer for software users if they could modify interaction designs as easily as applying a little duct tape, a Post-It™, or extra paint here and there?

Figure 8 below shows how a car-owner created an artefact to replace an inadequate physical affordance – a built-in drink holder that was too small and too flimsy for today's super-sized drinks. During one trip, the user improvised with a shoe, resulting in this interesting example of a user-installed artefact.

Figure 8. A user-made automobile cup-holder artefact (used with permission from Roundel magazine, BMW Car Club of America, Inc. [Howarth, 2002])

Another car example is shown in Figure 9, featuring a car with a rear window having a significantly horizontal orientation. Despite the sporty styling, the design fell short in physical affordance, leading the owner to add an after-market 'grating' over the window to ward off reflections from the sun, snow from above, and other material that can too easily accumulate on the flat window.

Figure 9. User-added artefact to make the rear window more usable

As a final example, I occasionally need to use my desktop printer to print a letter on a single sheet of letterhead stationery. Inserting the stationery on top of the existing plain paper supply in the printer does this rather easily. The only problem is that I can't easily determine the correct orientation of the sheet as inserted, which is not obvious to me because:

1. I lack a clear mental model of how the sheet travels through in interior mechanism of the printer,
2. printers can vary in this configuration, and
3. the design of the printer itself gives no cognitive affordance for loading a single sheet of letterhead.

Thus, I have attached my own white adhesive label that says, 'letterhead here, face up and upside down', adding yet another user-created artefact attesting to inadequate design. As

Norman [1990, p.9] says, 'When simple things need pictures, labels, or instructions, the design has failed.'

5. Applying affordance concepts in usability engineering

The importance of affordance concepts to usability practitioners is in the application to interaction design and evaluation. In our own work at Virginia Tech, we have put these concepts to work within the usability engineering process. We have been working on usability engineering support tools built on a common, theory-based framework called the User Action Framework (UAF), a structured knowledge base of usability concepts and issues [Andre et al., 2001].

5.1. Adapting Norman's stages-of-action model

Norman's stages of action model of human-computer interaction [1986] had an essential influence on the UAF, along with the cognitive walkthrough [Lewis, Polson, Wharton, & Rieman, 1990], the structure of which is similar in many ways to Norman's model. Both approaches ask questions about:

- whether the user can determine what to do with the system to achieve a goal in the work domain,
- how to do it in terms of user actions,
- how easily the user can perform the required physical actions, and
- (to a lesser extent in the cognitive walkthrough) how well the user can tell whether the actions were successful in moving toward task completion.

Our work is not the first to use Norman's model as a basis for usability inspection, classification, or analysis. Several approaches (e.g., [Cuomo & Bowen, 1992; Kaur, Maiden,

& Sutcliffe, 1999; Lim, Benbasat, & Todd, 1996; Rizzo, Marchigiani, & Andreadis, 1997]) have used Norman's model and found it helpful for classifying and communicating about usability problems. Even before the concepts of user-interaction design were stable and well documented in Norman's [1986] model, Rasmussen [1983] provided foundational support by constructing a description of system usage in a functional abstraction hierarchy.

Norman's stages of action model, illustrated in Figure 10, shows a generic sequence of user activity as a user interacts with some machine in the world (annotation outside the box added here).

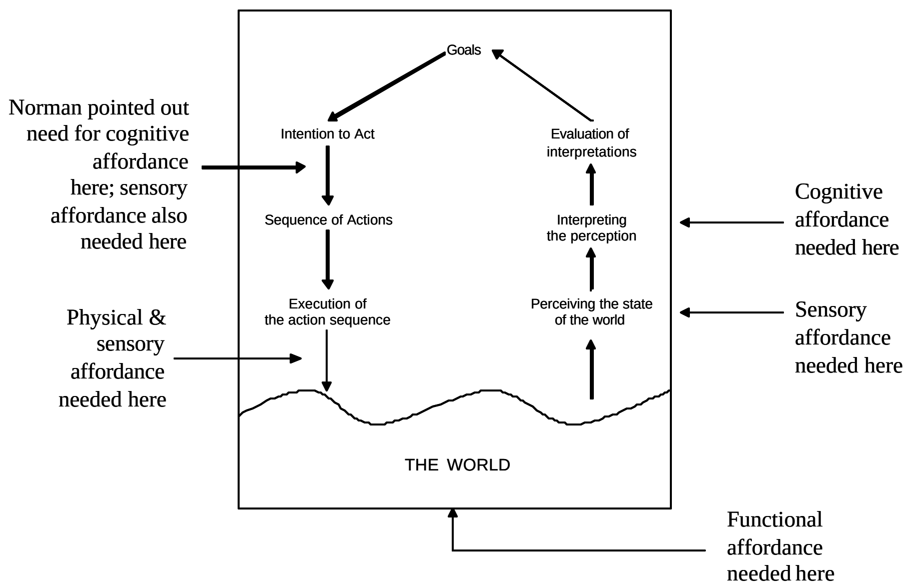


Figure 10. Norman's stages-of-action model (adapted with permission [1990])

Users begin at the top by formulating goals in their work domain. The goals are decomposed into tasks and then into specific intentions, which are mapped to specifications for action sequences. The user then executes the physical actions, causing a state change in the physical world, which is then sensed by the user via feedback, interpreted, and evaluated by comparing the outcome to the original goals. The interaction is successful if the actions in the cycle so far have brought the user closer to the goals.

Although cognitive affordance can be used to help the user with mental activities anywhere in the top part of Norman's diagram, Norman highlights the essential role cognitive affordance plays on the left-hand side of this model, at the point indicated by our top-most arrow pointing into the figure. This is the point where users map intentions into action sequence specifications prior to making the corresponding physical actions, the point where users most need help in knowing how to do things with a machine/computer. Mismatches between the designer's model and the user's view of this mapping contribute to the well-known Gulf of Execution [Hutchins, Hollan, & Norman, 1986; Norman, 1986]. The most effective way for the interaction designer to help users make this mapping from intention to action specification is with effective design of cognitive affordances (e.g. cues given by labels, icons, and prompt messages).

The right hand side of Figure 10 is where users evaluate their actions by comparing system feedback describing outcomes against their goals and intentions. This is the point where users need the most help in knowing about outcomes. Since system outcomes can be seen only through interaction feedback, mismatches between what designers provide and feedback users need contribute to the well-known Gulf of Evaluation [Hutchins et al., 1986; 1986].

5.2. From Norman's model to our Interaction Cycle

As a first step we adapted Norman's model into our Interaction Cycle (see Figure 11), which includes all of Norman's stages but organises them pragmatically in a slightly different way. Like Norman's model, the Interaction Cycle is a picture of how interaction happens for a human user with <u>any</u> machine, in terms of sequences of cognitive, physical, and sensory user actions.

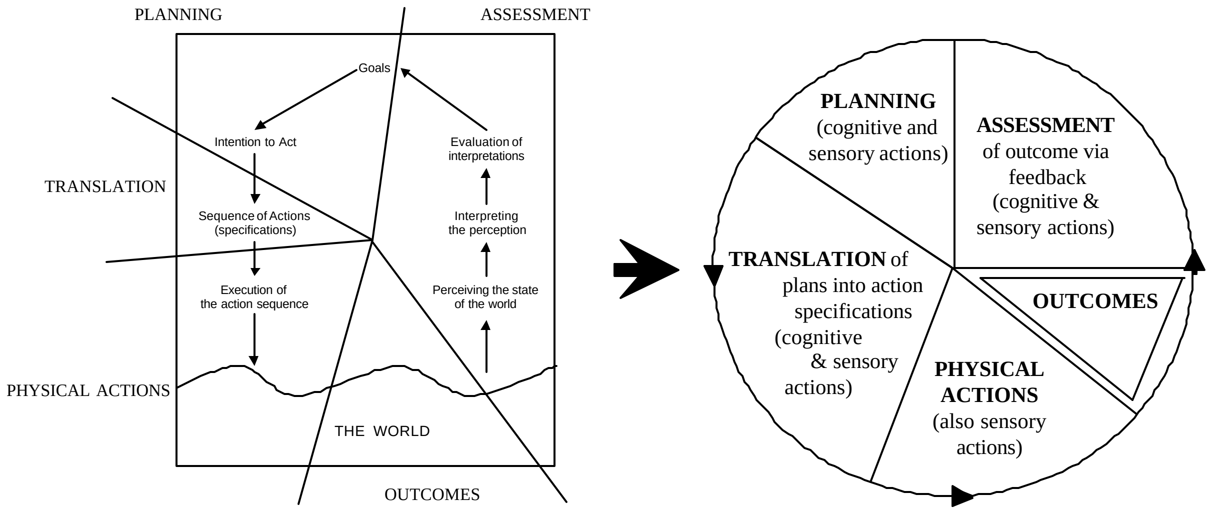


Figure 11. Transition from Norman's model to our Interaction Cycle

The linear cycle of Planning[2], Translation, Physical Action, Outcome, and Assessment represents the simplest sequencing, common in a user-initiated turn-taking dialogue style with a computer. Other starting points and orders of sequencing, plus gaps and overlapping, are possible and occur in the world.

The left-hand side of Figure 11 shows how we abstracted Norman's stages into four basic kinds of user activities, plus Outcomes, to form our Interaction Cycle, on the right-hand side of Figure 11: Planning of actions, Translating task plans and intentions into action specifications, doing Physical Actions, and Assessment of outcomes of those actions. Outcomes in the system occur between Physical Actions and Assessment in what Norman labels 'The World'. Because the Outcomes category does not include user actions, but is entirely internal to the system and not part of the user interface, we show it as a 'detached'

[2] We use capitalization to indicate category names in the User Action Framework.

segment of the Interaction Cycle in Figures 11 and 12. We found that we could associate each observed usability problem and each usability issue, concept, or design guideline with one or more of these categories within the context of a user's cycle of interaction.

5.3. From the Interaction Cycle to the User Action Framework

We use the stages of the Interaction Cycle as the high-level organising scheme, as shown in Figure 12 on the right-hand side, for the UAF, a hierarchically structured knowledge base of usability issues, and concepts. The resulting UAF provides a highly reliable [Andre et al., 2001] underlying foundation for usability engineering support tools. High reliability means agreement among users on the meaning of the UAF and how to apply it in the tools.

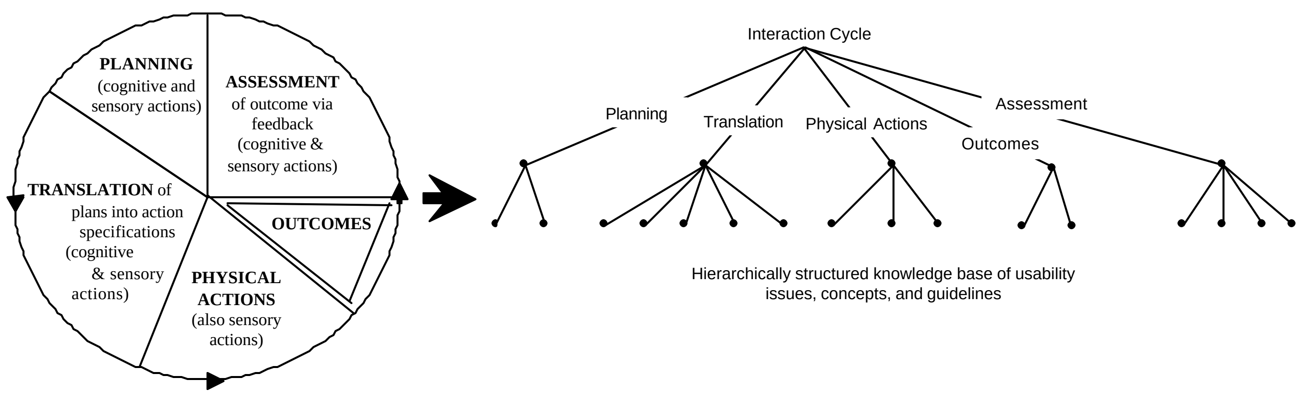


Figure 12. Basic kinds of user actions, plus Outcomes, from the Interaction Cycle as top-level structure of UAF, a usability knowledge base

UAF content under Planning is about how well an interaction design supports the user in determining <u>what to do</u> with the system to achieve work domain goals and includes usability design issues such as the user's model of system, metaphors, and task planning and decomposition. UAF content under Translation is about how well an interaction design supports the user in determining <u>how to do</u> what was planned in terms of user actions on artefacts in the system, translating task plans into action specifications. Translation includes usability design issues such as the existence of a cognitive affordance (e.g. instructive cue), presentation of a cognitive affordance (sensory issues), content and meaning of a cognitive affordance, and task structure and interaction control (e.g. locus of control, direct manipulation, cognitive directness).

UAF content under the Physical Actions category is about how well an interaction design supports the user in doing the actions. Outcomes represent the system's reaction to physical actions by users, computed by the non-user-interface software. This functionality provides the functional affordances, the usefulness that fulfills the purpose of user actions. Since Outcomes are not directly visible to users, interaction designers must provide feedback representing Outcomes. UAF content under Assessment is about how well feedback in an interaction design supports the user in assessing outcomes of actions.

5.3.1 UAF-based usability engineering support tools

The UAF serves as a common underlying foundation for a suite of usability engineering support tools that we are developing. No tool has its own content; all tools draw on the UAF in a shared relational database for contents of each node in the UAF structure. The mapping to a given tool retains the content and structure of the UAF, but the expression of each concept reflects the specific purpose of the tool. The UAF-based tools include the:

- UAF Explorer tool for teaching usability concepts;
- Usability Problem Diagnosis tool for extracting, analyzing, diagnosing, and reporting usability problems by problem type and by causes;

- Usability DataBase tool for maintaining a life history record of each problem within a project and for supporting aggregate data analysis such as cost-importance analysis [Hix & Hartson, 1993] and usability data visualisation;
- Usability Problem Inspection tool for conducting focused usability inspections, guided by the categories and sub-categories of the UAF; and
- Usability Design Guidelines tool for organising and applying usability design guidelines in a systematic way.

5.3.2 Interaction style and device independence

Norman's stages-of-action model was an ideal starting point for the UAF because:

1. it is a model of sequences of cognitive and physical actions users make when interacting with any kind of machine, and
2. it is general enough to include potentially all interaction styles, platforms, and devices that are likely to be encountered.

The interaction style, platform, and device independence that the UAF derives from its theory base in Norman's model is a long-term advantage. The UAF applies not only to GUI and Web designs, but equally well to 3-D interaction, virtual environments, PDAs, cell phones, refrigerators, ATMs, cars, elevators, and new interaction styles and devices as they arise.

5.4. Affordance roles in the User Action Framework

Affordance is perhaps the single most important overall concept in the UAF, and affordance issues are distributed throughout the interaction design space represented within the UAF. Cognitive, sensory, and physical actions, each with its own affordance needs in design, often overlap significantly in direct manipulation interaction with computers, in virtual environments, and in non-computer task performance such as in driving a car.

When McGrenere & Ho [2000] use the term 'degree of affordance', they are referring to how well an affordance works to help the user, or to the degree of usability afforded. The UAF, via its usability engineering support tools, supports practitioners in their pursuit of high usability, and many of the associated design issues centre on effectiveness of affordances in helping users do things (sensing, cognition, physical actions, and functionality) within the Interaction Cycle. Although all user types need all four kinds of affordances at some time during usage, designs for different kinds of users emphasize different kinds of affordance.

5.4.1 Cognitive affordance in the User Action Framework

Cognitive user actions occur in Planning, Translation, and Assessment within the Interaction Cycle and include a broad range of possibly complex cognitive processes, including rule-based cognition, habitual cognitive actions, explicit causal reasoning for conscious problem solving, and subconscious mental activity. Cognitive affordances appear in the UAF wherever there are issues about helping the user with these cognitive actions, such as knowing what to do (in Planning), knowing how to do it (in Translation), and knowing whether it was successful (in Assessment).

Design quality factors for cognitive affordance (including cues and feedback) are at the heart of a large part of UAF content[3], as represented by the sub-categories in Table 2.

Table 2. Representative UAF components relating to cognitive affordance quality

- Content, meaning (of a cognitive affordance)
  - Clarity, precision, predictability of meaning (of cognitive affordance)
    - Precise use of words
      - Labels for naming a form field
      - Labels for buttons, menus
    - Concise expression
    - Clearly labeled exits

[3] Although very stable, UAF content is subject to on-going refinement and revision to details and wording. Thus, these tables represent a snapshot of UAF categories.

- Completeness and sufficiency of meaning (of cognitive affordance)
  - Complete labels for buttons and menus
  - Complete information for error recovery
  - Complete alternatives in confirmation requests
- Distinguishability (of cognitive affordances)
- Relevance of content (of cognitive affordance)
- Convincingness of content, meaning (of cognitive affordance)
- User-centeredness of wording, design of cognitive affordance content
- Consistency and compliance of cognitive affordance meaning
- Error avoidance (in content, meaning of a cognitive affordance)
  - Correctness of content (of cognitive affordance)
  - Make inappropriate options unavailable
  - Anticipate and head-off potential user errors
  - Request user confirmation to avoid potentially costly or destructive errors
  - Distinguish modes
- Layout and grouping (of cognitive affordances)
  - Complexity of layout
- Cognitive directness
  - Direct presentation of cognitive affordance, rather than an encoding
  - Cognitive aspects of manipulable objects, interaction techniques
    - Consistency of manipulation helps user learning
    - Cognitive issues of direct manipulation
      - Direct manipulation paradigm not understood
    - Cognitive affordance content to help know how to manipulate an object, use an interaction technique
- Mnemonically meaningful cognitive affordances to support human memory limits
- Content, meaning of cognitive affordances for data entry
  - Appropriate default values for data entry
  - Indicate data type and format expected
    - Field size as indication of allowable data value length
    - Monospace type font (fixed width characters)
- Meaning contained in cognitive affordance presentation features
- Preferences and efficiency for content (meaning) of cognitive affordances
  - User ability to set preferences, parameters
  - Accommodating different user classes
  - Style of cognitive affordance content
    - Aesthetics, taste
    - Wording, word choice, vocabulary
    - Anthropomorphism, poor attempts at humor
    - User-centeredness in wording, design
    - Apparent loss of user control due to wording
    - Writing style, reading level (of prompt content)
- Getting started in a task

An example of a cognitive affordance for Translation is a button label or a menu choice. During Translation of intentions into action specifications, designers must ask (per Table 2) if the choice of label wording, for example, is precise enough to provide critical clues required for its proper operation. Is the wording complete enough to avoid ambiguity about the functionality behind a button? Is the wording distinguishable from other choices and consistent enough to avoid erroneous user actions? Similarly, an example of a cognitive affordance issue for Assessment is the clarity of wording in a feedback message, affecting how well it informs users about errors occurring as the result of certain Physical Actions.

Mnemonic affordances, affordances that help users remember (supporting human memory limitations), are a kind of cognitive affordance. Similarly, time affordances [Conn, 1995], affordances to help users know about or understand time delays in feedback and other output, are a kind of cognitive affordance to support Assessment.

Cognitive affordances are the most abundant type of affordance in interaction designs and account for the most UAF content. Three out of the four major categories of user actions (Planning, Translation, and Assessment) involve cognitive actions. Depending on work domains and user classes, cognitive affordance arguably has the broadest and most important role of all the affordance types in interaction design and, consequently, in the UAF. This is because cognitive affordance is the primary mechanism to support learning and remembering by all users except expert (error-free) users, who have automated Translation actions by training and experience. While expert users may account for a significant percentage of usage time, new or intermediate users comprise the vast majority of the total user population. Even expert users of one system are novice users of many other systems.

We do not report an empirical study in this paper, but our experience from many usability labs in many different settings in business, industry, and government over the years has left a clear impression that flaws in the design of cognitive affordances (or a lack of cognitive affordances) account for as many as 75% of the usability problems observed, primarily in the Translation category of the UAF. Cuomo and Bowen [1992], who also classified usability problems per Norman's theory of action, similarly found the majority of problems in the action specification stage (our Translation part).

5.4.2 Sensory affordance in the User Action Framework

Sensory user actions occur in support of Planning, Translation, Physical Actions, and Assessment within the Interaction Cycle. For all users except extreme experts, who can make some actions almost 'without looking', each part of the Interaction Cycle generally requires the user to sense (e.g., see, hear, feel) artefacts (including text) in the interaction design that support the corresponding cognitive or physical user activity. Design quality factors for sensory affordance account for significant areas of UAF content, as represented by the categories in Table 3.

Table 3. Representative UAF content about sensory affordance quality

- Sensory issues
  - Noticeability, likeliness to be sensed
  - Color, contrast
  - Timing of appearance of cognitive affordance
  - Layout complexity
  - Location of cognitive affordance, object with respect to user focus of attention
  - Focused vs. divided user attention
  - User focus of attention
  - Visibility (of cognitive affordance)
  - Findability
  - Discernability, recognizability, identifiability, intelligibility(of cognitive affordance)
  - Legibility of text (of cognitive affordance)
  - Detectability, distinguishability of sound, force
  - Bandwidth issues
  - Sensory disabilities and special limitations
  - Presentation medium choice (e.g., text vs. voice)
  - Visual quality of graphics
  - Auditory quality of audio
  - Quality of haptic, tactile, force interaction

In Planning, Translation, Physical Actions, and Assessment, UAF issues about sensory affordances are under the Presentation sub-category (presentation, or appearance, of artefacts used as cues, physical affordances, or feedback). As an example, font size or colour used in button labels and messages might affect text discernability and, therefore, legibility. Sensory issues are separate in the UAF from issues of understanding, which occur under the Content and Meaning category (of both Translation and Assessment).

As an example of discernability, an audio artefact such as a cautionary announcement heard when debarking an escalator, cannot be understood and heeded if the sound is too low in volume or the audio is garbled. As an example of noticeability, a sign in an elevator giving information about the contents of each floor cannot be used to advantage if it is unseen because it is posted too far above eye level. Such cases of difficult Noticeability or Findability might be called: 'Crouching error, hidden affordance'.

To illustrate sensory affordance in support of physical affordance, clicking on a user interface artefact can be troublesome if the artefact is difficult to see because of poor colour contrast with the background or if it is not noticeable because of poor location (e.g., outside the user's focus of attention in the screen layout) or timing of appearance (e.g., delayed or not persistent).

An example of a sensory affordance design issue based on a real usability problem case involves a tool palette with a large number of small drawing tool icons in a CAD system. For expert users the icons generally did not present cognitive affordance issues; they usually knew what at least the most frequently used icons meant. But sometimes it proved difficult visually to pick out the needed icon from the dense group in order to click on it. This is a sensory issue in support of Physical Actions for object manipulation, in particular a Findability issue, owing to the overly crowded layout of the visual design. A usability evaluator might also suspect physical affordance issues here, too, since small size and close proximity might make it more difficult to click quickly and accurately on an icon.

While it is important for designers to help all users see and hear cognitive and physical affordances, special attention is required in design of sensory affordances for users with sensory disabilities. For example, sometimes designers must build in tradeoffs between visual and audio presentation to be selected by users with hearing and seeing disabilities. Issues about sensory disabilities are included in the UAF, extending both Norman's Gulf of Execution and his Gulf of Evaluation [1986] to include sensing.

5.4.3 Physical affordance in the User Action Framework

Well-designed physical affordances support a high level of expert (error-free) user performance and productivity – high usability for power users. Design quality factors for physical affordances, as represented by the categories in Table 4, occur in the Physical Actions category of UAF content, the only category relevant to helping users with physical actions.

Table 4. Representative UAF components of physical affordance quality

- Physical Actions (Design helping user do the actions)
  - Manipulating objects
    - Physical control
      - Difficulty manipulating an object (e.g., clicking, grabbing, selecting, dragging)
      - Object not manipulable, or not in the desired way
      - Issues about kinesthetics of a device
        - Issues about manipulating a direct manipulation design
      - Physical fatigue, stress, strain
      - Gross motor coordination
      - Fine motor coordination
    - Physical layout
      - Proximity and size of objects as a factor in moving between (Fitts' law issues)
      - Proximity (closeness) of object as a factor in ability to manipulate reliably
      - Proximity of objects as a factor in grouping (or sensing of grouping), interference by unrelated objects

- Display inertia and consistency of object location
- Shape of object(s)
- Inconsistent location of objects

Physical object design
Interaction devices, I/O devices
Inconsistency in the way objects or devices are manipulated
Interaction techniques, interaction styles

- Object not manipulable
- Objects not manipulable in desirable way
- Physical direct manipulation issues
  - Using direct manipulation when appropriate

Preferences and efficiency (for manipulating objects)

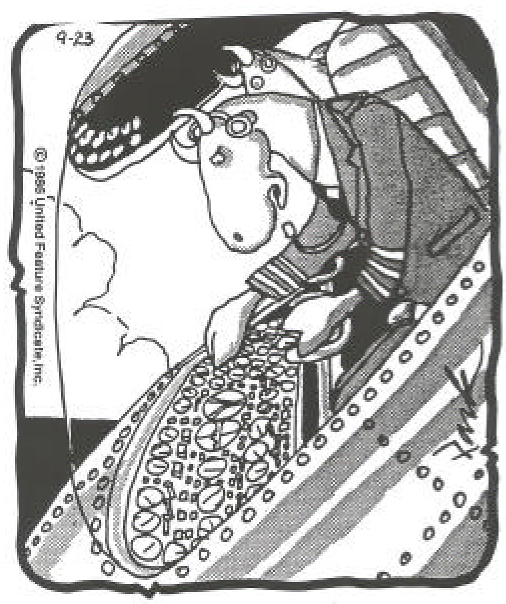
- Efficiency of (single) physical actions (for MOST OR ALL users or user classes)
- Awkwardness in physical actions for MOST OR ALL users or user classes
- Accommodating different user classes and physical disabilities
  - Making physical actions efficient for expert users
  - Awkwardness in physical actions for SOME users or user classes

While expert users can ignore many cognitive affordances in an interaction design, all users make use of physical affordances during computer-based task performance. The physical affordance part of the UAF is about operating the 'doorknobs of the user interface'. Of the two main sub-categories of the Physical Action category in the UAF, sensing artefacts to manipulate and manipulating artefacts, only the latter involves physical affordances. The 'artefacts' to be manipulated are the physical affordances for performing tasks. Manipulation issues for physical affordance design include, for example, awkwardness and fatigue, physical disabilities, power performance for experts, and ease of physical clicking as a function of artefact size and distance from where the pointer will be for other related steps in the associated task, according to Fitts' law [Fitts, 1954; MacKenzie, 1992].

Physical affordance design factors also include the design of I/O devices, direct manipulation issues, physical fatigue, and physical movements associated with virtual environments, gestures, and interaction devices (e.g. different keyboard layouts, haptic devices, speech I/O, and interaction using two hands and feet). Physical affordances are also particularly important to the usability concerns of another kind of user, the disabled user. Extending

Norman's Gulf of Execution [1986] to include Physical Actions, physical affordance issues in the UAF address users with physical disabilities, to whom ordinary designs can pose barriers to physical actions. Disabled users may need assistive technology or accommodation to improve physical affordance to allow, for example, user preferences for larger buttons to support easier clicking by users with limited fine motor control.

The cartoon in Figure 13 is a humorous illustration of a mismatch in physical affordances provided by designers and the physical needs of at least one class of users. Notice, too, the tendency to self-blame by the user, a phenomenon not uncommon in similar situations with computer users.



"Darn these hooves! I hit the wrong switch again! Who designs these instrument panels, raccoons?"

Figure 13. Mismatch in physical affordances provided by designers and physical needs of users (used with permission from W. B. Park)

A computer-related example of a useful physical affordance for a physical action is the 'snap to grid' feature for precise placement of an object in a drawing program (except when that is not what the users want, in which case the feature is a hindrance rather than an affordance). A classic example of a bad system feature with respect to physical affordances is uncontrolled scrolling. In a certain word processor on the PC, dragging selected text to move it outside text showing on the screen causes scrolling when the cursor gets to the top or bottom of the screen. Unfortunately, the speed of scrolling is limited only by the speed of the machine and ends up being too fast for the user to control manually. The result is thoroughly intimidating and frustrating. The system has put the user in a difficult spot, having to hold the mouse button depressed, with the text attached to the cursor, going back and forth unable to find a place to put it.

5.4.4 Functional affordance in the User Action Framework

Effective functional affordance gives all users high usefulness. Design quality factors for functional affordance appear in the Outcomes category of the UAF, the only UAF category containing issues about functionality of the internal, non-user interface software (core application functionality). An example of a functional affordance issue is seen in a case where a word processor performs automatic typing correction, even against the intentions of the user, arbitrarily changing an intended word into an incorrect word. The result for the user is loss of control. This system behaviour definitely affects usability, but it is not just an interaction design problem. Usability engineering developers must work with non-user-interface software engineers to modify this feature, its interface representation and its functionality.

5.4.5 Affordance concepts in usability problem extraction, analysis, and diagnosis

Understanding affordance types and being aware of their roles in interaction design can help practitioners in diagnosing usability problems observed in usability evaluation. As in design, affordances are not the whole story of usability problem analysis. Like design, analysis involving affordance is mostly about analysis of artefacts. The task component must also be analysed by looking at planning support, especially task decomposition, as well as task structure and interaction control (sub-categories under Translation in the UAF).

Usability problem diagnosis begins with observational data, raw usability data often in the form of critical incident observations and verbal protocol, collected in a usability evaluation setting – e.g., lab-based usability testing, usability inspection, or remote usability evaluation. Observational data are converted to complete and accurate usability problem descriptions through problem extraction, analysis, and diagnosis, in which consideration of affordances plays a major role.

As an example, consider the following usability problem from a real-world usability lab.

> A user thinks he knows what he is doing on a certain task, but when he selects an object and clicks on an icon, he gets an error message. The user complains that the error message is in a very small font and the colour is too close to the background colour, so he has difficulty reading the message.

Since this case statement is about a message, which is an interaction design artefact, it is appropriate to use affordance concepts to guide the analysis. Questions such as those in Table 5 below (skipping those for Planning in the UAF for now) can help pinpoint the diagnosis:

Table 5. Example affordance-guided problem diagnosis questions

1. Was the trouble in determining which icon to click on (Translation)?
   a. Was the trouble in seeing the icons, and labels (sensory affordance in support of cognitive affordance)?
   b. Was the trouble in understanding the meaning of the icons and labels (cognitive affordance in Translation)? Was user confused? Did user make an error?
2. Was the trouble in doing the clicking (Physical Action)?
   a. Was the trouble in seeing the icon in order to click on it (sensory affordance in support of physical affordance)?
   b. Was the trouble in doing the clicking quickly, easily, and reliably (physical affordance)?
3. Was the trouble in determining if the outcome of the action was favorable (Assessment) and, if something went wrong, in determining what went wrong?
   a. Was the trouble in seeing, discerning the feedback message text (sensory affordance in support of cognitive affordance for feedback)?
   b. Was the trouble in understanding the feedback message content or meaning?

Our example case indicates two possible usability problems. The display of an error message clearly shows that an error must have occurred. When a critical incident arises due to the occurrence of an error and nothing is wrong with the resulting message, the focus is on the error itself and its causes. This is in the Translation (of plans to action specifications) category of the UAF and in question 1 of the table, since this category is about cognitive affordances that help the user determine correctly how to do something and to avoid errors. However, in our current example the user’s complaint is about the quality of the message, not the occurrence of the error itself, so we answer ‘no’ to question 1 in the table for this particular problem. However, the problem of the error occurring is retained and becomes a separate implied problem to be extracted and its diagnosis will require further data (about what happened earlier, probably a cognitive affordance failure, to cause the error).

The physical action of clicking was not an issue, so we answer ‘no’ to question 2 in the table, but we must answer ‘yes’ to question 3, which is about feedback and Assessment. An Assessment problem can be about Presentation of feedback (where sensory aspects are found in the UAF, relating to question 3a), including such issues as feedback Noticeability, Discernability, Timing of appearance, and Graphical quality. Or it can be about feedback

Content and meaning (where cognitive aspects are found in the UAF, relating to question 3b), including such issues as feedback Clarity, Completeness, Correctness, and Relevance.

The problem case statement says that the user has difficulty reading the message, which can be ambiguous. An inexperienced practitioner might be tempted to skip further analysis and jump to the conclusion that this about the user not being able to read the error message in the sense of being unable to understand it completely, a common kind of cognitive affordance problem in Assessment. However, the wording of the case statement makes it clear that the problem is about the user's inability to discern the text of the message; the user cannot easily make out the characters in order to read the words. The problem now comes into focus as a sensory affordance problem in the feedback design, found in the UAF under Assessment, Feedback issues, Presentation of feedback, and Sensory issues of feedback. The problem diagnosis is further traced in the UAF to Discernability, and then Legibility of text and then to Font colour and contrast (with background).

Accurate diagnosis is essential to fixing causes of the right problem, the problem that actually affected the user. Different problems, involving different types of affordance, require entirely different solutions (e.g., changing the font size vs. changing the message wording). It is important for practitioners and developers to understand the distinctions, which are often best understood in terms of affordance concepts. Fixing the wrong problem can waste resources and leave the original problem unsolved.

Not fixing all the problems can lead to missed opportunities. For example, improving only the cognitive affordance to avoid the error should make this problem occur less frequently, but would leave the error message problem unsolved for those times when the error does occur. Revising the expression of the meaning in the error message might be an improvement, but would not solve this sensory affordance problem.

Finally, data visualisation based on affordance types can be used to improve a usability engineering process. This kind of usability data visualisation requires storing records of usability problems for a project in a database with affordance-related attributes. We use our UAF-based Usability DataBase tool, within which each usability problem is stored, having been diagnosed by problem type and causes among UAF categories. We then tag nodes of the UAF with their associations to each affordance type and are able to visualise the usability data as clustered by affordance type. While the interpretation of clusters is an open question, a large number of usability problems involving the meaning of cognitive affordances would seem to imply design shortcomings involving precise use of words, semantics, and meanings of words and icons – shortcomings that might be addressed by hiring a professional writer, for example, to the interaction development team.

Similarly, large numbers of problems involving physical affordances are a possible indicator of design problems that could be addressed by hiring an expert in ergonomics, human factors engineering, and physical device design. Finally, large numbers of problems involving sensory affordances might be addressed by hiring a graphic designer or layout artist. Formal studies will be required to validate the hypotheses behind these expectations.

6. Conclusion and future work

We agree with Norman's concern that the term <u>affordance</u> has been used with more enthusiasm than knowledge. Perhaps the concepts associated with affordance are so natural and so necessary that people either couldn't resist implicit, undeclared extensions or they may have believed that the kind of extensions we propose were already accepted usage. We have proposed and explored the use of the complementary terms, cognitive affordance, physical affordance, sensory affordance, and functional affordance to refer to the corresponding concepts in interaction analysis and design. We think an independent concept of cognitive affordance is equally important as the concept of physical affordance. It is a good match and a parallel to physical affordance and is essential to interaction analysis and design, as Norman himself has pointed out many times. We also think that sensory affordance is necessary to support cognitive and physical affordance throughout the user's Interaction Cycle.

In order to get the most practical utility from the concept of physical affordance, we have proposed that each reference to it by researchers or practitioners appear with a statement of purpose, which should be supported by functional affordance in the non-user interface software. Finally, we have developed the UAF to connect these and other interaction design concepts in the domain of design and analysis for usability.

We hope that the suggestions here will bridge the gap between Norman's concerns about misuse of affordance terminology and the needs of practitioners to use the concepts in a practical way. Now usability researchers and practitioners can refer unambiguously to all four types of affordance in the context of interaction design and analysis.

We have explored the relationship between the affordance types associated with observed usability problems. Practitioners can apply usability case data to identify where affordance issues are involved in flawed designs and produce case studies of how increased attention to affordances can improve interaction design.

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Finally, all photos were taken with a small consumer-grade digital camera (brand to remain unnamed to protect the guilty) from our Usability Methods Research Laboratory that has its on-off power switch where most cameras have their shutter-release button. On more than one occasion, after struggling with multiple menus to configure the camera setting just right, at the precise moment of capture, this design 'affordance' has led to my unintentionally

shutting off the camera. Further, each time I turn on the camera power, the lens telescopes out, knocking the lens cap off onto the ground (or worse). Let's hear it for good design!

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