3 Cognitive aspects of product use

In his environment every person is confronted with dozens of objects that can be used. These objects were once designed to serve as an extension, as a tool for that person. But how is someone able to handle all of these objects without making too many errors when using them? This is partially locked in the functioning of the human mind, in the psychology of thinking. But it is also a result of the design of these products themselves. How clear is the information provided by the product, in other words, how skilful was the designer in projecting a correct image of the functioning of the object? A very simple example can be found in Norman (1988): a door only poses two essential questions: in which direction does it move and on which side (left/right) will it open? The answer should be given by the design itself, without the user having to apply any ‘trial and error’. Despite this people often run into doors in many public buildings, because they do not ‘reveal’ beforehand to which side they open. The more complex the object or system is, the greater the need will be for unambiguous operation. Why this is the case is mostly explained by the way in which people control their actions on the basis of mental activities. This is why it is important to pay attention to those mental or cognitive efforts within ergonomics. Cognitive factors play a role at all levels of human-product interaction. In various places in this reader references are made to these factors in relation to both physical and sensory aspects of the user who handles an object or operates a system. It would go too far to discuss all of these aspects. This is why we will limit ourselves here to an exploration of information processing by individuals in so far as it affects product use.

In this chapter we will focus on the various aspects of use in relation to ‘mental’ efforts.

3.1 Human thinking and product use

An object or product can be defined as a function performer. This function performance is the result of ‘the meeting in place and time of product characteristics, user actions and environmental aspects’ (more information about this can be found in chapters 2 to 4). Via the *user actions* we can identify the user. The observing of the object and the handling that follows it will result in a number of stimuli received by the user. These stimuli enter via sensory perception and then evoke either a mental activity or a motor activity directly. The object will then perform its function in that way. For products that are unknown to us a higher level of mental activity will initially be required. This also applies to products that have complicated controls. If you don’t programme the video very often you will have trouble doing so every time. In this case more trouble means: having to think more about the procedure to follow. Obviously ‘ease of use’ will be one of the first design requirements. However, designs often fail to meet this requirement, for example, because a large number of functions are combined into one and the same product or part of a product. Examples are a computer with its various software programmes or a modern telephone as described in box 1.

With objects like these, one and the same key or a combination of keys will sometimes control completely different functions. The introduction of electronics in equipment may have expanded the possible functions considerably, but this has been accompanied by an ever increasing complexity of operation. More and more often the necessary control actions have to be learned first before the function of the device can be used.

Box 1: The complexity of a telephone

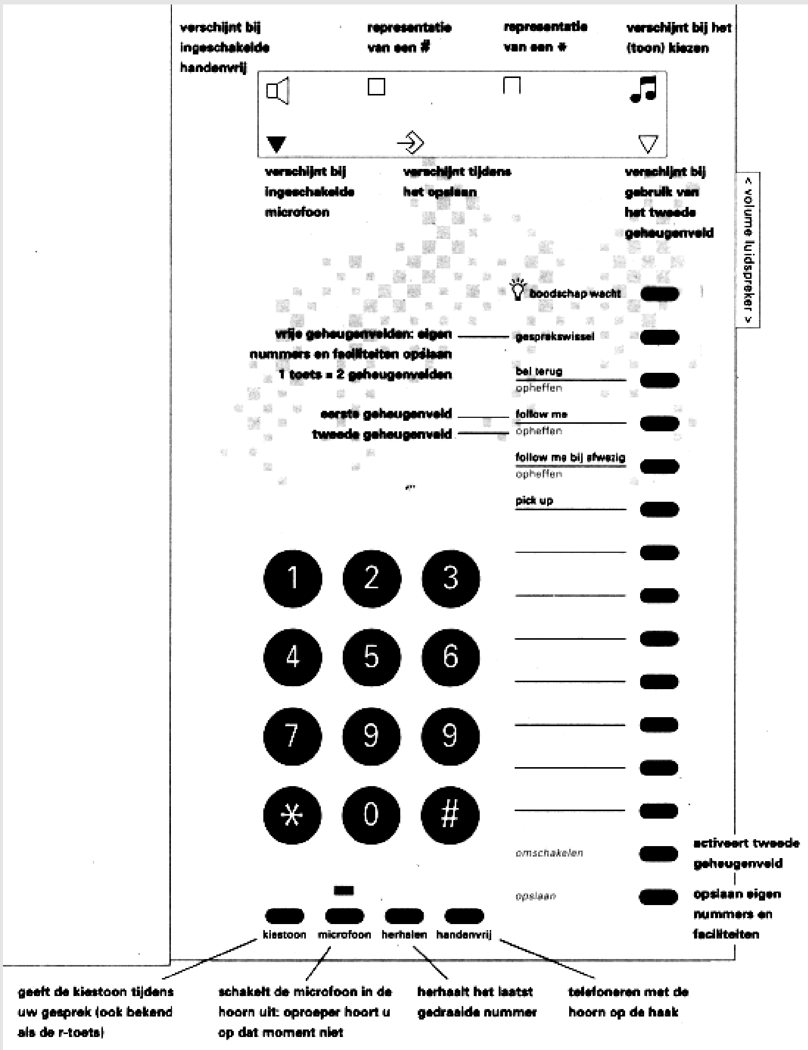
Delft University of Technology uses a so-called ‘Standard TU telephone’. And the telephone has a large number of user options, which befits a ‘technical’ environment. They are summed up in the 28-page manual. We will list a number of these functions here:

1. The conversation can be held either using the handset or ‘hands-free’.
2. The number dialled last can be repeated by pressing a button.
3. You can redirect calls to your phone to a different internal telephone (‘follow me’). This can be cancelled as well by pressing a combination of keys.
4. The same as 3, but now for a longer period of absence (‘follow me when absent’).
5. The same a 3, but now when your telephone is engaged (‘follow me when engaged’)
6. Transferring a call.
7. Answering a second call.
8. Automatic call-back when engaged/no answer (‘call-back’).
9. Consultation by telephone.
10. Saving numbers/facilities I
11. Saving numbers/facilities II. Setting up a conference call

Special facilities:

12. Answering machine (‘voicemail’). *Voicemail has 7 function keys with corresponding functions.
13. Permanent follow me
14. Communication group

Call signals: dial tone (low/high), interrupted dial tone, free tone, acceptance tone, engaged tone, error tone, call-waiting tone, break-in tone, communication tone.



It hardly takes any mental effort to operate the telephone to call someone, but this becomes a different story if you want to save a number under one of the keys on the right-hand side of the telephone or if you want to connect someone who is on the line to a different telephone. You will forget operations like these if you only perform them, for example, once every six months.

And ‘learning’ means making a mental effort, which is an effort that not every person is able or willing to make. This is because, for example, the functioning of the brain shows that humans tend to burden their memory as little as possible. This may partially be laziness, but partially it is a cost-benefit analysis: people have limited memory capacity.

In the large stream of information people will therefore have to select what to memorise or not. As a result of this, cognitive burden is an important consideration when designing objects for use.

As Baecker & Buxton (1987) indicated, the level at which a person is burdened mentally is closely related to:

(a) the time this person requires to learn something,
(b) his or her level of tiredness at that moment,
(c) any stress he or she may have,
(d) his or her ‘proneness to error’ and
(e) his or her ability or inability to ‘timeshare’. *Timesharing* plays a role when two tasks are performed at the same time, for example, driving a car and listening to the radio at the same time. This is possible because some of our actions are internalised to such an extent that they hardly require any control from our brains. However, if acute danger is present on the road, the driver will direct all his attention to that and no longer hear the radio.

It should be clear that the extent to which these five factors play a role differs from person to person and also depends on the situation of each person. This makes it very difficult for the designer to take into account all these differences between people and circumstances in his or her design. This is why an ‘average’ person is taken as a starting point, which is usually the designer himself. Quite often this starting point turns out to be wrong, but not until the product is introduced to the market. By now, more details are available relating to the thinking processes of users which may benefit designers. This chapter presents an introduction to these. For the time being this concerns the outlining of a more accurate image of the thinking process that takes places during actions such as the handling of an object. The starting point will remain the fact that an insight into the way in which the mental efforts of the individual affect product use may lead to product improvements.

3.2 Humans as an information processing system

There are various ways in which to observe individuals as ‘data processors’. The focus may lie on the psycho-physiological processes of sensory perception. Another approach has a cognitive nature and views humans as information processors. In that case we look at the way in which information is stored or remembered and the effects of previous experiences on observations and behaviour in relation to product use. In this chapter we will limit ourselves to the second approach. In the literature concerning the functioning of the human mind computers are often used as a metaphor, including the corresponding terms: input/output, memory, storage and processing of information. This comparison is obviously not entirely valid, but it does have advantages as a model of actual practice. It is assumed that ‘operators’ are applied to a particular ‘problem status’ while performing a task or solving a problem. Take, for example, the equation: $\mathbf{2x^2+3x+5=0}$. This sum can be identified as a ‘problem status’: a description of the elements in the problem, such as the numbers and the unknown in the sum. The signs **+**, **-**, **:** and **x** are operators. Each ‘operator’ represents every step which the problem solver believes can be taken ‘legally’. An ‘operator’ like that can be applied both physically and mentally, in other words, you can solve the sum ‘in your head’, but also on paper. Once part of the sum has been resolved a new situation will have been created.

When looking for examples of problem solving you will easily come across school problems like the equation mentioned above. But terms such as problem status and operators naturally also apply when dealing with problems regarding the operation of a device, for example: how do I programme the thermostat of my heating? Operators can then be described in terms of: ‘press button A and slide C to point X, ...’, etc. This type of analysis will often provide a clear insight into the level of complexity of the use, but also into the logic and understandability of the successive steps that have to be followed.

If operating new, as yet unknown products can be considered the same as solving a problem, the solving process can be described in two ways (Mayer, 1992):

1. As a succession of mental processes or operations that are performed in the brain of a person on the basis of information.
2. As a succession of internal states or changes to information that develop in the direction of the target.

You need information if you want to learn to handle an unknown product. Some of that information will probably already be present in your head; another part can often be ‘read’ from the product itself or is included in ‘instructions’.

Once experience has been gained in solving the problem or, in this case, the use/operation of a product, this will usually result in an automatic series of actions over time with a minimum amount of mental effort. If operating a product is easy the process required for it will probably be memorisable and/or be stored in our memory as a kind of procedure. However, for a more complex procedure, for example, programming your video recorder, the risk will be present that some or all of it is forgotten, especially if the action is only performed rarely.

So how does this information processing and learning actually work? For this we will discuss the functioning of memory.

3.3 The structure of memory

Our senses are constantly bombarded with signals, externally from our environment and internally from our own body, relating to posture and functioning. This is a potential chaos which, nevertheless, we don’t perceive as such, as usually only a very small part of these signals make it through, in other words, are given our highly selective attention. Perception or the extraction of information from this abundance of signals and the processing of it takes place against the background of previous experiences, memories, assignments, needs, expectations, hope and fear, which make up our internal world.

☞ The human memory system can be divided into three subsystems: the sensory short-term memory, the working memory and the long-term memory. The literature offers many models for the processing of information by human beings. These models describe what are assumed to be the most important sections or stages of the process and their mutual relationship.

As an example we will use the model by Wickens (1984). In the diagram used by Wickens (Figure 1) the arrow between the block ‘long-term memory’ and the block ‘perception’ indicates that our perception and information processing is affected by earlier experiences, by things we have learned and by the tasks we have been assigned.

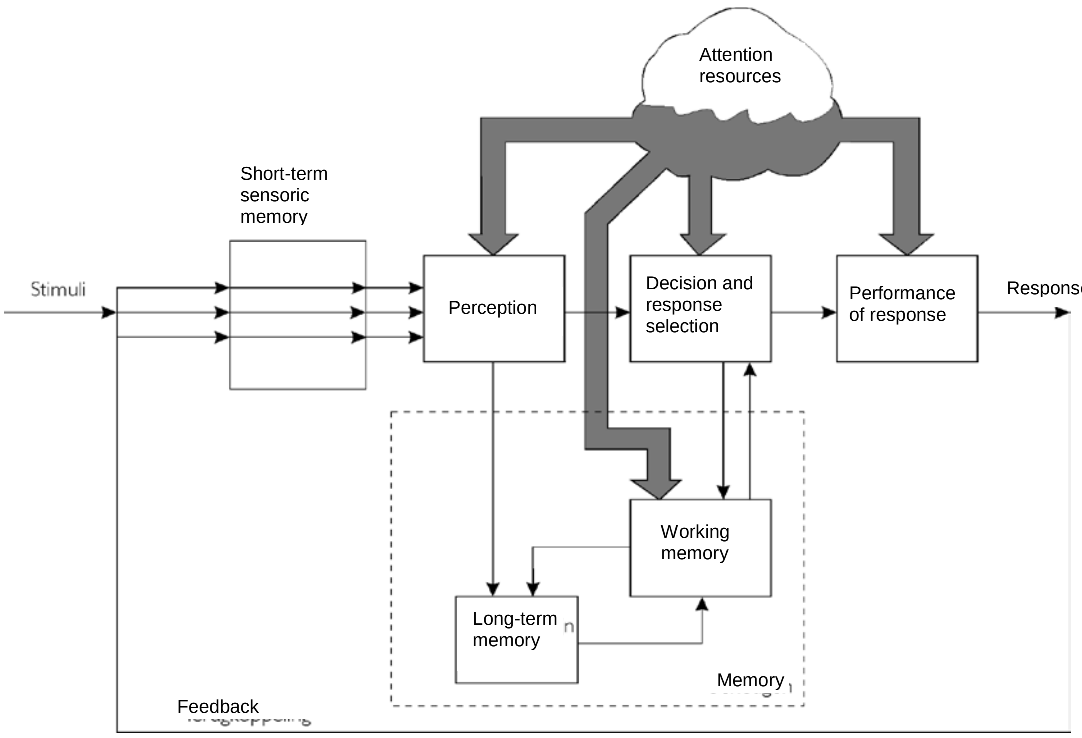


Figure 1: Model of human memory (Wickens (1984)).

The working memory also serves as the gateway to the long-term memory. The information from the sensory short-term memory must pass through the working memory in order to be stored in the long-term memory. Human memory is enormous, but far from perfect. We store huge amounts of global information in the long-term memory, but in many cases we have trouble retrieving information whenever we need it. Here we will only discuss the way in which information is encoded into the three subsystems and a number of practical implications of this. There are many models that describe the functioning of (part of) human memory, but none of these models include the various characteristics that are associated with the working memory.

3.3.1 Sensory short-term memory

☞ Each sensory channel appears to have a temporary storage mechanism, as a result of which the representation of the stimulus is extended for a short period of time once it has been presented. Most is known about the mechanisms that form part of the visual system, iconic memory, and the auditive system, or sound memory. There is limited proof for the existence of tactile and olfactory memory, but very little is currently known about that.

If a visual stimulus is presented for a very short period of time, the iconic memory will retain this image for a short period of time, as a result of which it will be possible to process the signal further. This iconic storage will generally last for less than around one second. For auditive signals this storage may last for several seconds, after which the sound will fade. Information in the sensory memory has not been encoded yet, but it is retained in its original sensory representation. This storage does not require a conscious effort by the individual. In short, storage in the sensory memory is a relatively ! automatic process and people can do little to retain this information in that location for a prolonged period of time. To store the information for a longer period it must be encoded and transferred to the working memory.

3.3.2 Working memory

☞ In order to encode and transfer information to the working memory the person will have to make an effort. It is generally assumed that three types of codes are used to encode it into the working memory: visual, phonetic and semantic. Visual and phonetic codes are visual and auditive representations of stimuli. These representations can also be generated by stimuli of the other type or internally from the long-term memory. For example, the visually presented word ‘DOG’ can be phonetically encoded as the sound that is generated as the word is spoken. Conversely, upon hearing the word ‘DOG’ a visual code (mental image) of a dog may be generated. Additionally, it is possible to form a visual image of an object on the basis of information from long-term memory, without seeing or hearing it at that moment.

Semantic codes are representations of the abstract significance of a stimulus rather than the image or sound of it. Especially semantic codes are important for long-term memory. Even though the physical codes naturally progress into semantic codes, there are clues that all three codes coexist in the working memory.

Practical proof of the coexistence of codes is the fact that letters which are read from paper are automatically converted into phonetic codes. When subjects are assigned the task to read a list of letters and repeat these from memory later, they appear to make more errors as a result of acoustic confusion rather than visual confusion (remembering an E as a D because it sounds almost the same instead of remembering an E as an F because it looks more or less the same). If, for example, an ! alphabetical code must be used on a computer screen, it is important to choose letters that are not phonetically similar.

The capacity of the working memory

The best way to store information in the working memory is via repetition. In an experiment this can be proven by presenting four letters to a subject (e.g. J, T, N and L) and then giving him/her the assignment to count backwards from 187 in steps of three. After counting for 15 seconds (which means that the letters cannot be repeated) the subject will probably no longer be able to reproduce the letters. However, even with repetition in between the information may be lost from the working memory after a while. The more data is present in the working memory, the sooner data will be lost. One explanation for this is that for a large amount of data the time between the consecutive repetitions of a particular piece of data becomes longer.

As it is known that repetition is slowed down by increasing the amount of data, the question can be asked what the maximum amount of data is that can be stored in the working memory. The answer is 7±2 (in other words 5 to 9). In order to assess the actual significance of this number, it is important to know how a piece of data like this is defined. According to Miller (1956), people can divide information into blocks of known units, regardless of their size, and can remember them as a whole. In this way the limit becomes 7±2 blocks, for example, the letters C.A.T.D.O.G.R.A.T. Instead of remembering these as a row of nine letters, Miller says that people will remember them as three blocks: cat, dog and rat. In a similar manner words would be combined into meaningful sentences and these sentences would then be remembered. In this way the capacity of the working memory is used more efficiently.

The way in which the information is presented can simplify the division of that information into blocks. An example is that relatively long numbers can be remembered better by dividing them into blocks of, for example, three or four digits (010 422 6631 is easier to remember than 0104226631). It is also easier to remember a block if it has a particular significance (KPN MTV CD is easier to remember than JWM CHT PF).

! The practical implications of all of this are:

1. Avoid presenting more than five to nine blocks of information if people have to remember this information;
2. Present information in meaningful and distinguishable blocks;
3. Offer training to improve the retrieval of information by dividing it into blocks.

Schneidermann (1980) indicates that, when a menu is shown on a computer screen and the options in the menu have to be compared simultaneously, the number of options must not be greater than the maximum capacity of the working memory. If more than seven options are presented, there is already a chance that the first one has been forgotten before the user reaches the final option.

Searching the working memory

The time required to find a piece of data in the working memory increases proportionally to the amount of data in it. This means that the search time is added to the time required for perception and decoding, as a result of which the overall response time for each piece of data is around 38 ms. It is interesting to note here that it does not matter whether the piece of data that is being searched is actually present in the memory or not. This implies that all data is searched, even if a ‘match’ is found directly at the start.

3.3.3 Long-term memory

☞ Information in the working memory is transferred to the long-term memory by encoding it semantically, in other words, by assigning a meaning to the information and relating it to the information that has already been stored. For example, when studying course material, repeated reading is not sufficient to be able to reproduce the subject matter at a later point. This is because the semantic encoding has not received enough attention. To be able to reproduce more information it must be analysed, compared and linked to existing information. The more the information is organised initially, the easier it is to transfer it to long-term memory. On the other hand, it is easier to retrieve information from the long-term memory if it is stored in a more organised fashion. The retrieval of (accurate) information is usually the limiting factor when using long-term memory.

A condition for the correct functioning of our brains is that we are able to retrieve information quickly and efficiently in order to apply it where required. In everyday situations we are constantly busy performing more or less complex operations, either mentally or using a particular object. The text you are reading now has been transferred to paper using a word processor. The typist has acquired such typing skills that it would not have cost that much time. He or she has learned to work with the word processor, in other words, has learned and stored the procedures required to perform the tasks. It would be inconvenient to have to learn the standard procedures for operating the word processor time and time again.
If the capacity of long-term memory is therefore unlimited, the problem lies in the organisation of information stored. Storing and retrieving information is easier if the subject matter has a significance, if it fits into what is already known (Norman, 1988).

People do not resemble machines in the way they learn or remember things, that is to say, they don't have a passive computer memory, but they handle information actively and selectively. The theory of ‘Gestalt’ psychology already contained the idea that someone’s insight into a problem depends on the way in which the problem is ‘represented’ in his or her memory. One of the most influential theories in this area was introduced by Bartlett (1932) in his ‘schemata’ theory (see for a detailed description Mayer, 1983). According to this theory ‘insight’ or understanding means: constructing a schema and assimilating incoming information into the schema. A schema is present in your memory if you know something about a particular subject or theme. Take the subject ‘chair’: you will undoubtedly know various types of chairs and as a future designer you will also know different styles per type. If you think about that now you will easily be able to retrieve these types from your memory. The representations of these chairs are probably clustered in your memory. These clusters are called schemata.

There is a good chance that this concept is also clustered in your memory under the more general subject of ‘furniture’. But it may also form part of the schema ‘home interior’, depending on the situation in which the concept is evoked. A schema can therefore be described as a general knowledge structure that is used for selecting and organising incoming information into an integrated, useful framework, as well as for quickly retrieving information from memory and then applying it. One of the most important characteristics of this knowledge structure is that people develop a *pattern of expectations* on the basis of their knowledge, which strongly affects the way in which they react to their surroundings. People, for example, judge others on the basis of their appearance alone (‘love at first sight’). Similarly, people will have expectations about how to use a product on the basis of its appearance. The fact that appearances can sometimes be deceiving will be discussed later for the use of can openers. It should be clear that it is crucially important for the designer to be aware of these expectations.

An interesting example of assimilating incoming information into an existing schema and basing expectations on it is presented in an experiment by Bartlett (in Mayer, 1992) that involved telling and remembering a story. In a group the first person was given the story to read, a folk tale from an unknown culture, after which this person had to tell it to the next person, etc. The results of this were interesting, not only because the contents of the story changed as it was passed on, but also because this happened in a systematic manner. The following picture (by Bartlett) shows this again. The top-left drawing is the original.

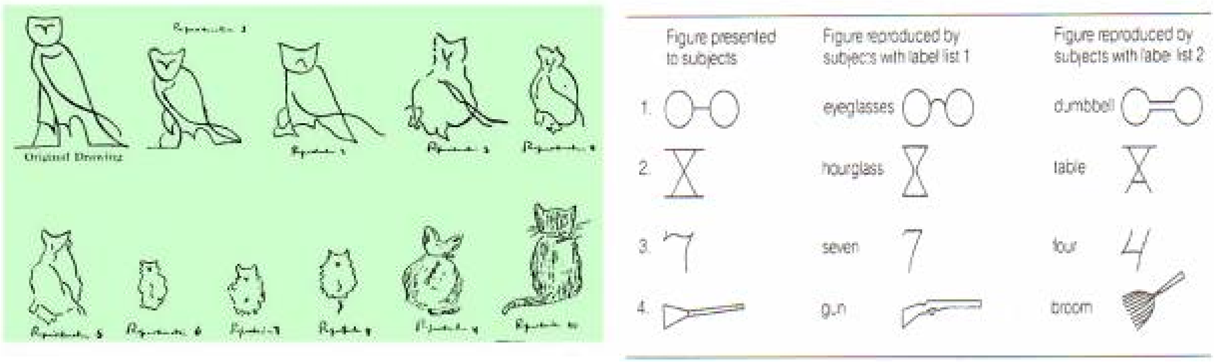


Figure 2: Examples of assimilation

Mayer describes the observations by Bartlett as follows:

- *Levelling.* Most of the details of the story, such as names and titles, were lost. Bartlett blames a lack of prior knowledge for that and his conclusion is: without a general setting or label in our memory information cannot be assimilated or remembered.
- *Sharpening.* A couple of details are remembered or even exaggerated.
- *Rationalisation.* Passages become more compact, more coherent and more consistent with the expectations of the person. Bartlett views this as an attempt of the person to adopt the story to his or her own expectations.

Generally speaking, when gathering information people will assimilate the new material into already existing concepts or schemata. This means that people change this information to make it fit. When retrieving information from memory, the theory states that an existing schema like that is used to create an image. In an experiment with pictures by Carmichael, Hogan and Walter (1932) Bartlett's experiment is confirmed. See Figure 2, in which the first column shows figures that were presented to subjects. Before doing so, the test leader would say, for example, about the first figure in one condition that this figure resembles a pair of glasses and in the other condition that it resembles a barbell. When subjects were asked to remember what they had seen, this was clearly affected by the prior knowledge.

Other more modern variations of the 'schema' concept are *script* (Schank & Abelson, 1977), *plan* (Neisser, 1976) and *frame* (Minsky, 1975). Basically, however, the ideas about memory structure are still the same. Even though schemata are intended as a tool to handle a variety of new situations, they are not always triggered at the correct moment. People appear to be strongly attached to their opinions and thought patterns when they are confronted with a problem. They often do not realise that a smart resolution procedure, which they developed even before a particular problem, can be applied to the new and similar problem. This is also the most essential principle of ‘learning’. Knowledge ‘transfer’ is the key word here: you can solve a new problem by remembering a different problem that you can already solve, by extracting the relevant information from that problem and finally by creating a link between this information and the solution to the new problem.

With regard to product use it is important to be aware of the structures and principles mentioned above, as prior knowledge and expectations also play an important role in the use of products. Quite often new objects are purchased that are slightly different to the objects with which people already have experience. In that case the user will have to adapt and create new schemata. A study by Loopik et al. (1994) into the use of new vacuum cleaners showed that the most important problems relating to use arise at a cognitive level. Many functional instructions are interpreted incorrectly. It often forced the subjects to refer to outside information, including the manual. Another study, in this case by Gelderblom (2001), also shows the effects of prior knowledge. See for this box 2. In this study into can openers it was initially investigated whether people form an image of a can opener and, if so, what kind of image. The second question was whether this mental image plays a role when using can openers that use an unknown technical principle. The study beautifully shows that, even for outwardly simple products with an uncomplicated manual, significant problems may occur when they are used.

3.3.4 Mental model

The widely used concept ‘mental model’ is closely related to concepts such as schema and script. The idea is that as you perform a task, for example, using a product you form a mental model, an internal representation of that task and the product. This allows you to simulate the use mentally as well. A general definition of mental model is taken from Wilson & Rutherford (1989):

☞ *A mental model is a conceptual representation of a system and/or task that is created by the user. This model is based both on previous experience and direct observation. This kind of model provides the user with a certain predictive and explanatory power over the system and aids the interaction with the system. It also ensures that less mental effort is required for the performance of tasks that are already known.*

The difficulty of the task partially depends on which internal representations and fitting handling procedures are already present. In other words, for an unknown task the person will search his or her memory for a suitable representation. The more prior knowledge and experience the person has with comparable tasks, the larger the search area will be and the greater the chance will be of finding a correct solution to the performance of the task. The fact that the size of the search area is an important deciding factor for success when performing the task was ascertained in the can opener experiment in box 2. Subjects who had experience with various types of can openers had less difficulty successfully using a type that was unknown to them.

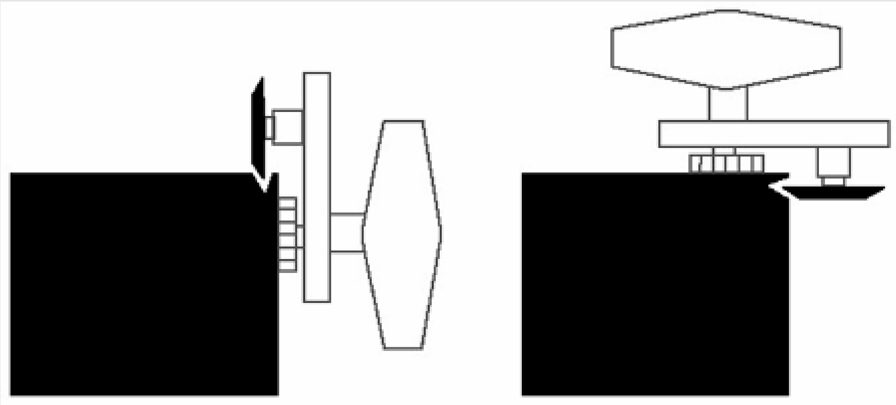
3.3.5 Fixation

An interesting result of experiments like the one with can openers or condensed milk tubs is the so-called ‘fixation effect’, also indicated by the German term ‘Einstellung’. Previous experience may have a negative effect in certain situations whereby new tasks have to be performed, as the person continues to hold on to procedures or rules that were already stored and do not apply to the new situation. A study that is often quoted is the one by Luchins (Luchins, 1942; Luchins & Luchins, 1950).

! Their *water jug problem* provides an interesting insight into this effect. In each case they presented a hypothetical situation to subjects involving 3 water jugs with different volumes. They asked the subjects to measure a particular volume of water using the three jugs of water, each with a particular volume. Imagine having a jug of 20 litres and a jug of 4 litres. To go from 20 litres to 12 litres you will have to remove 8 litres. You can do this by filling the 4-litre jug twice and emptying it. Box 3 lists the questions the subjects were asked.

Box 2: A can opener experiment

At the section Applied Ergonomics and Design of the Industrial Design Faculty at Delft University of Technology a number of experiments were performed relating to the use of 'ordinary' can openers (Gelderblom, 2001). The aim was to find out which role the human mind plays when using known and unknown types of can openers. The figure shows two of these types, one opener that cuts into the top of the can and one that cuts into the side of the can. The latter type was unknown to all subjects.
Both types were similar in terms of outward appearance.



Top cutter (familiar) Side cutter

What were the most important results:
Subjects are hardly capable of drawing or describing a can opener in a detailed fashion. Their mental image is rather superficial.
For the unknown type most subjects persisted in applying the procedure they knew, which was not suitable for this type of opener (but it is for the opener with which they are familiar). Some subjects thought they were being tricked, because 'for a can opener like this the procedure should work'.
Only a few subjects appeared to be able to solve this 'problem' on the basis of experience with different types of can openers. Knowledge of structural features plays an important role here.

The experiment was repeated later with known and unknown types of corkscrews, with the same result.

It appeared that, for the critical questions (from question 7), most subjects from the experimental group chose the more complicated solution strategy, whilst subjects from the control group used the short formula. A similar thing was observed in the can opener experiment. When operating the unknown side cutter, most subjects stuck to the strategy they use for the top cutter with which they are familiar. They were unable to let go of this rule, also because this is not required when they always use the same can opener and always buy the same one again. All of this can partially be explained by the phenomenon mentioned above that people naturally aim for an efficient use of their memory and therefore a reduction of their cognitive efforts. As Reason (1990, page 66) states:

‘In short, human beings are furious pattern matchers. They are strongly disposed to exploit the parallel and automatic operations of specialised, pre-established processing units: schemata (-), frames (-), and memory organising packets (-). These knowledge structures are capable of simplifying the problem configuration by filling in the gaps left by missing or incomprehensible data on the basis of “default values”.’

Box 3: Luchins’s water jug problem (taken from Luchins, 1942; Luchins & Luchins, 1950)

Question	Given 3 jugs with the following volumes (litres of water)			How do you measure the following amount of water?
	A	B	C	
1.	29	3		20
2. Fixation 1	21	127	3	100
3. Fixation 2	14	163	25	99
4. Fixation 3	18	43	10	5
5. Fixation 4	9	42	6	21
6. Fixation 5	20	59	4	31
7. Critical 1	23	49	3	20
8. Critical 2	15	39	3	18
9.	28	76	3	25
10. Critical 3	18	48	4	22
11. Critical 4	14	36	8	6

Question:	‘Fixation’ solution	Direct solution
7	49 - 23 - 3 - 3 = 20	23 - 3 = 20
8	39 - 15 - 3 - 3 = 18	15 + 3 = 18
10	48 - 18 - 4 - 4 = 22	18 + 4 = 22
11	36 - 14 - 8 - 8 = 6	14 - 8 = 6

Question 1, with 2 jugs, was meant to be an example. The experimental group was presented with questions 2 to 11, one by one. The control group was only given questions 7–11. Questions 2 to 6 were intended to achieve a fixation on the type of solution (in this case b – a – 2c).
Questions 7, 8, 10 and 11 could be solved with this formula, but also with the more simple formula a - c. Question 9 was provided to allow subjects to recover from the fixation, as this question cannot be solved with b – a - 2c.

3.4 Acquiring knowledge and skills

In the previous section (prior) knowledge and experience were discussed on various occasions without explicitly specifying the types of knowledge and skills that are required for performing a particular task or solving a problem, nor was the acquisition of knowledge and/or skills discussed. Various ‘theories for learning’ have been developed in this area. One of the more recent and more common theories in the field of information processing was formulated by Anderson (1983), which is called Adaptive Control of Thought* (ACT*) (see Fig. 3).

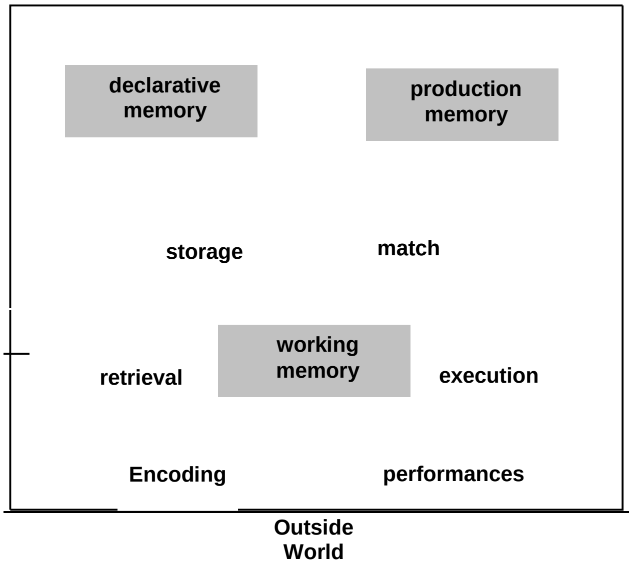


Figure 3: Anderson's ACT model (1983)*

Anderson distinguishes *declarative* knowledge and *procedural* knowledge. Declarative knowledge is 'knowing that', mainly factual knowledge, as it is presented to us in statements every day, verbally or on paper. Procedural knowledge is 'knowing how', how to use knowledge, how to apply it and the procedures that are available for that.
In the computer simulation model that Anderson created on the basis of his theory procedural knowledge is represented in the form of production rules, in other words, 'if..then' lines. The operation of a device can be explained in the form of if-then rules. *'If you turn the knob to the right the water will be cut off.'*

Declarative knowledge can be acquired relatively easily. You basically do this during your study by listening to a lecturer or reading a textbook. It's not about the question of how you will be using that knowledge yet. Procedural knowledge on the other hand, applying it, for example, to solve a problem often requires more effort. The learning process is defined by Anderson as the compilation of knowledge, which consists of two components: composition and proceduralisation.

Composition means that different productions are reduced to only a few, as a result of which steps in the thinking process can be skipped. When programming a video recorder, for example, it will be necessary at first to follow the included manual step by step. Afterwards you may hope that some of the steps are performed automatically and subconsciously. If this is not the case, it often means that this programming is not yet procedural knowledge. It should be clear that the complexity and consistency of the task affect the speed at which procedural knowledge is acquired. Proceduralisation concerns the inclusion of declarative knowledge to a production or procedure. Take the example mentioned above about the telephone number that is looked up and only stored temporarily. If this telephone number had to be used often or it was very important to remember it, this number would be proceduralised and it would therefore be easily retrieved without making a cognitive effort.

Beginners and experts

Many studies have been performed into the differences between beginners and experts in many fields of expertise. A good example is the study into expertise relating to chess. Figure 4 shows an example from the study by Chase & Simon (1973). They confronted beginner, advanced and experienced chess players with board situations like those in the example. They could be one of two types of positions: a real position from a chess game (left side of figure) or a random position (right). Try for yourself what you can remember about these two positions. The study revealed that a beginner was able to remember around 4 positions of either of the two positions. For an expert there was a great difference between the left and right position. For the random position only 4 positions were remembered as well, whilst the left position could be reproduced almost completely. A number of general conclusions can be drawn from this study and others.

It's not that experts have better skills in remembering or a larger memory capacity as such, but they have stored a large number of configurations in their memory. This kind of knowledge is acquired based on years of experience. Whereas the thoughts of beginners will mostly still be fragmented, experts will think in larger functional units. Other differences are that a beginner who is confronted with a new problem will pay more attention to the superficial characteristics, whilst the expert will look for underlying structural characteristics.

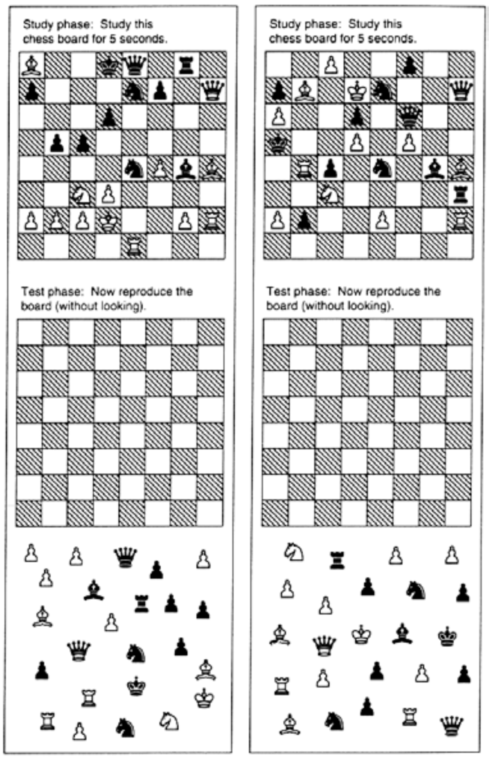


Figure 4: Differences between novices and experts (Chase & Simon, 1973).

What is the relation with the subject of this chapter, product use?

People forget all too often that a large number of products confront users with a problem. This may be because the product is new or so complicated that the correct tasks are forgotten time and time again. Knowledge about the object can also be divided into to declarative knowledge, the factual data, and procedural knowledge, how to operate the device.

This means that expertise plays an important role in the way that certain tasks are performed and the speed at which they are performed. Alba & Hutchinson (1985) state five aspects of increasing expertise when using products:

- The performance of a task improves by repeatedly performing it, as the cognitive effort required to perform the task is reduced. In a number of cases repetition will result in automatic task performance.
- The cognitive structures that are used to distinguish between products become more refined and complete as familiarity increases.

- The capacity to analyse information and isolate the most important and relevant aspects for the task improves as familiarity increases.
- The capacity to modify the information available and, as a result of this, acquire knowledge that surpasses the information available will increase as familiarity increases.
- The capacity to remember information about products increases as the familiarity of the product increases.

3.5 Cognitive control over actions

Based on the above we can say something about the functioning of memory, about the structure that is assumed to be involved, as well as the type of knowledge that is relevant. If we now direct our attention to the user in relation to the performance of tasks, will it then be possible to say something about how mental control is exercised over the tasks to be performed? Researchers have been active in this field as well. It is remarkable, though, that the attention for this mainly arose via studies into *human error* (among others Rasmussen, 1986; Reason, 1990). The contribution of the former author stemmed from his study into errors in control rooms of industrial installations, such as nuclear reactors and chemical plants. Obviously, human errors could have disastrous consequences in those situations.

However, Rasmussen's approach is highly useful in a large number of situations that involve a man-product 'interface' without the errors having serious consequences. Operating a video recorder incorrectly will at most result in frustration. We will discuss Rasmussen's contribution in some more detail. In his 'skill-rule-knowledge' model he assumes that there are three levels of performance. Each level is linked to the level of familiarity with the task. Figure 5 shows a simplified version of this model.

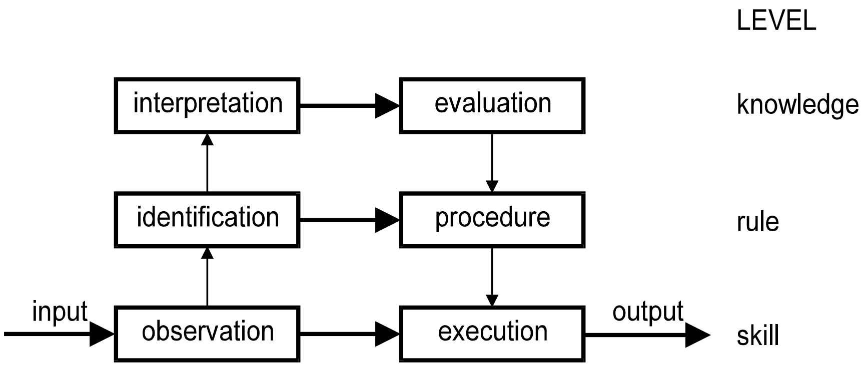


Figure 5: Rasmussen's skill-rule-knowledge model

'Skill-based' level

At this level the performance is completely controlled by stored, pre-programmed 'skills'. In the above references were made in this regard to knowledge that is stored in 'schemata'. At first sight there no longer is any conscious cognitive mediation at this level. A direct link is made between the perception of the task and/or the object and the motor operation that is required to perform the task. One example of this is cycling. You have had to learn this in the past (procedural knowledge), but the actions are now automatic to such an extent that you would not be able to tell exactly how you keep your balance on the bicycle. This also applies to the actions involved when using a wide variety of products. You no longer have to think about it, there no longer is any cognitive burden, nor is there any interference when you perform a different task at the same time (knitting and watching TV).

☞ **<u>‘Rule-based’ level</u>**

At this level behaviour for a particular task is controlled via ‘rules’. That is to say, there is still some cognitive activity, as a particular rule has to be retrieved from memory in order to perform the task. In the above a rule of that kind has also been called a ‘production rule’, in the form of ‘if-then’ (in the model: *identification* → *procedure*). Using a word processor or programming a video recorder are typical tasks that require a number of rules which are stored in memory. Both tasks are too complex to perform them completely automatically.

☞ **<u>‘Knowledge-based’ level</u>**

Control is required at this level when confronted with an unknown task or a new problem. In that case actions have to be prepared on the basis of knowledge already present or experience and information from outside (in the model: *interpretation* and *evaluation*).

According to Rasmussen the concept ‘mental model’ plays a role at this level. The user will create an internal representation of the problem in order to generate a solution that way. Once the problem has been solved the newly created procedures will be stored and retrieved the next time in the same situation. A number of these rules will become completely automatic as experience increases and will therefore be processed at ‘skill-based’ level. As the position of the arrows in the model shows, there is a constant trend to reduce the cognitive burden as quickly as possible.

This cognitive control can be compared very well with the ACT* theory of Anderson referred to above, in which the learning process is called knowledge compilation, consisting of composition and proceduralisation. Anderson’s proceduralisation of knowledge can be described in the Rasmussen model as the process of full control at ‘knowledge-based’ level up to ‘skill-based’ level, at which conscious cognitive control is no longer required.

The division into three levels by Rasmussen can be illustrated again on the basis of the can opener experiment in Box 1. The use of your own, familiar can opener will be controlled at ‘skill-based’ level. It does not require any mental effort. This becomes a different story if you have to use an unknown can opener. Initially you will rely on the ‘procedures’ that are already present in your memory. Especially if the unknown can opener looks like the familiar one, it is quite obvious for that person to try and apply the procedure that is successful for his or her own can opener. If that procedure fails, the user will have a problem and he or she will have to come up with a new procedure on the basis of what he or she knows and what new information he or she gets from the can opener itself (certain external characteristics and mechanisms). Once that procedure has been found, it will be stored and applied at a later opportunity. The difficulty of the task and the amount of experience performing the task determine whether the procedure is stored and could possibly be controlled at ‘skill-based’ level.

3.6 Individual capacities

The models and examples referred to above are often presented as generally applicable truths. It should be emphasised again that many factors affect the behaviour of people, as a result of which the generalisability of these models is a point of discussion.

Elsewhere in this reader it was emphasised that there is great inter-individual variance, both at cognitive and at sensory and physical level. The designer will have to determine to what extent these differences should be reflected in the design. It would go too far to discuss all of these differences in detail. That is why only an example will be given here: the individual differences in information processing as a result of age. The capacity to absorb information deteriorates with age. These issues are also discussed elsewhere in the reader. It is surprising that designers or manufacturers hardly take this into account. The trend to integrate more and more functions and information about them in one and the same device or components of the device is a problem especially for this category of people. A telephone is a good example of this, but to an increasing degree also audiovisual equipment and kitchen appliances, including microwaves. An example of the way in which various age groups perform an unknown task with a product is included in Box 4. In experiments by Bremner & Gelderblom and Gelderblom (Gelderblom, 2001) it was established how elderly people and first or second year students handle the memory function of telephones.

Box 4 Experiments with telephone memory

In 1993 and 1994 a number of experiments were performed relating to the use of the memory function of various telephones at the section Product and System Ergonomics of the Industrial Design Faculty at Delft University of Technology (Gelderblom, in print). The aim was to find out which role the human mind plays when using this complicated system and what effect age has on operating skills.
Four (existing) telephones were available, each with its own method of operation.
To call a number stored in the memory the following tasks had to be performed for each telephone: Telephone 1: Press the ‘M’ key and then the code of the memory location that corresponds with the number to be called (each of the 10 memory locations has its own single-digit code (0–9)).
Telephone 2: Press the memory key that corresponds with the number to be called (the telephone has 10 memory keys that are separate from the number keys).
Telephone 3: Press the ‘shift’ key and then the memory key that corresponds with the number to be called (this is a different function of telephone 2; ‘shift’ is used to call a secondary memory).
Telephone 4: Press the ‘Directory’ key and use the ‘scan’ key to browse the memory until the display shows the required number. Then press the ‘dial’ key.

A group of elderly people were asked to operate each of the telephones. The results of the study were:

- None of the participants were able to form a mental image of the functioning of the telephone memory.
- Only the more simple types of memory (tel. 1 and 2) were successfully operated by some of the participants.
- The strategy used was: ‘trial and error’.
- Experience using a memory function only resulted in success for the same type of telephone memory. This means that there was no ‘knowledge transfer’, apart from one exception: one participant with a great deal of experience.
- The use of the memory function of each telephone was explained afterwards each time, demonstrated and finally practised by the participant. Retention after six months appeared to be minimal.

3.7 Instructions for the designer

Based on the considerations in the previous paragraphs, a start can be made on deriving a number of instructions for the designer. Within design practice it is striking that ergonomics is often ‘included’ in the design process in so far as it concerns the physical aspects of the user. However, every adjustment of a product or system to the user requires some insight into human behaviour. An analysis of the complexity of the task is the least we may expect from the designer. This expectation often fails to materialise, as the designer himself is also a user. And for simple products with what appears to be a simple method of operation the designer will therefore not be bothered to look beyond himself. An example of a simple product like this is a can opener, the level of difficulty of which has already been shown above. Another example is a novice sailor who is sailing a ship according to a particular compass heading (taken from Norman, 1986). This alone shows how difficult it can be to use single-control mechanisms in order to obtain a single result. The compatibility of the movement of the helm with regard to the boat heading is the opposite of what a novice sailor may sometimes expect. And the compatibility of the compass movement with regard to the boat movement is just as confusing. An experienced sailor will not have any steering trouble thanks to the correct mental model.

3.8 The performance of a task

Knowledge about the mental activities relating to product use results in a number of ‘tips’ for the designer. In his book ‘The psychology of everyday things’ (1988) Norman pays a great deal of attention to this in particular, based on the average user. In his opinion, it is of essential importance to the designer to consider the action the user will have to perform on the object in order to reach the target before starting. Imagine I would like to call my colleague at Eindhoven University of Technology. I don’t know his number by heart, but I believe it’s under one of the memory keys of my telephone. I will therefore pick up the receiver and perform the tasks that are necessary to call a number from the memory. Once that has succeeded I will have reached my target. I could also have achieved this by looking up his number in my diary and entering that.

In this process both psychological and physical variables play a role. I started with targets and intentions, which exist in my head and are directly linked to my needs and interests. However, the task had to be performed using a physical system, with a mechanism that can be manipulated physically. As soon as I perform that task, the physical variables and the state of the system will change. In other words, the general rule is that the physical variables have to be interpreted in view of the psychological targets and the psychological intentions must be translated into physical actions performed on the mechanism.

According to Norman, this process can be divided into seven stages (see Figure 6), three of which are used for performance and three of which are used for checking. These stages are:

1. Choice of target (contact with my colleague).
2. Creation of an intention (which task should I perform, which specific actions?).
3. Specification of a task (reaching for the telephone, listening to the dial tone, using my fingers to press the keys, etc.).
4. Performance of the task (performing the actions under 3).
5. Observation of the state of the world (the response of the telephone via audio signals).
6. Interpretation of the state of the world (is it a dial tone, an engaged tone or something else?).
7. Evaluation of the results.

In many situations people do not have to worry about all sorts of psychological and physical variables, as they are easy to control. However, to illustrate the complexity of user actions again for a relatively simple system another example is presented below, again taken from Norman (1986). This concerns controlling the water in a bathtub. The aim of it was to control both the amount of water and the temperature. However, water was supplied via two pipes: hot and cold. The simplest system had two taps and two streams. This means there were two physical mechanisms, one for the amount of hot water and one for the amount of cold water. In other words, the variables that were relevant to the user interacted with the two physical variables: the total stream was the sum of the two physical variables; the temperature was a function of their difference.

The problems that arise here stem from a number of sources:

1. Compatibility problems. Which tap is hot and which one is cold? In which direction should each tap be turned? (Despite a universal standard for direction, more and more exceptions are found.)
2. Ease of use. In order to raise the temperature of the water without changing the amount, both taps will have to be operated.

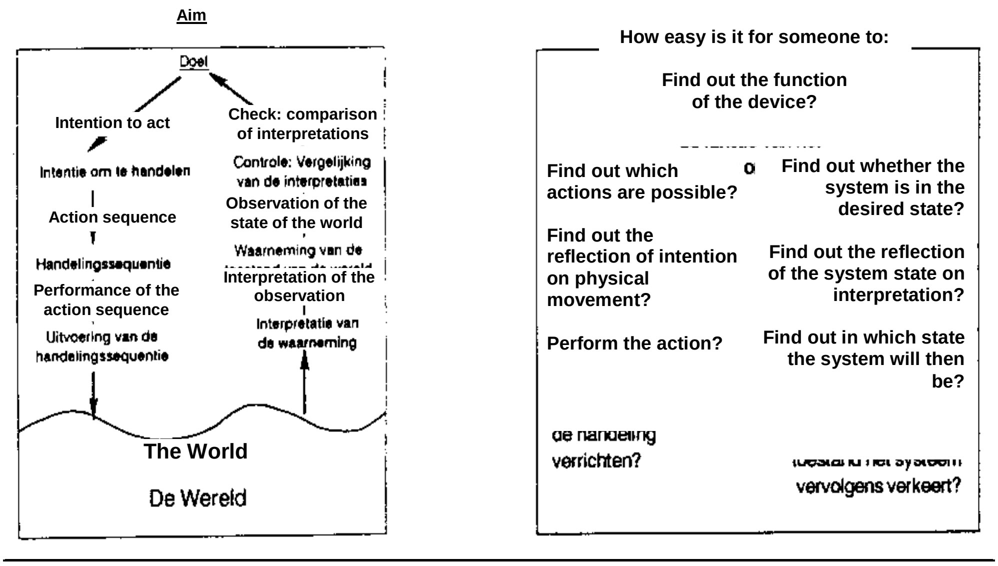


Figure 6: User actions (Norman, 1988)

3 Evaluation. With two taps it can sometimes be difficult to determine whether the correct result has been achieved.

According to Norman, technology has helped a little to solve the problem. Mixer taps were manufactured first; these resolved the evaluation problem. Afterwards, 'single control' taps were manufactured; these changed the psychological factors directly: one dimension of movement affects the amount, the other affects the temperature. Despite these improvements there is still a compatibility problem: which movement of which part of the mechanism controls which variable? And as the mechanism is no longer visible, which is the case for a two-tap system, it is not as easy for first-time users. It becomes more complicated if control also involves a delayed response. An example of this is the temperature controller in a fridge. The feedback of it is very slow.

By the time people are able to determine the results of the action, so much time has passed that they no longer remember the action, as a result of which it will be difficult to correct the action. If the instructions are also vague or the correct operations are not stated, it will be almost impossible to record a mental model in memory.
The conclusion is that, even with two variables, the number of aspects that require consideration is surprisingly large.

3.9 Design principles

The entire cycle of seven stages is not always followed. But it should be clear that there is continuous feedback from the object or system that is used and from the results of the action. According to Norman, these different stages can be translated into the following design principles:

1. *Visibility.* The object or system can make it clear which actions have to be performed. It can provide a clear image of the status. Not all knowledge or information about operation has to be in a person's head. Norman indicates that one part of the knowledge can be locked 'in the world' and another part can be locked in the physical restrictions of the world. Knowledge present in the world may therefore serve as an external memory and may thereby relieve the burden on a person's own memory in the form of reminders. As soon as information required for a task is readily available within the world the need to learn it is reduced. One condition is that information provided by the object or system is clear and unambiguous.
2. *A good conceptual model.* The user must form a clear mental model. To achieve this the controls and results must be presented in a consistent manner. You should therefore not design two similar can openers that have to be operated in a completely different manner. Mental models, however, are often incomplete. If people are able to control a device or handle an object with limited knowledge of it, why would people then make an effort to store a more detailed image in memory? After all, we have already seen that people wish to burden their memory as little as possible. An inadequate image, however, will often lead to frustration or worse. We saw this, for example, in the study relating to can openers and one of the telephone functions. Theory shows why people create expectations on the basis of their knowledge of the environment. Expectations on the basis of the external characteristics of a product often result in a fixation on the pattern of actions. This fixation has often not been intended by the designer. The designer can and must take this into account in his or her design. This means that a clear 'system image' is crucial.
3. *Correct visual relations.* A designer should take into account the consistent use of relations between two linked aspects of an action. For example, the configuration of the knobs of a hob and the burners or the location of the light switches in a room in which various light sources have been installed. In various rooms in the university three switches are present in a row, whilst the light sources are behind each other. The fact that the switch on the right operates the light that is closest to the window is illogical. The consequences are not serious, in this case it will only lead to irritation. This changes when illogical relations are present in the design of the control section of aircraft or chemical installations, which may result in operating errors. In practice designers can make use of 'natural' relationships. A distinction can be made here between 'physical' or 'spatial' analogies and 'cultural' analogies/standards. An example of a spatial analogy is an object that is moved up or down with a

control knob. This means that moving the knob up and down provides a natural relationship. Examples of cultural standards: a louder sound means a greater amount, a rising level means more, a dropping level means less.

☞ 4. *Feedback.* During the action the user should be receiving feedback over the results all the time: is he/she doing it correctly or not. It often happens that machines do not provide any information about this other than the refusal to work.

3.10 Possibilities and impossibilities of users

In the above attention was mainly paid to the consequences of human behaviour for the principles of a good design, however, attention will have to be paid to the user himself as well. For which individual or category of people do you create a design? What are the possibilities and impossibilities of this individual or this group in physical and mental terms? Examples are categories such as children or elderly people. Elsewhere in the reader a lot of information can be found about physical characteristics. Unfortunately it happens quite often that the designer only takes into account physical and mental limitations and as a result of this limits his or her design freedom. However, studying human behaviour may yield information that in fact increases the freedom of the designer. In an explanation of a design it often seems that the ergonomic knowledge is translated into P5 and P95. The example in box 5 shows how a particular design for children in a particular age group can be improved using information about the behavioural characteristics of that group.
Take, for example, a particular problem for a specific group and devise a solution using a design that uses information about the behaviour of the people who are part of that group.

Box 5: Types of play and activities (resting, movement, fantasy and construction).

In 1993 a study was performed by Christiaans and Van Andel into the effects of the presentation of information to the designers on the eventual design. The study was performed during a design exercise at the Industrial Design Engineering Faculty. The assignment for the students was to design a ‘Flying Dutchman’ for children in the age group between 4–8. The standard information pack consisted of technical, business-related and ergonomic data. The ergonomic information mainly related to the physical size of children within that age group, as well as information about safety standards. The additional information in the study focused on the *playing behaviour* of children. Roughly speaking, the following knowledge was transferred by the researchers:

1. Types of play and activities (resting, movement, fantasy and construction).
2. Social activities (playing with other children, small/large groups, playing individually).
3. Differences between boys and girls (boys : more often outside, more often further from home, different games, etc.)
4. Differences between age groups (younger children play more construction and fantasy games, older children ‘hang around’ and cycle more, do more sport)
5. Types of toys (agility, teamwork, perception, party games, mental games, technical toys).
6. Play areas (inside and outside)

The students were divided into two groups and were given this information verbally, but in different ways. In the control condition this knowledge was transferred plainly, using overhead sheets. In the experimental condition the material was handled in a more active manner using examples on slides and working out an example of their own. Once the students had completed the entire exercise their designs (a materialised Flying Dutchman) and their reports were assessed by experts on features such as ‘child friendliness’, ‘suitability for the age group’, ‘multifunctionality’, and ‘fantasy-provocation’.

The results showed that the information provided in the experimental condition resulted in a greater variability of products. It gave the (student) designers more room and options to add something extra to their designs. It also appeared that this was done more successfully by the experimental group. For the students in this group the information transfer method had an effect on the way the information was absorbed in their memory.