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User-centred design of smart products

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In and around our homes and offices we are confronted with a rapidly increasing variety of smart products, such as microwave ovens, video-recorders, facsimile equipment, and automatic teller machines. For casual users, particularly, the interaction with these modern electronic products is potentially difficult as, for commercial reasons, most of them integrate multiple and complex functions, with dozens of features, while lacking user interfaces that foster a coherent conceptual model that makes functionality apparent and comprehensible. Adherence to an iterative, user-centred design process, instead of the common, technology and market driven one, leads to more useful and usable products. These products have a reduced functionality that matches real user needs and preferences. This paper describes the process of user-centred design as it has been developed over the past 25 years at the Faculty of Industrial Design Engineering of Delft University of Technology. It focuses on the methods for extracting design oriented information from and about the prospective users in the early phases of idea generation, and evaluation of the process. It is in these phases that the major decisions with respect to functionality and basic principles of interaction are made. It appears that small-scale qualitative user studies and unstructured walkthrough methods with experts stand the best chance of being adopted here. The timely availability of adequate representations of the design concepts in question, such as sketches and models, is essential, not only to involve users and experts effectively, but also to enhance communication between members of the multidisciplinary design team. It is concluded that good user-centred design shortens overall development time and costs by reducing the number of expensive changes required late in the design process, and results in better quality products. This is very important in a market that, understandably, is becoming more discriminating, both with respect to usefulness and usability.

1. Introduction

In our homes, offices and outdoor living environment we are being confronted with an astonishingly wide and rapidly increasing variety of modern micro-electronic products. They range from simple programmable kitchen appliances, alarm clocks, CD players, microwave ovens, dish washers, video-recorders and remote control TV sets, via telephones with extended functionality, facsimile equipment and copiers to parking meters and automatic teller machines (ATMs).

All these so-called ‘smart’ products have a common built-in processing power and a programmable memory allowing them at least some self-controlled operation. Technically speaking, the inclusion of additional functions in these products is easy and cheap. For often questionable commercial reasons, most of the smart products integrate multiple and complex functions with dozens of features, usually made accessible to the users in more than one way. For the casual users that these modern electronic products are intended for in particular, the interaction is potentially difficult as intuitive use and further exploration is limited. The main reason is that these products have a low *a priori* 'guessability' as they lack most of the intrinsic feedback (movements, noise) and the characteristic form elements of conventional products. Processors and memory chips do their work invisibly, obscuring functionality and causing the great axiom of more traditional design 'form follows function' to lose much of its significance. If not compensated for by well-executed design, these intrinsic drawbacks can be very detrimental to the formation of effective conceptual models that guide the users in their understanding of the underlying devices as a whole.

The consequences are well known. Even with the manual at hand, only a minority of the owners can set their video-recorders for delayed recording. Users experience major problems when they have to re-set the channels on their TV sets and for remote control devices only a few basic functions are used regularly and with difficulty. It is no great surprise as these small devices, usually different ones for TV, video-recorder and an audio system, often feature more than 30 tiny push buttons each. These buttons have to be located and operated in dimly-lit environments where people can't identify the minuscule, low-contrast pictograms and inscriptions, even if they wear their reading glasses. What are your own experiences with your new office telephone with extended functionality? Do you benefit from it fully yourself? (figure 1).

However, from a marketing viewpoint despite all shortcomings in design, and the resulting usability problems, the future for smart products looks bright. Areas of application and capabilities are growing rapidly, keeping pace with the ever-increasing power of processors, memory chips and channels for telecommunication.

Figure 1. Example of an office telephone set with extended functionality; courtesy of Tiptel b.v., Almere, The Netherlands.

At the same time, prices keep falling significantly, which is in sharp contrast to the rising costs of human labour and physical transport that these micro-electronic products replace or support.

What is badly needed are better designed products where functionality has been substantially reduced in accordance with real user needs, and where user interfaces are clear, coherent and consistent. This would allow users to interact more naturally again, and focus on their goals and tasks instead of on the underlying technology and the interaction it requires. This is certainly not an easy task. It is crucial to have a thorough examination of the functions and product features, as first they should closely match the needs and preferences of a diverse user population. Second, it is important because in general, an inversely proportional relationship can be expected between functional complexity and usability of these types of products (Wiklund 1994). These circumstances and the need for integrated design of both software and dedicated hardware with a high aesthetic appeal, make the design of smart products even more demanding than the design of so-called human computer interaction (HCI). Usually the latter, which gets much more exposure in the literature, deals with less diverse expert users, and the design of software mainly for implementation on available, standard hardware. At the same time it is also common practice for future professional users to receive training, unlike domestic consumers. Fortunately good design, focusing timely and primarily on users instead of on technology and cost price, can to some extent obviate these extra difficulties, turning back the present negative trend, and delivering smart products with considerable, although balanced, functionality. The user interfaces of these products foster a coherent conceptual model that makes functionality apparent and comprehensible. Furthermore, such design balances the need for innovation with the desirability of adhering to, *de facto*, standards for consistency.

Of course, these are products that manufacturers, distributors and users dream of. Unfortunately, there is no simple straightforward procedure guaranteed to produce such prominent designs. The most promising process is complicated, with many pitfalls, is laborious and in need of repeated iteration after successive end-user testing of sketches of ideas and concepts, preliminary design models, simulations and (working) prototypes. It has become broadly accepted that, especially for smart products, it is impossible to get the design 'right first time' using the traditional intuitive approach, and some worldwide agreement is settling upon the need for what can be called user-centred design. Although a very welcome change in the attitude of designers who used to place their own opinions above the consumers' point of view (Gould and Lewis 1985), there is still only limited agreement on how that should be done (Marinissen 1993).

2. The process of user-centred design

As has been pointed out previously, from an ergonomics point of view, adherence to a user-centred design process should primarily lead to more useful smart products with considerably better usability for the casual user. Usefulness has to do with the appropriate inclusion of functions in the product, and usability with the quality of the interaction. However, ISO 9241-11, dealing with office work with visual display terminals (ISO 1995), provides a standard definition of usability as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'. According to this definition, usability is to be measured against three criteria:

- effectiveness, or to what degree does functionality allow intended goals to be achieved, a criterion that clearly overlaps with the conception of usefulness introduced earlier in this paper;
- efficiency, or what demand is placed on users' resources, both cognitive and physical, in achieving these goals; and
- satisfaction, a very subjective criterion, expressing the opinions of the users as to acceptability of the interaction.

As already stated, there are considerable differences in the use and hence the usability between professional products, such as visual display terminals for office work, and smart consumer products. Usually with consumer products there are neither clearly specified users, goals, nor contexts of use. As discussed by de Vet (1993) effectiveness and efficiency are less important as consumers often seem to prefer to use products in less efficient but more pleasant ways. It is certainly pleasure and early success that motivate consumers to explore further functionality and interaction autonomously. This is a very important issue as one cannot expect consumers to follow courses or go through extensive documentation. So for consumer products, it seems appropriate to extend the set of usability criteria to include 'pleasure', and at the same time lay less emphasis on the efficiency criterion. This is more advisable as, contrary to most professional users, consumers can choose whether to buy and use a product or not. The administering of these usability criteria should not be limited to the intended use of the product only, but also to readily foreseeable, alternative uses.

The subjectivity of usability criteria as 'satisfaction' and 'pleasure' (the latter pre-eminently important for smart products with an entertainment function) calls for active user involvement throughout the design process. Of course usability is not the only issue to be taken into account in such a process. Other important issues are, for example, functionality, cost price, manufacturing constraints, serviceability, reliability, aesthetics and the use of natural resources during the product life-cycle. This means that a design is the result of several trade-offs between properties that are often hard to compare. This is acceptable, however, if usability is treated as an equally important and integral part of design, and not as previously, as an optional convenience for users only (Bevan 1996). This latter idea accords with the outmoded, but still prevalent, opinion that the human mind and body are so flexible that the understanding and control of smart products with poor usability will only require a short period of learning and training.

Several authors (Gould and Lewis 1985, Sanders 1993, de Vet 1993, Roozenburg and Eekels 1995, Johnson and Westwater 1996) describe in varying detail a process of user-centred design. Although these descriptions differ significantly in nomenclature used and in their emphasis on the various aspects, they all include four basic steps already defined by Gould and Lewis (1985) in the early 1980s:

- know your users;
- incorporate the current knowledge of users in the early information stage of design;
- confront users repeatedly with early prototypes for evaluation purposes; and
- re-design as often as necessary.

Figure 2 shows a diagram adapted from Marinissen (1993). It depicts the result of the development of the process of user-centred design as it is being taught to the approximately 1600 current students of the School of Industrial Design Engineering at Delft University of Technology. Over 1700 graduates of the school have been taught this process, in earlier phases of development, over the past 25 years. As many of these graduates have used this process for designing smart products (Vorst *et al.* 1992, Voûte *et al.* 1993, den Buurman 1995, 1996) and have provided feedback, there is a lot of experience included and that makes it worthwhile describing the process in a bit more detail.

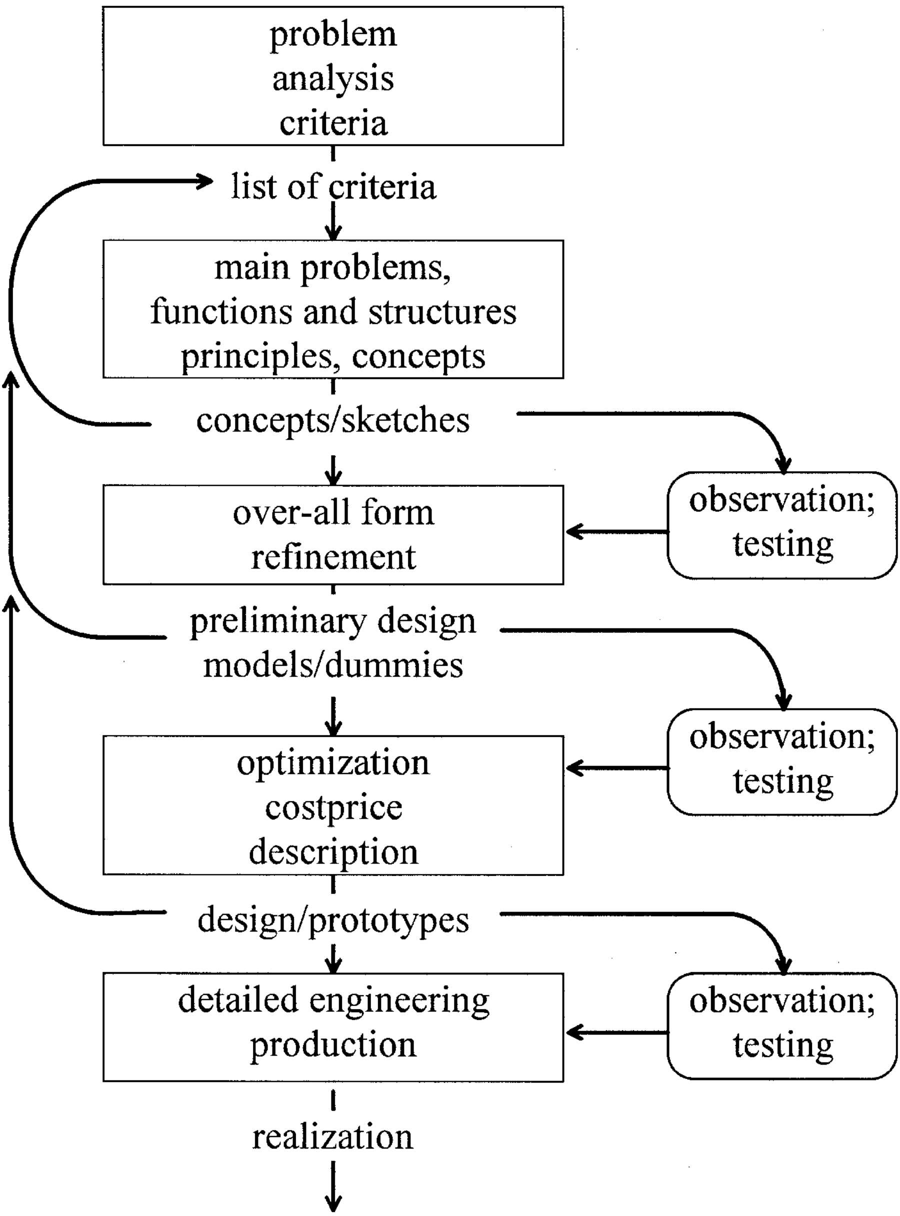

Figure 2. The process of user-centred design; adapted from Marinissen (1993).

The process usually starts with a commission from a client, a problem to be solved or a global idea for design. In figure 2 the design process has been split up into five successive groups of coherent activities (the blocks) that form the different phases in the elaboration of a design. Basically these phases are analysis, synthesis, detailing, optimization and engineering for production. In between the blocks, the expected outcomes of the activities in the preceding block are listed. As can be seen at the right of figure 2, these outcomes should be used for discussion with users and observations of use, or subjected to more formal user testing in order to extract detailed information about usefulness and usability. The results obtained via iteration cycles, as schematically indicated at the left of figure 2 should also be checked with the outcomes of earlier phases in the design process. If necessary, outcomes here should be adapted and the design process repeated.

The first phase of design, comprises information gathering, analysis and the development of a list of criteria. Information about users, usage, usability and contexts of use should be derived from the literature on related topics, from interviewing and observing users dealing with a competitor's product or one that has to be redesigned, or even with a different product that has comparable functionality. It is good practice to use check lists to make sure that no relevant aspects of information have been neglected. These check lists usually closely follow the life cycle of a product, from creation, via distribution and use to disassembly and preferably, recycling. The most concrete result of this analysis phase is a systematic, design-oriented list of criteria for the final product to meet.

The second phase of synthesis includes the definition of main problems and of the functions to be generated, principles to be developed and choices to be made. After that has been done, the most promising ideas and principles can be integrated into two or three different design concepts worked out in hand-drawn sketches. Then, based on the opinion of experts, on interviews with intended users and observations of the simulated use of concepts, a choice is made. Usually the concept that is chosen is the one that came out best, with its weak points eliminated and replaced by the higher rated features of the other concepts. Sometimes it is decided to choose a combination of two different concepts, taking the strong points of each and adding promising details that came up during the interviews and observations. Sometimes the decision is made to go on with two different concepts. If no satisfying concept can be put together at all, the second phase of the design process has to be repeated, and perhaps the starting points adapted.

In the third phase, the chosen concept or concepts have to be refined with respect to the definition of over-all form, the filling in of important details and the selection of materials. The results of this phase are preliminary design models or dummies that will be subjected to user evaluation again, now in near real-life situations. Additional review by experts is also advisable. Based on the outcomes of this phase, in the next phase of optimization choices are made, faults are eliminated and form and details finalized. Cost price is calculated, and parts and assembly are meticulously described. A working prototype design, usually with limited functionality, in the properly form-given case, is the most tangible result of this phase. After thorough user testing of this prototype, with the results being translated into design improvements, the fifth phase of detailed engineering for production, assembly and transport starts. Although the smart product is still far from being available to the general public by then, the description of the creation process is ended here, as the remaining phases of preparation for production are not considered to be the topic of this paper.

From the foregoing, however, it must be clear that user evaluation in its different forms is the core item of the process of user-centred design. In addition, it is important to note that the design of smart products can no longer be done properly by a single individual, no matter how gifted and well trained that person is. Good design involves a multidisciplinary team (ISO 1996) with all members communicating effectively during the whole design process, a process that should also include parallel development by the designers of the necessary user documentation (Freudenthal 1996). Only with a successful exchange of views between representatives of the different disciplines, can there be some guarantee of sensible trade-offs between the competing aspects of innovativeness, usability, usefulness, functionality, cost price, serviceability, aesthetics, engineering, logistics and marketability.

This paper now goes on to discuss in some detail different types and aspects of evaluation methods, such as interviewing users, observations of use, expert walkthroughs and formal laboratory testing. This discussion will focus on their respective suitability and feasibility in the early, decisive phases of the design process, and on the subjects and means needed and available. Some attention will be given to the additional roles that concept sketches and design models can play to enhance communication in design teams, which designers frequently experience as defective (Bekker 1995).

3. Evaluation methods

The conceptual effect of understanding a product's prospective users, their needs and preferences and the future context of the product's use, is potentially largest if this information is available right at the beginning of the design process and in a form that suits the design team. The causes are two-fold. In the first place, the basic decisions with respect to functionality and the way that it will be made accessible to the users, are largely made in the early phases of the design process. Second, the accumulating investments in mental effort, time and money usually result in a growing design conservatism in the successive phases of that process.

Understandably, in the later phases of the process, designers are more inclined to keep looking for additional information supporting their earlier views and decisions than to open mindedly consider even obvious information that might imply the need for a thorough revision of their starting points and a drastic redesign. This natural human attitude is further strengthened where strict deadlines are imposed with substantial penalties. However, no matter how human, this unprofessional attitude is detrimental, affecting both the direct costs of the product itself, and the hidden costs such as the company's image and the confidence of the members of the design team. The costs of a product finally failing in the market and having to be withdrawn, far exceed the costs of even the most radical and late redesign changes done before production.

From the foregoing it will be clear that there is a strong need for practical methods to elicit appropriate information from and about users in the early stages of the design process. In the literature on the design of human-computer interfaces particularly, much attention is paid to such methods (see for example, Bekker and Vermeeren 1992, Bødker and Grønbaeck 1991, Grudin 1991, Jeffries and Desurvire 1992, Johnson and Vianen 1992). However, from the same literature it is quite clear that, in practice, designers still have considerable problems in obtaining the information they need (Bekker and Vermeeren 1992) and that, on the basis of this literature, selection of the evaluation method most suitable in a specific design situation is difficult (Jeffries and Desurvire 1992).

Vermeeren and Bekker (1993) point out that in early product design, user evaluation mainly serves the purpose of helping the design team look forward and value ideas for elaborating and improving the design with respect to the underlying principles and the ways of interaction. In the more advanced phases of the design process, evaluation may look back, assessing the overall quality of the design proposal with respect to usefulness, usability and aesthetics. Furthermore, Vermeeren and Bekker present a general checklist to assist designers with the selection of early evaluation methods in practical design situations. Their preliminary conclusion is that, with respect to the hardware aspects of the products, primarily small-scale qualitative user studies should be used, whereas for evaluating software aspects, unstructured walkthrough methods are the best.

Small-scale qualitative user studies provide empirical evaluation from observing a small number of subjects using some simulation, for example a 'Wizard of Oz' approach (Landauer 1987) with paper sketches of design ideas, or from the opinions of these subjects about that usage. The empirical set-up is usually rather informal and loosely controlled, and the studies can focus on aspects of usability as well as usefulness or even acceptability. Usually, these studies generate many ideas for the design team and are quite convincing as they deal with the subjects actually interacting with the design ideas. There might be a problem, however, with the validity of the results, as there will probably be differences in motivation of the subjects as compared with the future users. From the experiments on the usage of multifunctional car radios of Johnson and Vianen (1992) and Vianen and Johnson (1994), it has become clear that having subjects creating or completing drawings of the design they really want, can provide a rich supplementary source of ideas for the design team, and give them insights in the preferences of (future) users for particular configurations and ways of interaction.

Walkthrough methods that use indirect knowledge from theories, guidelines or experts to evaluate design concepts, focus on usability only. They usually yield a large number of potential problems, but hardly discriminate between major and minor ones. Unstructured walkthroughs, based on guidelines or expert knowledge, can be carried out relatively quickly, but they do not provide insight into the actual use of the design nor are they particularly effective in generating ideas for improvement and elaboration of the concepts. As the methods do not involve naive subjects resembling future users, the validity of the results is even more questionable than in the case of qualitative user studies. A lot depends on the expertise of the evaluators, the expert(s) as well as the controller(s) of the walkthroughs.

Despite the limitations and uncertainties of the methods described here, other evaluation methods, like structured walkthroughs and quantitative user studies, seem much less suitable for application in early design situations, both with respect to hardware and software aspects. Structured walkthough methods, based as they are on scientific theories, (for example the Cognitive Walkthrough method of Polson *et al*. 1992) require an expertise that usually cannot be found in the design teams. In addition, they are too tedious and time-consuming, both to conduct and in the analysis of the results to extract the design-relevant clues. The same applies to the necessarily large-scale, quantitative user tests that involve large numbers of subjects and strictly controlled experimental set-ups. In this case, the additional need for robust prototypes with integrated hard and software is largely prohibitive as, understandably, these are not available in the early phases of design and are very costly and time-consuming to produce in later phases.

However, from the work of Bekker and Vermeeren (1993) and Bekker (1995) it is clear that the members of a design team cannot do without adequate representations such as sketches, models and prototypes of the design they are working on. They are invaluable for involving the users fully in the process, but also for communicating effectively with their colleague team members. Furthermore, it was found that the resolution of the representations used influences the way the design proposal is perceived and discussed. Hand-drawn sketches, for example, usually have a low resolution and computer made drawings a high one. Proposals are considered more definitive when the representation has a high resolution, and hence these representations mainly seem to evoke comments on details of the design. Low resolution representations are needed for eliciting comments and structuring discussions on the starting points and basic principles of interaction of the design. Members of the design team re-use representations, in later phases of the design process, to capture the evolution of the design and challenge earlier decisions. Team members from different background disciplines are more likely to experience communication problems (figure 3) as they tend to use different types of representations emphasizing different aspects of the design proposal. Designers think that working interactively, making representations together with the other members of the team, will enhance understanding and agreement between members with, possibly, a positive influence on the results.

4. Concluding remarks

At first glance, user-centred design might seem a time-consuming and expensive affair. In fact, looking at the process of product development as a whole, the opposite is quite true.

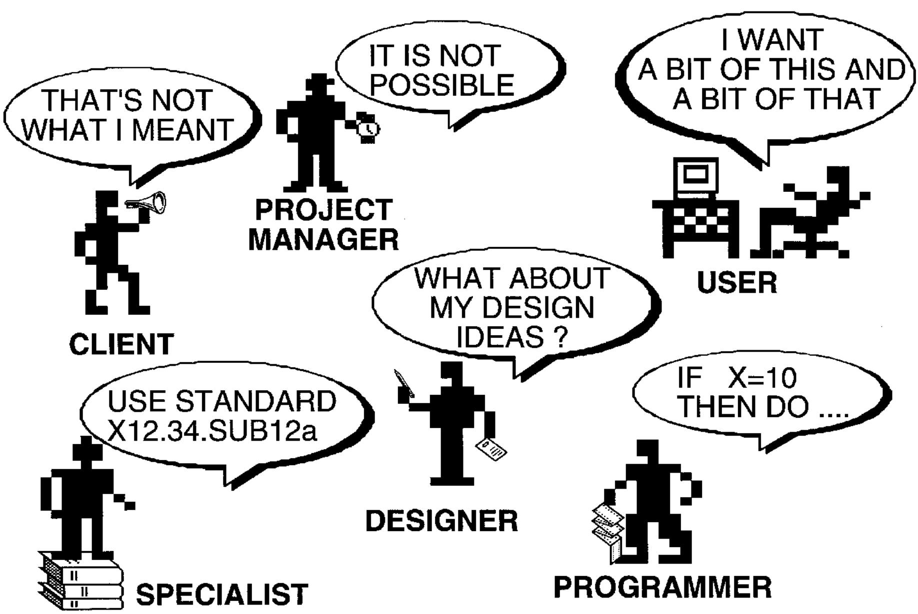

Figure 3. Illustration of communication problems between members of a design team and other people involved in the project; adapted from Bekker and Vermeeren (1993).

Well executed user-centred design shortens overall development time by reducing the number of expensive changes required late in the design process and during preparation for production and results in improved product quality in a market that is getting increasingly more discriminating both with respect to usefulness and usability. This is all the more important if we realize that only 1 or 2% of all ideas for innovative products finally result in a product being successfully introduced into the market.

The best opportunities for improving the process of user-centred design and, consequently, the products that result from it, are situated in facilitating the access to end-users and improving communication between the members of the multi-disciplinary design team, especially during the early process of idea generation. Computer tools that adequately support the production of suitable representations could be of great help there.

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