“From our perspective, one of HCI’s main objectives in the future is to contribute to our quality of life by designing for pleasure rather than for absence of pain.”

Marc Hassenzahl
Darmstadt University of Technology, Germany

Noam Tractinsky
Ben-Gurion University, Israel

(March 2006)
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The Bachelor thesis on hand

“Optimization of Human-Machine Interaction
Taking the User Interface of the “DAC Plus” as an Example”

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Bensheim, 5th March 2013

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PREFACE

This thesis has benefited from the support of many people, some of whom I would like to thank in the following.

First and foremost, I would like to express my gratitude to my supervising tutor, Dieter Rensch, who made this thesis possible by offering me the chance to work on this project. Furthermore, he supported me with his practical experience, knowledge, and motivation while giving me the freedom to work independently.

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Finally, I would like to thank my fellow students and friends, Alisa Finocchiaro and Kathrin Steinbach, for reading my thesis and giving me their critical feedback and helpful comments.
ABSTRACT

The DAC belongs to the hygiene product range of the Sirona Dental Systems, Inc., one of the world’s largest manufacturers of dental equipment. The device efficiently reprocesses the instruments used by dentists for treating the patients. One of the main purposes of the DAC is to facilitate the daily work flow of dental practices. However, several weak points concerning the handling are leading to frequent help desk calls and customer complaints. Therefore, the thesis on hand aims to improve the Human-Machine Interaction of the next product generation. The focus of attention lies on the design of a new user interface as playing a central role in the interaction between user and device.

Within the usual product development process, the aspect of Human-Machine Interaction is often perceived to play a minor role. Furthermore, the effort to analyze the user performance is often perceived as too high. Therefore, the first part of this thesis assesses the theoretical foundations of the User-Centered Design approach, in order to draw an overview of the possibilities existing to improve the HMI. Providing a wide range of efficient methods, the theory emphasizes an early integration of the user into the development process. The second part of this work shows how selected methods were applied in the case of the DAC. First of all, the criteria of an optimal HMI were identified, which served as a basis for the design of a user interface prototype. Afterwards a user test was conducted, measuring not only the usability but also the user experience.

The analysis revealed important insights into the user’s needs and preferences. Various usability problems have been identified and solved leading to a significant improvement of the HMI. The successful analysis proves that even with a small amount of participants and a low-technology prototype, important contributions can be achieved. However, the results cannot be generalized, as the method applied generated only qualitative data. As a consequence, further quantitative research needs to be done in order to verify the outcome of the analysis.
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<th>Abbreviation</th>
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<tbody>
<tr>
<td>CRS</td>
<td>Customer Requirement Specification</td>
</tr>
<tr>
<td>C&amp;C</td>
<td>Check &amp; Clean</td>
</tr>
<tr>
<td>DAC</td>
<td>Dental Autoclave</td>
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<td>DIN</td>
<td>Deutsches Institut für Normung</td>
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<tr>
<td>HCI</td>
<td>Human-Computer Interaction</td>
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<td>HMI Inc.</td>
<td>Human-Machine Interaction Incorporated</td>
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<tr>
<td>ISO</td>
<td>International Organization of Standardization</td>
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<tr>
<td>PC</td>
<td>Personal Computer</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
</tr>
<tr>
<td>Sirona</td>
<td>Sirona Dental Systems, Inc.</td>
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<tr>
<td>SUMI</td>
<td>Software Usability Measurement Inventory</td>
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<tr>
<td>SUS</td>
<td>System Usability Scale</td>
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<tr>
<td>UCD</td>
<td>User-Centered Design</td>
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<td>UX</td>
<td>User Experience</td>
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1. The Challenge of Designing a Human-Machine Interface

“The user interface consists of the language through which the user and product communicate“ (Mayhew 1999, p.1). Even though this statement seems to be simple, it implies a great challenge for everyone involved in product design. In order to provide optimal human-machine communication, the product developer, first needs to understand the “language” of the potential user, i.e. the context of the usage, the user’s aims, background, and preferences. As a second step this language must be incorporated into the product, meaning that it should support the user in achieving his goals by responding in the expected way. Especially nowadays, where technology is used in almost every field of daily life, users are becoming more diverse, and product complexity is steadily rising. Consequently, this issue increasingly attracts interest (cf. Moser 2012, p.3; Rosson/Carroll 2002, pp.5-9).

The relevance of this topic is emphasized by the argumentation of Dahm (2006, p.18). He claims that there is no use of high technology and innovation, if users do not know how to apply them, and as a consequence even reject the usage. When referring to medical devices, like in the case of Sirona Dental Systems, Inc., this point has even higher significance. The products are not only used for entertainment or pleasure, but primarily to support the user in his work (cf. Rensch 2012). Sirona Dental Systems, Inc. (in the following referred to as Sirona) is one of the global leaders in manufacturing dental equipment, selling its high technology products to dental practices, clinics and laboratories. The company employs a workforce of more than 3,000 at 29 branch offices on all continents, with its headquarters in Salzburg, Austria and its R&D center and main production plant in Bensheim, Germany. In the fiscal year 2012, Sirona generated revenues of $979 million (cf. Sirona Dental Systems, Inc. 2013a). Sirona covers the whole spectrum of dental capital goods. Its product range consists of four groups, which also represent the four business divisions of the company: Digital Dentistry, Imaging Systems, Treatment Centers and Instruments & Hygiene Systems (cf. Figure 1).
The thesis on hand concentrates on the Human-Machine Interaction (HMI) of the *DAC Universal* (cf. Figure 2), a product which belongs to the Instruments & Hygiene Systems division. With respect to the annual revenues, it represents the smallest division in comparison to the remaining three, with a share of 11% (cf. Sirona Dental Systems, Inc. 2013c). Its product range includes straight and contra angle handpieces, turbines, scaler, and laser (cf. Sirona Dental Systems, Inc. 2013d). The hygiene systems, like the DAC, are used to clean, lubricate and sterilize the instruments mentioned before. The latest version, launched in 2009, is capable of processing six dental instruments within 16 minutes (cf. Sirona Dental Systems Inc. 2013e).

In comparison to other hygiene systems, the DAC Universal stands out due to its high speed sterilization process leading to a more efficient work flow for dental practices (cf. Rensch 2012). Although the product is sold successfully worldwide, Sirona as being an innovation leader has the steady demand for product improvements. In 2012 internal sources within Sirona such as the development department, customer service center, and technical support staff were interviewed in order to identify critical aspects and suggestions for improvement. In summary, weak points concerning the handling of the DAC were mentioned, resulting in frequent help desk calls (cf. Jost 2012, p.87). Since the product aims to facilitate the work flow of dental practices, the *interaction* between the dental assistant and the product plays a central role for the customer. Currently, no specific methods to analyze the HMI are integrated into the product development process within Sirona. As a consequence, this thesis aims to apply a new approach in order to integrate the user and his performance into the product design process. The focus of the work presented lies on the optimization of the current *user interface*, as playing a cen-
tral role in HMI. Generally, the user interacts with various interfaces of the device. In the following, the user interface only refers to the operation of the system through the screen, the part of the DAC enlarged in Figure 2. Other aspects like the process of loading and unloading the device or the user manual are not part of this research study.

![Figure 2: DAC Universal](image)

Source: Sirona Dental Systems Inc. (2013e).

The thesis on hand applies user-centered development methods in order to identify the user’s needs and to evaluate his interaction with the user interface. Part of this work is the development of a user interface prototype based on guidelines derived from a user analysis. However, theoretical approaches concerning the graphical design of a user interface such as layout, icons and menu structure are not part of the thesis. The center of attentions lies on the evaluation of the interaction between user and prototype. Following the User-Centered-Design Model, an early involvement of the end user into the development process is pursued. Since the fundamental structure and design of the user interface are still open for discussion, this research study concentrates on qualitative analysis methods which allow for direct contact and interaction with the potential end users.
The content of this thesis is divided into four parts. After this first chapter of introduction, a theoretical foundation of the Human-Machine Interaction concept, its scope and influencing factors, are discussed. Furthermore, an outline of the theoretical approaches to HMI design is presented, followed by the development of a user-centered design model. The model serves as a framework for the further analysis process. In chapter 2.2 the steps to be taken are discussed more in detail. Besides, this part also includes an outline of several research studies and lately published articles related to the topic. The third chapter applies the design model, presented in chapter two. The focus lies on the evaluation of the user interface prototype, which was developed based on a user requirements analysis. After having presented the selected methods for the HMI analysis, the implementation and results are assessed. Moreover, the limitations of the research study and further consequences for the product development process are discussed. The last chapter identifies the possible future role of human-machine interaction within Sirona.
2. Theoretical Approaches to Analyze Human-Machine Interaction

2.1 The Concept of Human-Machine Interaction

2.1.1 Types of Human-Machine Interaction

In order to use a product, interaction is always needed no matter if using a toaster, DVD player or large industrial machine (cf. Stapelkamp 2010, p.13). The term Human-Machine Interaction (HMI) describes the process of information exchange between a human being and a machine\(^1\) in order to reach a specific goal (cf. Moser 2012, p.122). All parts, both hardware and software, which (a) provide information, e.g. through a screen or loud speaker, and (b) give the opportunity to control a system, e.g. through buttons or a mouse, form part of the user interface (cf. ISO 2010, p.7). In chapter one, the user interface is defined as the “language through which the user and product communicate” (Mayhew 1999, p.1). This chapter takes a closer look on the communication process and its influencing factors.

Analyzing the basic steps throughout the HMI process, the Action Cycle (cf. Figure 3) was developed by Norman/Draper (1986, pp.38-43). The American psychologists defined three main stages of interaction: Formulating a goal, executing an action, and evaluating the output (cf. Norman 1988, p.38-43 for this paragraph). As mentioned before, the user aims to achieve a goal with the help of a machine, e.g. “toasting bread”, “watch a DVD”, or in the case of the DAC Universal “sterilize dental instruments”. The intention then needs to be transformed into actions by transmitting information through the user interface to the machine. Taking the DVD as an example, the user pushes a button to open the DVD player, inserts the DVD, closes the DVD player via another button, and then pushes the “Start”-button. The DVD player has received the information to start the DVD. After that, the machine transmits the information to the user; e.g. a green light shines and the movie starts. The user then interprets and evaluates the perceived response by checking if the initial goal is achieved. In the above example this refers to the desire of watching a movie.

\(^1\) In the following, the terms “machine”, “product”, “device” and “system” are used synonymously.
The challenge is to bridge the gap between the user goals and the product, i.e. designing the user interface (cf. Norman/Draper 1986, p.43). The Execution gap needs to be filled with possibilities to transmit information input from the user to the product. The Evaluation gap needs to be filled with plausible output which can be interpreted easily by the user. For both gaps the aim is to keep the cognitive effort as small as possible (cf. for this paragraph Norman/Draper 1986, p.95).

Norman’s model gives a structured overview of the HMI process, in reality however, several difficulties can emerge. For instance, it is possible that the system is not able to offer the possibilities searched by the user, or the system does not provide sufficient or clearly understandable information to evaluate the outcome of an action (cf. Norman 1988, pp.51-52). There are various reasons, which can disrupt the optimal HMI. Some of them can be derived from the model presented in Figure 4. It illustrates the possible methods of communication and the main differences regarding the information exchange process between a human being and a machine concerning. There are significant differences in the way how a human and a machine send and process the information.
The model illustrates, that not only the user (blue) and the product (orange) are influencing the HMI, but also the product designer (grey) (cf. Norman 1988, p.16). Furthermore, the asymmetric use of mediums to exchange information between each other is presented in the blue and orange arrows (cf. Dahm 2006, p.19). On the one hand, the human being can express itself through the use of the voice if the device has a microphone or through using a button, joy stick, keyboard, or touch screen. On the other hand, a machine can use verbal or nonverbal sound effects, show a text, pictures or videos. As a result, the information expressed with a touch could be replied with a certain sound. This use of unequal mediums is not typical for the communication between human beings, thus provoking misunderstandings in the HMI (cf. Dahm 2006, p.20).

Figure 4: Information Exchange Methods of Human-Machine Interaction
Source: Own Figure based on Dahm (2006, pp.18-20); Norman (1988, p.16).

Following the considerations of Dahm (2006, p.20), further differences exist in the processing of the information received. A human being is able to use its natural intelligence and broadly diversified knowledge. Besides, a human being has the ability to
adapt to the product’s concept of communication. These attributes are strongly influenced by the characteristics, feelings, experiences, and expectations of each individual (cf. Moser 2012, p.12). By watching advertisement, talking to a shop assistant or unwrapping the product, the user already creates certain expectations about the function, quality and usage. Thus, Moser (2012, p.10) argues, the interaction with a product can already start indirectly before the user actually holds the product in his hands.

In contrast, the machine only has the resources provided by the person who designed it. Neither is it able to learn from an experience made nor is it capable to adapt to unexpected situations (cf. Dahm 2006, p.21). Although a machine is not influenced by the environment or its emotions like the human being is, its user interface is based on the designer’s thought patterns. The designer expects a certain behavior from the potential user and designs an appropriate interface that suits these expectations (cf. Norman 1988, p.16). Consequently the thought patterns and expectations of the user need to match those of the designer creating the interface. These ideal prerequisites would lead to an optimal HMI. In reality, this demand can hardly be met due to the diversity of the users, the complex concept of HMI presented above. In order to get closer to an ideal HMI, a process concentrating on the user is presented in the following chapter.

2.1.2 Theoretical Approaches to Improve Human-Machine Interaction

“Users are people with a goal, which your product needs to support” (Barnum 2011, p.84). Especially in the case of the DAC, this statement is fully applicable. The DAC’s task is to facilitate the work of the dental assistant, thus saving time and money of the dentist. If it does not fulfill this demand, it can be easily replaced with a competitor’s solution. Therefore, the center of attention lies on the user’s needs and an optimal HMI. Several approaches to this issue have been made during the last four decades. An outline is given in the following.

In the 1970’s Scandinavian researchers presented their theory of Cooperative Design (cf. for this paragraph Bødker et al. 2000, p.1). The product development method aimed to “give the end user a voice” (Bødker et al. 2000, p.1). In the traditional “specialist
model”, an expert developed a product in order to facilitate the situation of the user (cf. Schuler et al. 1993, p.XI). The new approach argues that the user knows best what he needs to improve his work (cf. Czyzewski et al. 1990, p.II). One of the first research studies applying the theory was the UTOPIA project. The researchers integrated users in early design sessions having a direct discussion with the designers. Furthermore, they conducted user tests with low technology prototypes. After having reached awareness in Europe, the approach was introduced in the United States, where the term Participatory Design emerged (cf. Czyzewski et al. 1990, p.II).

A grand contribution to this topic was made by Gould/Lewis (1985, p.300) publishing a research study about their three principles of Participatory Design and how they are applied in real business life. The first principle is about the “early and continual focus on users”, meaning the user’s needs and tasks are to be understood and must be considered in every step of the development process (cf. for this paragraph Gould/Lewis 1985, p.300). Secondly, empirical measurements have to be used, such as real work situations with prototypes in order to evaluate the performance and reactions. The third principle refers to the need of iterative design, i.e. a repeating cycle of design, user evaluation, and redesign. Since the first user confrontation of a prototype can reveal unpredictable user needs, designers have to be prepared to significant changes in the product concept and sometimes even think about a completely new approach (cf. Gould/Lewis 1985, p.308).

Norman/Draper (1986, p.61) first introduced the term User-Centered Design (UCD) in 1986. Their radical approach not only lets the user participate or cooperate; the user and his nature of interaction are perceived as the driving force of technology and interface design. The product is to support the user instead of being “an elegant piece of programming” (Norman/Draper 1986, p.61). They even claim the user’s needs are decisive for the interface design, which in turn is decisive for the rest of the product.

A well-defined model about how exactly the process of human-centered design should be like was developed by Nielsen in 1993. With his eleven-step approach named Usability Engineering Lifecycle Model he took up the principles of Gould/Lewis (1985),
adding further stages like competitive analysis, setting usability goals, parallel design, and heuristic analysis methods (cf. Nielsen 1993, p.72). The full model is illustrated in Attachment 1. He points out, that not all stages have to be passed to achieve success. The appropriate methods rather need to be chosen according to the product. He also emphasizes that the earlier the user-tests and analysis start, the less expensive the development process will be, because less redesign is needed (cf. Nielsen 1993, p. 72).

After the emergence of various theories about UCD the International Organization of Standardization published a norm in 1999, which was revised in 2010, named “Human-Centred Design for Interactive Systems” (ISO 2010, p.3). According to their definition it is the aim of UCD is to concentrate on the usage of the product, applying knowledge from the fields of ergonomics and usability (cf. ISO 2010, p.6). The term usability will be further discussed in chapter 2.2.2. Ergonomics is a scientific discipline, dealing with the interaction of a human being with other systems aiming to enhance the well-being of the human and the performance of the whole system (cf. ISO 2010, p.6). According to ISO (2010, p.8) applying UCD creates a competitive advantage, resulting in better selling prospects for the product. Reasons for this are higher productivity and satisfaction of the user and the reduction of stress and uneasiness.

Theoretically, the argumentations presented above seem to be logical. In practice however, UCD rarely is applied. Gould/Lewis (1985, p.301) conducted a survey with 447 people in charge of product design, approving this assumption. In 2002 another research on this topic was conducted, confirming the conclusion of Gould’s and Lewis’ claim (cf. Vredenburg et al. 2002, p.471). 103 UCD experts mainly from the US and Europe, considered the integration of the user into the product development process to measure the customer satisfaction objectively as very important. In fact, the feedback of internal design teams is used far more than an external user evaluation (cf. Vredenburg et al. 2002, p.475). One reason for this could be the cost and time effort, which need to be invested into the UCD process. According to Vredenburg et al. (2002, p.474) 32% of the experts were not sure UCD saves costs and time of the product development process or not. 44% believed that costs are saved, 24% believed UCD increases costs. However, 80% of the respondents thought applying UCD methods leads to an improvement of the
“usefulness and usability of their products in their company” (Vredenburg et al. 2002, p.474).

The outcome of the study could lead to the following conclusion: If the usefulness and usability are improved, a competitive advantage is created which might increase the number of products sold. Consequently, higher costs and time can be compensated. Furthermore, Vredenburg (2002, p.474) adds the assumption that the respondents did not consider the costs of customer service and redesign after the launch. As already mentioned in chapter 1, the best technology is useless, if the user does not know how to apply it. Keeping these points in mind, a model based on the approaches discussed is developed in order to optimize the HMI (cf. Figure 5).

![Figure 5: The User-Centered Design Process](image)

Source: Own Figure based on Gould/Lewis (1985, p.300); ISO (2010, p.15); Nielsen (1993, p. 73).

Starting with an analysis of the user’s needs, expectations and tasks, the product specifications can be derived. These include the goals to be achieved and the criteria to measure the outcome. Afterwards, the first design phase starts, often beginning with low technology prototypes. The outcome then needs to be tested in order to verify if the goals, set in the beginning, have been met. If this is not the case, the prototype needs to be adapted to the findings. Having completed this step, the next testing phase begins. If unexpected user needs occur during the test, specifications might need to be changed as
well. The described procedure is to be repeated until the evaluation outcome matches the specifications.

The four stages of User Analysis, Specification, Evaluation, and Design will be further discussed in chapter 2.2. Since the goal of the thesis on hand is the optimization of the HMI of the DAC’s user interface, the model is applied in chapter three. The focus lies on the evaluation of the user interface prototype in chapter 3.4. Therefore, the preparation, implementation and interpretation of the evaluation method used are presented more in detail.

2.2 Stages of the User-Centered Design Process

2.2.1 Methods to Analyze the User and his Task

The approaches presented above all agree on the early integration of the user through the analysis of his needs and tasks (cf. Nielsen 1993, p.75). In order to figure out what is needed, Gould/Lewis (1985, pp.301) emphasize that the designer must understand the user, not “identifying, describing [or] stereotyping”. In the following, several methods concerning user analysis are discussed.

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