Usability Engineering

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Chapter 2 What Is Usability?

Back when computer vendors first started viewing users as more than an inconvenience, the term of choice was "user friendly" systems. This term is not really appropriate, however, for several reasons. First, it is unnecessarily anthropomorphic—users don't need machines to be friendly to them, they just need machines that will not stand in their way when they try to get their work done. And second, it implies that users' needs can be described along a single dimension by systems that are more or less friendly. In reality, different users have different needs, and a system that is "friendly" to one may feel very tedious to another.

Because of these problems with the term "user friendly," user interface professionals have tended to use other terms in recent years. The field itself is known under names like CHI (computer–human interaction), HCI (human–computer interaction, which is preferred by some who like "putting the human first" even if only done symbolically), UCD (user-centered design), MMI (man–machine interface), HMI (human–machine interface), OMI (operator–machine interface), UID (user interface design), HF (human factors), ergonomics,[1] etc.

I tend to use the term "usability" to denote the considerations that can be addressed by the methods covered in this book. As shown in the following section, there are also broader issues to consider within the overall framework of traditional "user friendliness."

2.1 *Usability and Other Considerations*

To some extent, usability is a narrow concern compared to the larger issue of system acceptability, which basically is the question of whether the system is good enough to satisfy all the needs and requirements of the users and other potential stakeholders, such as the users' clients and managers. The overall acceptability of a computer system is again a combination of its social acceptability and its practical acceptability. As an example of social acceptability, consider a system to investigate whether people applying for unemployment benefits are currently gainfully employed and thus have submitted fraudulent applications. The system might do this by asking applicants a number of questions and searching their answers for inconsistencies or profiles that are often indicative of cheaters. Some people may consider such a fraud-preventing system highly socially desirable, but others may find it offensive to subject applicants to this kind of quizzing and socially undesirable to delay benefits for people fitting certain profiles. Notice that people in the latter category may not find the system acceptable even if it got high scores on practical acceptability in terms of identifying many cheaters and were easy to use for the applicants.

Given that a system is socially acceptable, we can further analyze its practical acceptability within various categories, including traditional categories such as cost, support, reliability, compatibility with existing systems, etc., as well as the category of usefulness. *Usefulness* is the issue of whether the system can be used to achieve some desired goal. It can again be broken down into the

1. Human factors and ergonomics have a broader scope than just human–computer interaction. In fact, many usability methods apply equally well to the design of other complex systems, and even to simple ones that are not simple enough.

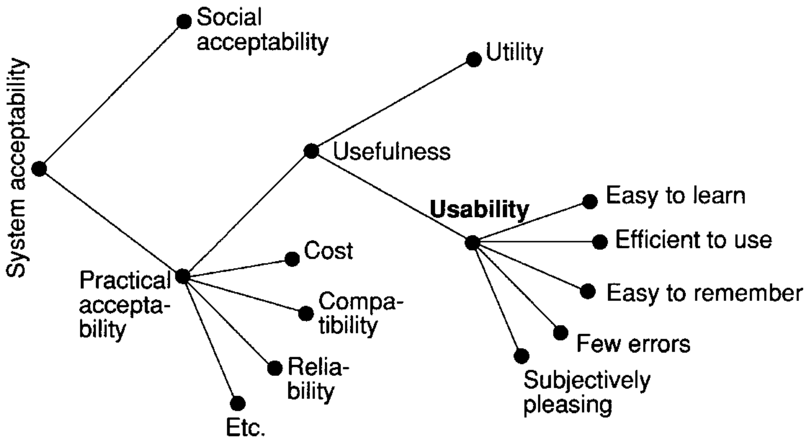

Figure 1 *A model of the attributes of system acceptability.*

two categories of utility and usability [Grudin 1992], where utility is the question of whether the functionality of the system in principle can do what is needed, and usability is the question of how well users can use that functionality. Note that the concept of "utility" does not necessarily have to be restricted to the domain of hard work. Educational software ("courseware") has high utility if students learn from using it, and an entertainment product has high utility if it is fun to use. Figure 1 shows the simple model of system acceptability outlined here. It is clear from the figure that system acceptability has many components and that usability must trade off against many other considerations in a development project.

Usability applies to all aspects of a system with which a human might interact, including installation and maintenance procedures. It is very rare to find a computer feature that truly has no user interface components. Even a facility to transfer data between two computers will normally include an interface to trouble-shoot the link when something goes wrong [Mulligan *et al.* 1991]. As another example, I recently established two electronic mail addresses for a committee I was managing. The two addresses were `ic93-papers-administrator` and `ic93-papers-committee` (for mail to my assistant and to the entire membership, respectively). It turned out that several people sent email to the wrong address, not realizing where their mail would go. My mistake was twofold: first in not realizing that even a pair of email addresses constituted a user interface of sorts, and second in breaking the well-known usability principle of avoiding easily confused names. A user who was taking a quick look at the "`To:`" field of an email message might be excused for thinking that the message was going to one address even though it was in fact going to the other.

2.2 Definition of Usability

It is important to realize that usability is not a single, one-dimensional property of a user interface. Usability has multiple components and is traditionally associated with these five usability attributes:

- *Learnability*: The system should be easy to learn so that the user can rapidly start getting some work done with the system.
- *Efficiency*: The system should be efficient to use, so that once the user has learned the system, a high level of productivity is possible.
- *Memorability*: The system should be easy to remember, so that the casual user is able to return to the system after some period of not having used it, without having to learn everything all over again.
- *Errors*: The system should have a low error rate, so that users make few errors during the use of the system, and so that if they do make errors they can easily recover from them. Further, catastrophic errors must not occur.
- *Satisfaction*: The system should be pleasant to use, so that users are subjectively satisfied when using it; they like it.

Each of these usability attributes will be discussed further in the following sections. Only by defining the abstract concept of "usability" in terms of these more precise and measurable components can we arrive at an engineering discipline where usability is not just argued about but is systematically approached, improved, and evaluated (possibly measured). Even if you do not intend to run formal measurement studies of the usability attributes of your system, it is an illuminating exercise to consider how its usability could be made measurable. Clarifying the measurable aspects of usability is much better than aiming at a warm, fuzzy feeling of "user friendliness" [Shackel 1991].

Usability is typically measured by having a number of test users (selected to be as representative as possible of the intended users) use the system to perform a prespecified set of tasks, though it can also be measured by having real users in the field perform whatever tasks they are doing anyway. In either case, an important point is that usability is measured relative to certain users and certain tasks. It could well be the case that the same system would be measured as having different usability characteristics if used by different users for different tasks. For example, a user wishing to write a letter may prefer a different word processor than a user wishing to maintain several hundred thousands of pages of technical documentation. As further discussed in Section 6.5 (page 185), usability measurement therefore starts with the definition of a representative set of test tasks, relative to which the different usability attributes can be measured.

To determine a system's overall usability on the basis of a set of usability measures, one normally takes the mean value of each of the attributes that have been measured and checks whether these means are better than some previously specified minimum (see the section on *Goal Setting* on page 80). Since users are known to be very different, it is probably better to consider the entire distribution of usability measures and not just the mean value. For example, a criterion for subjective satisfaction might be that the mean value should be at least 4 on a 1–5 scale; that at least 50% of the users should have given the system the top rating, 5; and that no more than 5% of the users gave the system the bottom rating, 1.

Learnability

Learnability is in some sense the most fundamental usability attribute, since most systems need to be easy to learn, and since the first experience most people have with a new system is that of

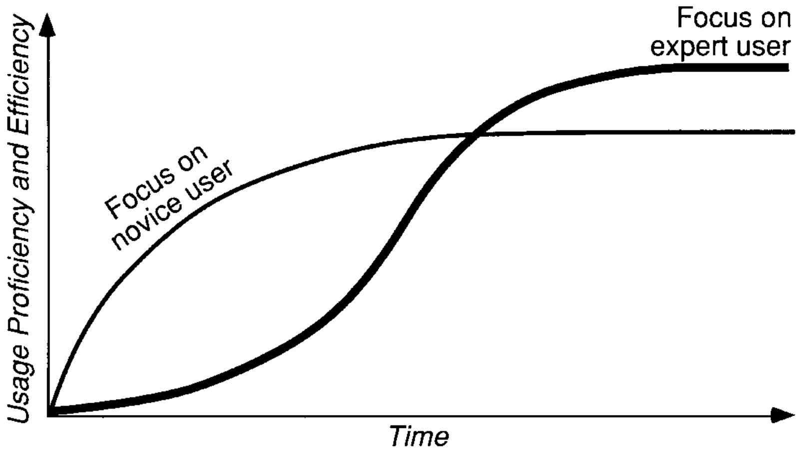

Figure 2 *Learning curves for a hypothetical system that focuses on the novice user, being easy to learn but less efficient to use, as well as one that is hard to learn but highly efficient for expert users. See also Section 2.4 (page 40) for a discussion of how to ride the best parts of both curves.*

learning to use it. Certainly, there are some systems for which one can afford to train users extensively to overcome a hard-to-learn interface, but in most cases, systems need to be easy to learn.

Ease of learning refers to the novice user's experience on the initial part of the learning curve, as shown in Figure 2. Highly learnable systems have a steep incline for the first part of the learning curve and allow users to reach a reasonable level of usage proficiency within a short time. Practically all user interfaces have learning curves that start out with the user being able to do nothing (have zero efficiency) at time zero (when they first start using it). Exceptions include the so-called walk-up-and-use systems such as museum information systems that are only intended to be used once and therefore need to have essentially zero learning time, allowing users to be successful from their very first attempt at using them.

The standard learning curve also does not apply to cases where the users are transferring skills from previous systems, such as when they upgrade from a previous release of a word processor to the new release [Telles 1990]. Assuming that the new system is reasonably consistent with the old, users should be able to start a fair bit up on the learning curve for the new system [Polson *et al.* 1986].

Initial ease of learning is probably the easiest of the usability attributes to measure, with the possible exception of subjective satisfaction. One simply picks some users who have not used the system before and measures the time it takes them to reach a specified level of proficiency in using it. Of course, the test users should be representative of the intended users of the system, and there might be a need to collect separate measurements from complete novices without any prior computer experience and from users with some typical computer experience. In earlier years, learnability studies focused exclusively on users without any computer experience, but since many people now have used computers, it is becoming more and more important to include such users in studies of system learnability.

The most common way to express the specified level of proficiency is simply to state that the users have to be able to complete a certain task successfully. Alternatively, one can specify that users need to be able to complete a set of tasks in a certain, minimum time before one will consider them as having "learned" the system. Of course, as shown in Figure 2, the learning curve actually represents a continuous series of improved user performance and not a dichotomous "learned"/"not learned" distinction. It is still common, however, to define a certain level of performance as indicating that the user has passed the learning stage and is able to use the system, and to measure the time it takes the user to reach that stage.

When analyzing learnability, one should keep in mind that users normally do not take the time to learn a complete interface fully before starting to use it. On the contrary, users often start using a system as soon as they have learned a part of the interface. For example, a survey of business professionals who were experienced personal computer users [Nielsen 1989e] found that 4 of the 6 highest-rated usability characteristics (out of 21 characteristics in the survey) related to exploratory learning: easy-to-understand error messages, possible to do useful work with program before having learned all of it, availability of undo, and confirming questions before execution of risky commands. Because of users' tendency to jump right in and start using a system, one should not just measure how long it takes users to achieve complete mastery of a system but also how long it takes to achieve a sufficient level of proficiency to do useful work.

Efficiency of Use

Efficiency refers to the expert user's steady-state level of performance at the time when the learning curve flattens out (again, see Figure 2). Of course, users may not necessarily reach that final level of performance any time soon. For example, some operating systems are so complex that it takes several years to reach expert-level performance and the ability to use certain composition operators to combine commands [Doane *et al.* 1990, 1992]. Also, some users will probably continue to learn indefinitely, though most users seem to plateau once they have learned "enough" [Rosson 1984, Carroll and Rosson 1987]. Unfortunately, this steady-state level of performance may not be optimal for the users who, by learning a few additional advanced features, sometimes would save more time over the course of their use of the system than the time it took to learn them.

To measure efficiency of use for experienced users, one obviously needs access to experienced users. For systems that have been in use for some time, "experience" is often defined somewhat informally, and users are considered experienced either if they say so themselves or if they have been users for more than a certain amount of time, such as a year. Experience can also be defined more formally in terms of number of hours spent using the system, and that definition is often used in experiments with new systems without an established user base: Test users are brought in and asked to use the system for a certain number of hours, after which their efficiency is measured. Finally, it is possible to define test users as experienced in terms of the learning curve itself: A user's performance is continuously measured (for example, in terms of number of seconds to do a specific task), and when the performance has not increased for some time, the user is assumed to have reached the steady-state level of performance for that user [Nielsen and Phillips 1993].

A typical way to measure efficiency of use is thus to decide on some definition of expertise, to get a representative sample of users with that expertise, and to measure the time it takes these users to perform some typical test tasks.

Memorability

Casual users are the third major category of users besides novice and expert users. Casual users are people who are using a system intermittently rather than having the fairly frequent use assumed for expert users. However, in contrast to novice users, casual users have used a system before, so they do not need to learn it from scratch, they just need to remember how to use it based on their previous learning. Casual use is typically seen for utility programs that are only used under exceptional circumstances, for supplementary applications that do not form part of a user's primary work but are useful every now and then, as well as for programs that are inherently only used at long intervals, such as a program for making a quarterly report.

Having an interface that is easy to remember is also important for users who return after having been on vacation or who for some other reason have temporarily stopped using a program. To a great extent, improvements in learnability often also make an interface easy to remember, but in principle, the usability of returning to a system is different from that of facing it for the first time. For example, consider the sign "Kiss and Ride" seen outside some Washington, DC, Metro stations. Initially, the meaning of this sign may not be obvious (it has poor learnability without outside assistance), but once you realize that it indicates a drop-off zone for commuters arriving in a car driven by somebody else, the sign becomes sufficiently memorable to allow you to find such zones at other stations (it is easy to remember).[2]

2. "Kiss and Ride" is an analogy with "Park and Ride" areas where people can leave their cars. The sign refers to commuters who are driven by their spouses and will kiss them before getting out of the car to take the train.

Interface memorability is rarely tested as thoroughly as the other usability attributes, but there are in principle two main ways of measuring it. One is to perform a standard user test with casual users who have been away from the system for a specified amount of time, and measure the time they need to perform some typical test tasks. Alternatively, it is possible to conduct a memory test with users after they finish a test session with the system and ask them to explain the effect of various commands or to name the command (or draw the icon) that does a certain thing. The interface's score for memorability is then the number of correct answers given by the users.

The performance test with casual users is most representative of the reason we want to measure memorability in the first way. The memory test may be easier to carry out but does have the problem that many modern user interfaces are built on the principle of making as much as possible visible to the users. Users of such systems do not need to be actively able to remember what is available, since the system will remind them when necessary. In fact, a study of one such graphical interface showed that users were unable to remember the contents of the menus when they were away from the system, even though they could use the same menus with no problems when they were sitting at the computer [Mayes *et al.* 1988].

Few and Noncatastrophic Errors

Users should make as few errors as possible when using a computer system. Typically, an error is defined as any action that does not accomplish the desired goal, and the system's error rate is measured by counting the number of such actions made by users while performing some specified task. Error rates can thus be measured as part of an experiment to measure other usability attributes.

Simply defining errors as being any incorrect user action does not take the highly varying impact of different errors into account. Some errors are corrected immediately by the user and have no other effect than to slow down the user's transaction rate somewhat. Such errors need not really be counted separately, as their effect is included in the efficiency of use if it is measured the normal way in terms of the user's transaction time.

Other errors are more catastrophic in nature, either because they are not discovered by the user, leading to a faulty work product, or because they destroy the user's work, making them difficult to recover from. Such catastrophic errors should be counted separately from minor errors, and special efforts should be made to minimize their frequency.

Subjective Satisfaction

The final usability attribute, subjective satisfaction, refers to how pleasant it is to use the system. Subjective satisfaction can be an especially important usability attribute for systems that are used on a discretionary basis in a nonwork environment, such as home computing, games, interactive fiction, or creative painting [Virzi 1991]. For some such systems, their entertainment value is more important then the speed with which things get done, since one might *want* to spend a long time having fun [Carroll and Thomas 1988]. Users should have an entertaining and/or moving and/or enriching experience when using such systems since they have no other goal.

Note that the notion of subjective satisfaction as an attribute of usability is different from the issue of the public's general attitudes toward computers. Even though it is likely that a person's feelings toward computers as a general phenomenon will impact the extent to which that person likes interacting with a particular system, peoples' attitudes toward computers in general should probably be seen as a component of the social acceptability of computers rather than their usability. See [LaLomia and Sidowski 1991] for a survey of such computer attitude studies. Computer enthusiasts may hope that steady improvements in computer usability will result in more positive attitudes toward computers. Little is currently known about the relation between attributes of individual computer systems and users' general attitudes, though users who perceive that they have a high degree of control over the computer have been found also to have positive attitudes toward computers [Kay 1989].

In principle, certain objective measures might be used instead of asking the users' subjective preference to assess the pleasing nature of an interface. In a few cases, psychophysiological measures such as EEGs, pupil dilation, heart rate, skin conductivity, blood pressure, and level of adrenaline in the blood have been used to estimate the users' stress and comfort levels [Mullins and Treu 1991; Schleifer 1990; Wastell 1990]. Unfortunately, such measures require intimidating experimental conditions such as wiring the user to an EEG machine or taking blood samples. Since test users are normally nervous enough as it is and since a relaxed atmosphere is an important condition for much user testing (see page 181), the psychophysiological approach will often be inappropriate for usability engineering studies.

Alternatively, subjective satisfaction may be measured by simply *asking* the users for their subjective opinion. From the perspective of any single user, the replies to such a question are subjective, but when replies from multiple users are averaged together, the result is an objective measure of the system's pleasantness. Since the entire purpose of having a subjective satisfaction usability attribute is to assess whether users like the system, it seems highly appropriate to measure it by asking the users, and this is indeed what is done in the overwhelming number of usability studies.

To ensure consistent measurements, subjective satisfaction is normally measured by a short questionnaire that is given to users as part of the debriefing session after a user test. Of course, questionnaires can also be given to users of installed systems in the field without the need to have them go through a special test procedure first. For new systems, however, it is important not to ask the users for their subjective opinions until after they have had a chance to try using the system for a real task. The answers users give to questions before and after having used a system are unfortunately not very highly correlated [Root and Draper 1983].

Users have been known to refuse to use a program because the manual was too big [Nielsen *et al.* 1986], without even trying to read it to see whether it was in fact as difficult as they thought. Therefore it is certainly reasonable to study the approachability of a

Please indicate the degree to which you agree or disagree with the following statements about the system:
"It was very easy to learn how to use this system."
"Using this system was a very frustrating experience."
"I feel that this system allows me to achieve very high productivity."
"I worry that many of the things I did with this system may have been wrong."
"This system can do all the things I think I would need."
"This system is very pleasant to work with."

Table 3 *Questions users might be asked to measure subjective satisfaction using a Likert scale. Users would typically indicate their degree of agreement on a 1–5 scale for each statement. One would normally refer to the system by its name rather than as "this system."*

system (this is especially important from a marketing perspective) [Angiolillo and Roberts 1991]. To do so, one can show the system to users and ask them, "How difficult do you think it would be to learn to use this?"—just don't expect the answers to have much relation to the *actual* learnability of the system.

Even when users do have experience using a system, their subjective ratings of its difficulty are much more closely related to the peak difficulty they experienced than to mean difficulty; the most difficult episode a user experienced is the most memorable for that user. In one experiment, the peak experienced difficulty while performing a task accounted for 31% of the users' subjective rating of the system's difficulty whereas the task time only accounted for 7% [Cordes 1993]. One conclusion is that one cannot rely solely on user ratings if the goal is to improve overall system performance. On the other hand, sales considerations imply a need to have users *believe* that the system is easy to generate positive word-of-mouth, and such impressions might be improved more by a bland interface with no extreme peak in difficulty than by a system that is mostly excellent but has one really hard part for users to overcome.

Subjective satisfaction questionnaires are typically very short, though some longer versions have been developed for more detailed studies [Chin *et al.* 1988]. Typically, users are asked to rate the system on 1–5 or 1–7 rating scales that are normally either Likert scales or semantic differential scales [LaLomia and Sidowski 1990]. For a *Likert scale*, the questionnaire postulates some state-

Please mark the positions that best reflect your impressions of this system:

Pleasing	_ _ _ _ _ _ _	Irritating
Complete	_ _ _ _ _ _ _	Incomplete
Cooperative	_ _ _ _ _ _ _	Uncooperative
Simple	_ _ _ _ _ _ _	Complicated
Fast to use	_ _ _ _ _ _ _	Slow to use
Safe	_ _ _ _ _ _ _	Unsafe

Table 4 *Some semantic differential scales to measure subjective satisfaction with computers. See [Coleman* et al. *1985] for a list of 17 such scales.*

ment (e.g., "I found this system very pleasant to use") and asks the users to rate their degree of agreement with the statement. When using a 1–5 rating scale, the reply options are typically 1 = strongly disagree, 2 = partly disagree, 3 = neither agree nor disagree, 4 = partly agree, and 5 = strongly agree.

A *semantic differential scale* lists two opposite terms along some dimension (for example, very easy to learn vs. very hard to learn) and asks the user to place the system on the most appropriate rating along the dimension. Table 3 and Table 4 list some sample questions that are often asked to measure subjective satisfaction. One could add a few questions addressing issues of special interest, such as "the quick reference card was very helpful," but it is normally best to keep the questionnaire short to maximize the response rate. A final rating for subjective satisfaction is often calculated simply as the mean of the ratings for the individual answers (after compensating for any use of reverse polarity), but it is also possible to use more sophisticated methods, drawing upon rating scale theory from sociology and psychometrics.

No matter what rating scales are used, they should be subjected to pilot testing (see page 174) to make sure that the questions are interpreted properly by the users. For example, a satisfaction questionnaire for a point-of-sales system used a dimension labelled "human contact vs. cold technology" to assess whether users felt that it was impersonal to be served by a machine. However, since no humans were present besides the user, many users felt that it was logically impossible to talk about "human contact," and did not answer the question in the intended manner.

When rating scales are used, one needs an anchor or baseline to calibrate the scale before it is possible to assess the results. If subjective satisfaction ratings are available for several different systems or several different versions of the same system, it is possible to consider the ratings in relation to the others and thus to determine which system is the most pleasant to use. If only a single user interface has been measured, one should take care in interpreting the ratings, since people are often too polite in their replies. Users normally know that the people who are asking for the ratings have a vested interest in the system being measured, and they will tend to be positive unless they have had a really unpleasant experience. This phenomenon can be partly counteracted by using reverse polarity on some of the questions, that is, having some questions to which an agreement would be a negative rating of the system.

Nielsen and Levy [1994] found that the median rating of subjective satisfaction for 127 user interfaces for which such ratings had been published was 3.6 on a 1–5 scale with 1 being the worst rating and 5 the best. Ostensibly, the rating 3 is the "neutral" point on a 1–5 rating scale, but since the median is the value where half of the systems were better and half were poorer, the value 3.6 seems to be a better estimate of "neutral" or "average" subjective satisfaction.

If multiple systems are tested, subjective satisfaction can be measured by asking users which system they would prefer or how strongly they prefer various systems over others. Finally, for systems that are in use, one can measure the extent that users choose to use them over any available alternatives. Data showing voluntary usage is really the ultimate subjective satisfaction rating.

2.3 *Example: Measuring the Usability of Icons*

To clarify the slightly abstract definition of usability in the previous section, this section gives several examples of how to measure the usability of a concrete user interface element: icons. Icons have become very popular elements in graphical user interfaces, but not all icons have equally good usability characteristics.

A systematic approach to icon usability would define measurable criteria for each of the usability attributes of interest to the system being developed. It is impossible to talk about the usability of an icon without knowing the context in which it will be shown and the circumstances under which it will be used. This section presents a few of the approaches to icon usability that have been published in the user interface literature. For some other examples, see [Green and Barnard 1990; Hakiel and Easterby 1987; Magyar 1990; Nolan 1989; Salasoo 1990; Stammers and Hoffman 1991; Zwaga 1989].

A classic study of icon usability was described by Bewley *et al.* [1983]. Four different sets of icons were designed for a graphical user interface with 17 icons. All of the icons were tested for ease of learning, efficiency of use, and subjective satisfaction. Ease of learning was assessed by several means: First, the intuitiveness[3] of the individual icons was tested by showing them to the users, one at a time, asking the user to describe "what you think it is." Second, since icons are normally not seen in isolation, the understandability of sets of icons was tested by showing the users entire sets of icons (one out of the four sets that had been designed). Users were then given the name of an icon and a short description of what it was supposed to do, and asked to point to the icon that best matched the description. Users were also given the complete set of names and asked to match up all the icons with their name. The score for all these learning tests was the proportion of the icons that were correctly described or named.

Two efficiency tests were conducted. In the first test, users who had already learned the meaning of the icons through participation in the learning tests were given the name of an icon and told that it might appear on the computer display. A random icon then

3. An early activity aimed at getting intuitive icons is to ask some users to draw icons they would like for each of the concepts that need to be depicted. The results will probably not look very good, but they can serve as a pool of ideas for the graphic designer.

appeared, and the users pressed a "yes" button if it was one they were looking for and a "no" button if it was some other icon. In the second test, users were shown a randomized display of icons and asked to click on a specific icon. Both these tests were timed, and the score for an icon was the users' reaction time in seconds.

Subjective satisfaction was measured in two ways. First, users were asked to rate each icon one at a time for how easy it was to pick out. Second, for each of the 17 concepts, the users were shown the four possible icons and asked to choose the one they preferred. The subjective score for an icon was the user rating for the first test and the proportion of users who preferred it for the second test.

Given the results from all these tests, it was possible to compare the four icon sets. One set that included the names of the commands as part of the icon got consistently high scores on the test where users had to describe what the icon represented. This result may not be all that surprising and has indeed been confirmed by later research on other interfaces [Egido and Patterson 1988; Kacmar and Carey 1991]. Unfortunately, this set of icons was not very graphically distinct, and many of the icons were hard to find on a screen with many similar icons. For the final system, a fifth set of icons was designed, mostly being based on one of the four original sets, but with some variations based on lessons from the tests as well as the aesthetic sensibilities of the graphic designers.

Icons are probably easier to design for objects than for operations since many objects can be depicted representationally. Rogers [1986] studied the usability of icon sets for operations by testing gradually more complex icons with more and more elements. The only usability parameter measured was comprehensibility, which was assessed by a matching test. For each level of icon complexity (for example, icons with few elements), an entire set of icons was designed to represent the commands in the system. For each such set, 10 users were shown all the icons as they went through a list of textual descriptions of the command functions.[4] For each textual description, the users picked the one icon they believed matched it best, and the total comprehension score for an icon set was then calculated as the number of correct matches.

The best icons showed both the concrete object being operated upon (for example a sheet of paper) and an abstract representation of the operation (for example an arrow). Icons with only one of these elements were harder to understand as were icons with even more information (such as replacing the arrow with a pointing finger with little cartoon-like lines denoting movement). So a medium level of complexity was best for comprehension. Also, icons for commands with a visual outcome (such as the movement of text in a word processor) were much easier to comprehend than were icons for commands with a nonvisual outcome (such as "save a file").

Icons that are intended for critical or widely used applications may need to satisfy more stringent quality criteria than other icons. International standards is certainly one area where one would want a high level of usability. Lindgaard *et al.* [1987] report on a case where the International Standards Organization (ISO) required that icons should be correctly interpreted by at least 66% of the subjects in a test for the icon to be considered for adoption as an international standard. Only half of the proposed icons actually passed this criterion when they were tested with technically knowledgeable users, and for naive subjects, only 1 out of 12 icons was good enough. Iterative design resulted in improved icons, but the important lesson from this study is the benefit of deciding on a reasonable criterion for measurable usability and then testing to see whether the goal has been met before releasing a product.

The examples in this section have shown that icon usability can be defined and measured in many different ways. The main conclusion from the examples is the need to refine the basic usability criteria listed in Section 2.2 with respect to the circumstances of each concrete project. There are many different ways of measuring usability, and no single measure will be optimal for all projects.

4. Users were shown the command descriptions one at a time, thus preventing them from matching icons to descriptions by exclusion. If the users had been able to see all the command descriptions at the same time as they were seeing all the icons, they could have assigned the last (and probably most difficult) icon to the remaining, unmatched command description.

2.4 Usability Trade-Offs

The learning curves in Figure 2 (page 28) may give the impression that one can have *either* a system that is easy to learn *or* one that is eventually efficient, though initially hard to learn. In fact, often a system that will give good novice learning will also be good for the experts. Also, it is often possible to ride the best parts of both learning curves by providing a user interface with multiple interaction styles, such that the user starts by learning one interaction style that is easy to learn and later changes to another that is more efficient for frequently used operations.

The typical way to achieve this "best-of-both-worlds" effect is to include *accelerators* in the user interface. Accelerators are user interface elements that allow the user to perform frequent tasks quickly, even though the same tasks can also be performed in a more general, and possibly slower, way. Typical examples of accelerators include function keys, command name abbreviations, and the use of double-clicking to activate an object. Section 5.7 (page 139) provides more examples of dialogue shortcuts that can serve as accelerators for the expert user.

Users of such a dual interface who are on the part of the learning curve where they are changing to expert mode may suffer a small dip in performance, so the learning curve will not necessarily be continuously increasing. Also, one should keep in mind that the increased interface complexity inherent in having both novice and expert modes can be a problem in itself. It is therefore important to design the interface in such a way that the novice users can use it without being confronted with the expert mode and the accelerators. For example, a command language system that allows abbreviations should always spell out the full name of the commands in any help and error messages. Also, any operation that is activated by double-clicking should also be made available as a menu choice or in some other visible fashion.

The trade-off between learnability for novice users and efficiency of use for expert users can sometimes be resolved to the benefit of both user groups without employing dual interaction styles. For example, unless the application involves a very large number of fields, one might as well use descriptive field labels in a dialog box, even though they would make it a little larger than if cryptic abbreviations were used. The expert users would not be hurt by such a concession to the novices.[5] Similarly, both user groups would benefit from appropriate choice of default values—experts because they would need to change the value less often, and novices because the system would conform to their typical needs without the need for them to learn about the nondefault options.

Even so, it is not always possible to achieve optimal scores for all usability attributes simultaneously. Trade-offs are inherent in any design process and apply no less to user interface design. For example, the desire to avoid catastrophic errors may lead to the decision to design a user interface that is less efficient to use than otherwise possible: typically because extra questions are asked to assure that the user is certain about wanting a particular action.

In cases where a usability trade-off seems necessary, attempts should first be made at finding a win–win solution that can satisfy both requirements. If that is not possible, the dilemma should be resolved under the directions set out by the project's usability goals (see page 79), which should define which usability attributes are the most important given the specific circumstances of the project.

Furthermore, considerations other than usability may lead to designs violating some usability principles. For example, security considerations often require access controls that are decidedly non-user friendly, such as not providing constructive error messages in case of an erroneously entered password. As another example, museum information systems and other publicly used systems may have hidden options, such as a command to reboot the system

5. Actually, Fitts' Law implies that it would be a little slower to move the mouse between fields in the larger version of the dialog box, since the time to point at an object is proportional to the logarithm of the distance to the object [Card *et al.* 1978]. However, expert users would be likely to move between the fields in the dialog box with the `Tab` key (another accelerator) if speed was of the essence, and they would therefore not be subject to Fitts' Law.

in case of trouble, in cases where the options are not intended to be used by the regular users.

2.5 *Categories of Users and Individual User Differences*

The two most important issues for usability are the users' task and their individual characteristics and differences. An analysis of 92 published comparisons of usability of hypertext systems found that 4 of the 10 largest effects (including all of the top 3 effects) in the studies were due to individual differences between users and that 2 were due to task differences [Nielsen 1989d]. It is therefore an important aspect of usability engineering to know the user. Understanding the major ways of classifying users may also help [Potosnak *et al.* 1986], though often the same system design will be good for many categories of users.

Figure 3 shows the "user cube" of the three main dimensions[6] along which users' experience differs: experience with the system, with computers in general, and with the task domain.

The users' experience with the specific user interface under consideration is the dimension that is normally referred to when discussing user expertise, and users are normally considered to be either novices or experts, or somewhere in-between. The transition from novice to expert user of a system often follows a learning curve somewhat like those shown in Figure 2.

Most of the usability principles discussed in this book will help make systems easier to learn, and thus allow users to reach expert status faster. In addition to general learnability, there are several

6. Note that the classification dimensions used here are different from those used in the "user cube" of Cotterman and Kumar [1989]. Their dimensions concerned the degree to which the user was the producer or consumer of information, whether the user had any part in developing the system, and the user's degree of decision-making authority over the system. These dimensions are certainly also of interest.

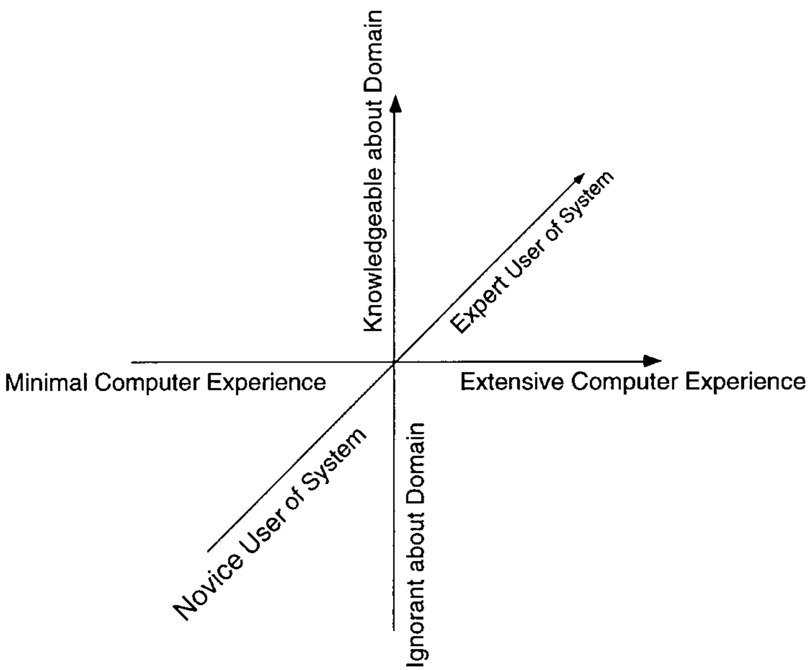

Figure 3 *The three main dimensions on which users' experience differs: knowledge about computers in general, expertise in using the specific system, and understanding of the task domain.*

user interface elements that can prod users to acquire expertise. A classic example is the way many menu systems list the appropriate shortcut for menu options as part of the menu itself. Such shortcuts are often function keys or command name abbreviations but, in any case, they can be mentioned in a way that does not hurt novice users while still encouraging them to try the alternative interaction technique. Online help systems may encourage users to broaden their understanding of a system by providing hypertext links to information that is related to their specific queries. It may even be possible for the system to analyze the user's actions and suggest alternative and better ways of achieving the same goal.

Some user interfaces are only intended to be used by novices, in that almost nobody will use them more than a few times. This is true for most walk-up-and-use systems, like a kiosk for making dinner reservations in an amusement park, but also for interfaces that may require a little reading of the instructions, such as installation programs, disk formatting routines, and tax return programs that change every year. Most interfaces, however, are intended for both novice and expert users and thus need to accommodate both usage styles.

As discussed in Section 2.4, a common way to cater to both expert and novice users is to include accelerators in the interface to allow expert users to use faster, but less obvious, interaction techniques. Several widely used systems come with two sets of menus, one for novice users (often called "short menus" to avoid any stigma) and one for expert users ("long menus"). This allows the system to offer a wide range of features to the experts without confusing the novices. Similarly, as discussed in Section 5.10, online help can assist the novice users without getting in the way of the experts. Interfaces that are solely intended for novices may not need special help systems, as they should include all the necessary user assistance in the primary interface itself.

In spite of the common simplistic distinction between expert and novice users, the reality is that most people do not acquire comprehensive expertise in all parts of a system, no matter how much they use it. Almost all systems of some complexity have so many features and so many uses that any given user only makes extensive use of a small subset [Draper 1984]. Thus, even an "expert" user may be quite novice with respect to many parts of the system not normally used by that user. As a consequence, expert users still need access to help systems for those parts of the interface that they do not use as often, and they will benefit from increased learnability of these features.

The users' general experience with computers also has impact on user interface design. As a simple example, consider a utility program distributed to mainframe systems administrators as compared with one that is to be used by home computer owners. Even though the two utilities may be intended for somewhat the same purpose, such as disk defragmentation, the interfaces should be very different. Even with more application-oriented interfaces, users with extensive experience from many other applications will normally be better off than users who have only used a single system, since experienced users will have some idea of what features to look for and how a computer normally deals with various situations. For example, a user with experience of a spreadsheet and a database program might try to look for a "sort" command in a new word processor. Furthermore, a user's programming experience will to a large degree determine the extent to which that user can use macro languages and other complex means of combining commands, and whether the resulting structures will be easily maintainable and modifiable when the user's needs change at a later date.

The final important dimension is the user's knowledge of the task domain addressed by the system. Interfaces for users with extensive domain knowledge can use specialized terminology and a higher density of information in the screen designs. Users with little domain knowledge will need to have the system explain what it is doing and what the different options mean, and the terminology used should not be as abbreviated and dense as for domain specialists. Consider, for example, the design of a financial planning system. The interface obviously needs to be very different depending on whether the intended users are finance professionals or whether the system is intended to help professionals from other fields invest and keep track of their money.

Users also differ in other ways than experience. Some differentiating factors are easy to observe, like age [Czaja 1988] and gender [Fowler and Murray 1987; Teasley *et al.* 1994]. Other factors are less immediately obvious, like differences in spatial memory and reasoning abilities [Gomez *et al.* 1986] and preferred learning style [Sein and Bostrom 1989], where some people learn better from abstract descriptions, and others learn better from concrete examples. The important lesson from studies of these and other differences is that one needs to consider the entire spectrum of intended users and make sure that the interface is usable for as many as possible, and not just for those who happen to have the same characteristics as the developers themselves. For example, the developers may find it easy to remember where everything is located in a hierarchical file system, but users with lower spatial memory abilities may find the user interface significantly easier to use if it included an overview map [Vincente and Williges 1988].

In addition to differences between groups of users, there are also important differences between individual users [Egan 1988]. The most extreme example may be in programming, where the difference in productivity between the best and the worst programmers typically is a factor of 20 [Curtis 1981]. That is, the program that one person can write in two weeks will take another a year—and the two-week program will often be of better quality. A practical implication of this result that has been found in several studies is that the most important aspect of improving software projects is to employ fewer, but better programmers. Even for nonprogramming tasks, the ratio between the best and the worst users' performance is typically a factor of between 4 and 10.

Since the ratio between best and worst users reflects the extremes and also depends on the number of users tested, one also commonly uses quartile ratios to express the magnitude of individual differences. Quartiles divide a sorted range of observations, such as a set of user performance data, into four equally large sets. The Q_3/Q_1 ratio indicates how much better the best 25% (the top, or fourth quartile)[7] of the users are compared with the worst 25% (the bottom, or first quartile). Q_3 indicates the level of performance where 25% of the users are better and 75% are worse. Similarly, Q_1 indicates the level of performance where 25% of the users are worse and 75% are better. For example, assume that 8 users had been measured as having task throughputs of 2, 3, 3, 4, 4, 5, 6, and 9 transactions per minute. Since there are 8 users, the bottom quartile will cut between the second worst and third worst users, or a level of 3. Similarly, the top quartile will cut between the second best and

7. The reason Q_3 is used to represent the performance of top users even though they are the *fourth* quartile is that Q_3 is the level separating the third and the fourth quartile. It would not be as representative to use Q_4 which is the other endpoint of the interval representing the top quartile, since Q_4 is the performance achieved by the single-best user.

third best, corresponding to a level of 5.5. Thus, the Q_3/Q_1 ratio is 5.5/3=1.8. For many computer tasks, the Q_3/Q_1 ratio is about two.

Attitude differences can also impact how people use computers. For whatever reason, some people simply love using computers and will go to extreme efforts to learn all about their system. I once interviewed a business professional who said that she liked to learn a new software package every month just to stay in shape, and many other "super-users" spend as much time as many hackers learning about obscure details in their computers, even though they are business professionals and not programmers [Nielsen *et al.* 1986]. Such super-users (also known as "power users" or "gurus") often serve an important function as liaisons between the regular users and new computer developments as introduced by an information management department or outside software vendors. The super-users' role as technology champions not only helps introduce new systems, but also provides the regular users with a local means of finding sympathetic and task-specific help [Gantt and Nardi 1992; Nardi and Miller 1991]. Since they often like to talk, super-users can also serve as a way for software developers to get feedback about changing user needs before the majority of users have reached a stage where these new needs have become apparent. Just remember that most users will be different from the super-users, so do not design the user interface purely on the basis of their desires.

Given the many differences between groups of users and between individual users, it might be tempting to give up and just allow the users to customize their interfaces to suit their individual preferences. However, as discussed under the heading *Users Are Not Designers* on page 12, it is not a good idea to go too far in that direction either. Most often, it is possible to design user interfaces to accommodate several kinds of users as long as attention is paid to all of the relevant groups during the design process. It is rare that an interface change that is necessary to help one group will be a major problem for another, or that it is at least not possible to work around the second group's difficulties.