HBiD

Human Behaviour in Design

Proceedings of the 2nd SIG conference
April 2019

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Kristin Paetzold

Institut für Technische Produktentwicklung
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Challenges for HBiD approaches towards the use of digital technologies

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1 Introduction

Digital technologies have spread rapidly through various products and product service systems in our everyday life. On the one hand, these technologies offer novel solutions for coping with everyday situations, but on the other hand, they also bring with them challenges that were previously not relevant for product development. When dealing with digital technologies, it is important to reflect on how their use changes our living environments and thus what effects this has on product development. Questions on how digital technologies must be integrated into our private and professional everyday life in order to support people in their active lifestyle and what methodological prerequisites are necessary for this will be discussed at this 2nd conference Human Behaviour in Design.

The aim of every kind of development is to support people in an active and self-determined way of life. The human being appears in two different roles within the development process:

- Looking at the human being in his role as a user, the focus is on identifying his needs. Research questions to be answered in this context deal with which information is needed by the user in order to better adapt technical systems to the human being and his situation.

- Looking at the human being in his role as a developer, the focus is on gaining an understanding of his approach to development in order to support him in working effectively and efficiently. Research questions should answer how developers think and work and what implications this has for method development.

These two roles appear at first glance to lead to fundamentally different approaches to support. In order to understand the effects of digital technologies on our living environments and to apply them in a beneficial way, an understanding of the socio-technical system human-product should first be built up.

2 The human-product-system

In order to be able to better classify the two roles of the human being in the development process described above, it seems helpful to look at the socio-technical system of the human-technical system from a rather social-scientific perspective. According to this, every kind of technical system, regardless of whether it is a product, a service or even a method, must always be understood as an assistance, which serves to compensate for one's own deficits in the sense of a division of competence and work [1]. At first, it is irrelevant whether this technical assistance only serves to transfer unpleasant work to the technical system or whether own deficits are to be compensated or even performance limits overcome. Technical assistance serves the purpose of carrying out activities of everyday life both in private and professional life in a time- and energy-saving manner, thereby creating space for self-realization.

The assistance serves to support action by providing resources [1]. The technical system as assistance enables the execution of actions and thus a continuous further action in an everyday situation for the person and thus becomes a support system. This results in the construction of a socio-technical system shown in Figure 1.

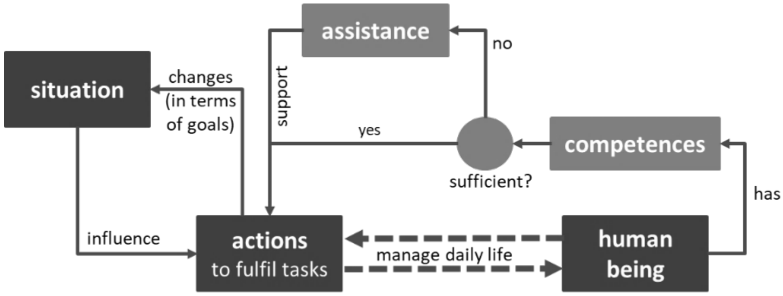

Figure 1: sociotechnical system human - technical assistance

The human being carries out activities in the sense of coping with everyday life. Support is necessary if it cannot be provided by the person alone, regardless of whether this is due to the specific situation or inadequate skills. Then technical assistance can be used. However, this refers only indirectly to the person, but primarily to the activities to be carried out [2]. This sociologically shaped way of thinking about the dualism between activities and support manifests itself in the classical approach in product development, where a system purpose is identified after each development. This system purpose is identified according to the principle of finality: a settling effect is considered and analyzed in order to derive from this causes how this effect can be achieved [3]. Therefore, the description of the system purpose implicitly depicts a desired action for which it is necessary to specify a system behavior within the framework of the development, which complements or replaces the human behavior, and which can be further broken down into system functionalities.

From this way of thinking it becomes clear that technical assistance can be interpreted in many ways. This can be a product or a product service system that supports the user in a specific everyday situation, but also a method or a tool to implement the method to support the developer in a work situation. As a consequence, the significance of the action situation results. In any case, the requirements for the specific support situation (professional/private everyday life) must be identified as a prerequisite for technical assistance. This is where the differentiation begins at the latest:

- For the role of humans as users, the requirement description includes the identification of their wishes and needs. It requires an understanding of the activity to be supported and typical situations in which these activities are carried out as well as the routines in which these activities are integrated.

- For the role of humans as developers it is of interest to build up an understanding of how the developer proceeds in the processing of specific development activities, which thought patterns are the basis for efficient solution finding and how the activities to be supported can be classified in development processes. From this, approaches can then be derived as to how he can be supported methodically and goal-oriented in the accomplishment of tasks.

In both of these perspectives, it is important for the individual to consider his or her integration into the development of technical assistance, his or her requirements, views and approaches to the problems to be solved. The development of technical assistance follows a scheme that is strongly oriented towards the problem-solving cycle [4]. This scheme (figure 2) will be briefly explained in the following.

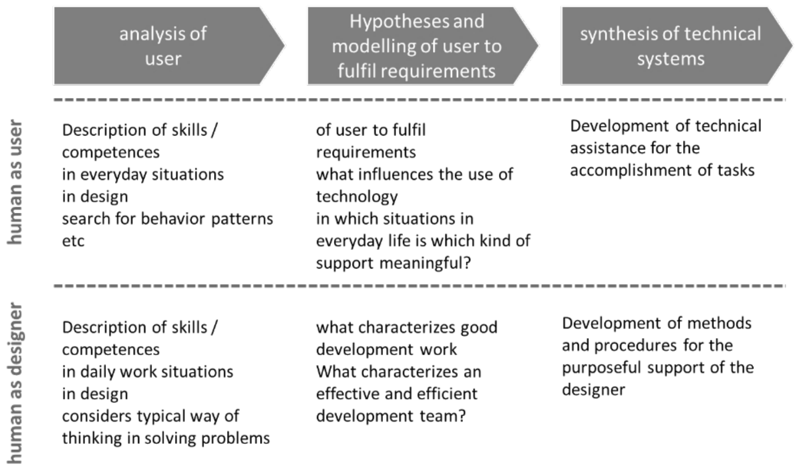

Figure 2: differentiation between interests and information about user and engineering designer

The starting point for the considerations is an **analysis phase**. The aim of this phase is to identify human needs in the sense of a requirement description. Essentially, the aim is to identify the discrepancy between people's abilities and competencies on the one hand and the abilities and competencies required to accomplish tasks on the other. The resulting difference description is important because it concretizes the functional scope and the functional characteristics of the technical assistance. The actual task accomplishment can be regarded as an activity integrated into the context of action [5]. This holistic understanding appears necessary because technical assistance is not accepted if it is not integrated into everyday routines, work routines and thought routines [6]. This is accompanied by the description of the task institution and the associated boundary conditions. Methodologically, this analysis phase is supported by approaches from the human and social sciences. Increasingly, engineering methods are also being used for data collection, because today's sensor technology can be used to record actions and procedures comparatively objectively. Examples are eye tracking [e.g. 7] or movement measurements [e.g. 8].

The data and information obtained during the analysis phase are summarized using **models and hypotheses**, generalized and evaluated to determine which discrepancies occur and how these are to be assessed. The primary task of the model and hypothesis formation phase is to make the needs of the individual explicit and to describe them and to convert them into concrete parameters in such a way that they can be used as a basis for the design of a technical assistance. Within the framework of this transformation process, it is a matter of transferring the more or less weakly formulated needs and discrepancies for the accomplishment of tasks into concrete technical parameters and, ideally, depositing them with technical parameters which can then be used as the basis for the actual development process.

The **synthesis** describes the actual process of generating ideas and developing technical assistance. This process, which is generally associated with a high degree of creativity, usually uses engineering approaches to find and implement ideas. This phase is characterized by the human being in his role as developer. The human being as user can be integrated into the development via methods and approaches of user integration and then appears in various roles as idea supplier, solution finder or evaluator.

For all three phases, it is necessary to differentiate between differences resulting from the role of the human being as user or as developer. This is shown in figure 2. However, this consideration also makes it clear that the differentiation of human beings in their respective roles does result in significant differences in the tasks to be mastered and in the approach to these. To describe the phenomena that describe and shape the support, however, a generic concept can be used. This is associated with similarities which can be identified for method support but also for method development and which can help to better explain the use of novel digital technologies in the various application contexts.

3 Challenges in using digital technologies

Digital technologies comprise information and communication technologies based on the coupling of hardware and software [9]. Digital technologies manifest themselves not only in digital infrastructures (e.g. social networks, Internet...), products (VR/AR, robotics...) and applications (e.g. apps, web applications...), but also in new business models and process organizations (e.g. crowdsourcing, cloud computing, IoT...) [10]. They are characterized by the possibility to record and evaluate a variety of data about people in their environment.

On the one hand, this provides the opportunity to record the competencies and abilities of people and their actions in everyday life in various activities and to evaluate them in a very detailed way. In this respect, behavioural characteristics of unknown detail and differentiation can be recorded and evaluated and activities in the professional and private everyday life can be completely reinterpreted. These analyses can, again using digital technologies, lead to novel approaches in technical assistance or novel support services for task accomplishment.

On the other hand, there are also some fears associated with digital technologies. Perhaps the most important aspect is that people become transparent, the wide accessibility of data can lead to misinterpretations, misuse and unwanted use. It is unclear who owns data. Especially in the environment of development, fears result from the fact that analytical skills based on artificial intelligence can replace human intelligence. Already today, the performance of computers using artificial intelligence is higher than that of humans [11] because, for example, human thought barriers are overcome due to limited capacity in the processing of information. For humans in their role as developers, there can be serious changes because, above all, analytical activities are replaced by technical assistance. Nevertheless, an evaluation and interpretation of these analysis results is necessary, not only to draw conclusions, but also to evaluate their relevance. This leads to a change in the tasks of the engineers, because their contribution to the development of knowledge will change. Comparable effects can also be expected in private everyday life through the use of appropriate technical assistants.

These few examples in the discussion reflect only a part of the possible aspects that have to be dealt with in the development in the sense of Human Behaviour in Design. It is not only the aspects of human analysis, model and hypothesis formation and synthesis that need to be discussed with regard to possible support potentials, as outlined in the previous chapter.

In his roles in the process of developing technical assistance, the human being himself fills out various activities. With the articulation of desires and needs, he is a supplier of ideas, contributes his abilities to finding solutions on the basis of his competences and experiences in coping with everyday life and ultimately also becomes an evaluator of technical assistance by testing their usefulness and usefulness and accepting technical assistance in coping with everyday life.

It is important to consider to what extent digital technologies can also contribute to methodically supporting these activities. Conversely, the question arises as to what methodological prerequisites need to be created in order to use digital technologies in a targeted manner for technical assistance.

4 The goal of the conference HBiD

Digital technologies offer great potential, not only to improve technical assistance for humans, but also to gain a better understanding of humans in mastering their everyday lives. To achieve this, however, it is necessary not only to deal intensively with the new technologies, but also to identify their possible use as well as risks and opportunities in their use, so that they can be used for the benefit of mankind. With this in mind, the conference will primarily discuss two questions:

- How can Human Behavior in Design (HBiD) contribute to a better and deeper understanding towards designing the interfaces of VR, AI and robots to better suit the user?

- What do we need to know about human behavior in various situations in order to develop support for different users (employees, managers, end user, etc.)?

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Augmented problem solving and design activities

Effects of a design support on practitioners designing a Product / Service System – a case study

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Abstract

This paper presents empirical evidence on which to ground the understanding of effects of a design support on Product/Service Systems (PSS) designing. The effects are measured by the extent of application of a systems perspective and level of integration of product and service elements during PSS designing. Protocol analyses of a control team and an experiment team, involving experienced practitioners performing an identical PSS design task are conducted. Only the experiment team is provided with the design support. The Function–Behavior–Structure ontology and a scheme for the systems perspective are utilized to code the data. Results show preliminary insight into the influence of a design support. The focus on systems level abstraction shows a three-fold increase, the cognitive effort spent on behavior of structure is halved and the effort on design description is more than doubled, in the experiment team.

Keywords: Product/Service Systems design, Function-Behavior-Structure Ontology, Protocol analysis, Design support

1 Introduction

There is an extensive literature on studying designing, and on studying design cognition in particular [1], reflecting the increasing interest in researching more foundational questions about designing. One such growing body of research is that of Product/Service System (PSS), which 'consists of a mix of tangible products and intangible services designed and combined so that they jointly are capable of fulfilling specific customer needs' [2]. As customers are increasingly demanding solutions for their needs rather than specific products, companies are increasingly exploring the prospect of developing and offering PSS [3]. Design is considered to be a critical aspect during the development and delivery of PSS as it determines the quality and characteristics of the final offering [4]. The process of designing a PSS is expected to inherently differ from designing its individual product or service part as the activity is conceptually characterized by the integration of the physical and intangible aspects [5], and application of a systems perspective [6, 7]. The differences may be so significant that PSS development is reported to potentially require a dedicated design approach [8, 9], in contrast to the widespread view in academia that suggests that, the fundamental issues and processes in designing are not unique to the nature of the domain [10, 11]. However, this is not examined in the research reported in this paper and it is assumed that the fundamental design cognition of designing PSS matches that of designing generally [10].

Two of the main objectives of research in design are to increase understanding of designing as an activity and to develop tools to aid designers [12]. PSS design research regarding the latter is developing, mainly due to the industrial demand for design support in the form of tools, methods or techniques [13]. The effectiveness of these advancements could be questioned, as they are mainly based on conceptual understanding of the characteristics of PSS designing with limited empirical evidence. To develop an empirically-grounded understanding of design, it is necessary to obtain reliable empirical insights from the activity of designing and one such way of achieving that is through the study of design cognition [11]. Through cognitive studies, empirical insights into how designers design products [14, 15] and the influence of design support on product designing [16] are established in academia. However, similar research regarding PSS designing as an activity, is still in its infancy with only a few studies [17, 18]. One such study is a recent explorative work by the authors, that provided preliminary empirical insight into what practitioners discuss during the design of a PSS in terms of distributions of design issues and processes [18]. It provided early indications of design issue distribution differences between other domains of design and PSS design, reporting increased focus on function in the latter. This research demonstrated that PSS designing could be described in the same way as product design. However, there is no similar research that provides empirical insight regarding how the use of a design support influences PSS designing. This lack of knowledge could lead to the ineffective development of PSS design support.

1.1 Aim and Research Question

This research aims to provide preliminary empirical insight into the influence of a design support on PSS designing activities with an explorative case study. The results can potentially be utilized as a basis for hypothesis generation. The resulting knowledge from these hypotheses, when tested with statistically reliable data sets can then be utilized by researchers to support the development of effective design support for practitioners [19]. The following research question will be addressed through this case study:

> How do the characteristics of PSS designing vary with and without the use of a design support?

Characteristics of PSS design activities in this research refers to its distribution of design issues and processes, extent of application of a systems perspective and level of integration of product, service and other elements within PSS design. A design support in the form of a set of recommendations for PSS design is adopted from a separate work of the authors [20]. The following sections will describe the research approach, results, discussions and conclusions.

2 Research approach

An exploratory case study approach involving two design experiments was conducted with experienced industrial practitioners in a controlled laboratory setting, to investigate the research question. The participants were provided with a conceptual PSS redesign task and were instructed to carry it out in teams of two. A conceptual design task was chosen as it allows the exchangeability of product and service aspects, which is vital for PSS design [21]. The participants were all instructed to engage in a think-aloud protocol [22]. The corresponding data was collected as recordings in both audio and visual formats and was later transcribed. Each pair included a product and a service designer. The teams were assigned to one of two distinct groups: control and experiment group. The experiment group was provided with the design support. The control group was not provided with any such support. The following sections will describe the case, the design support and the methods of analysis.

2.1 Description of case and design support

There were two pairs of individuals as participants one in the control group and one in the experiment group. The participants are experienced industrial practitioners based in Sweden. The aim of the design task given to the participants was to conceptually redesign the product and service aspects of an existing PSS (an office use coffee machine), to increase its resource efficiency. A design brief that details information regarding the PSS offering, the provider, customers, and main users, was provided to the participants (see [18]). The same design task was given to the participants in the previous work [18] of the authors. The participants in the experiment group were asked to perform the same task with the use of the design support [20]. The design support is a set of recommendations in the form of a procedure to follow, that is consolidated from the state of the art of PSS design literature (see [20] and the authors' ResearchGate pages as a supplement for the full description). It suggests the designers systematically assign a functional unit for the offering being designed, explore the various stakeholders involved, their potential requirements and value propositions, criteria for potential evaluations, identification of product, service or other elements that address requirements and value propositions, examine balance between the elements from a systems perspective, before selecting feasible combinations of these elements to synthesizing the solutions.

2.2 Methods of analysis

Protocol analysis, a highly developed, well accepted rigorous methodology for interpreting verbal data of thought sequences as a valid source of information on cognition [11, 23], is utilized to analyse the empirical data collected. It was chosen over other methods of analysis as it provides both quantitative and qualitative information regarding the protocol data. It has been widely utilized in similar design related research as reported in a recent review of protocol studies by Hay et al. [1], further motivating its use in this context. During the application of the methodology, the protocols are segmented, the following coding schemes are applied, and the segments are categorized accordingly.

2.2.1 Function – Behavior – Structure (FBS) ontology

FBS ontology [12] is utilized in this research as one of the coding schemes to interpret and describe the thinking process of the designers during PSS designing. It has been utilized widely in protocol studies as it is independent of the design task, experience of the designers and the settings in which they operate within, allowing the possibilities for comparative assessments of the results

[11], thus justifying its use in this context. This ontology provides a unifying framework for representing the design issues and processes with high level design semantics. The basis for this framework is formed around the following three classes of variables that describe the various aspects of the design object [24]: i) Function (F): describes the purpose of the design object; ii) Structure (S): describes the components of the design object and their relationships; iii) Behavior : describes the behavior expected (Be) or behavior derived (Bs) from the structure. Design requirements (R) represent the requirements the design object is expected to satisfy, and design descriptions (D) represents drawings or written information regarding the design. Since both requirements and descriptions are expressible in terms of either function, behavior or structure, no additional classes of variables are needed to describe them. Through the lens of this framework, the overarching objective of the activity of designing is to transform a set of functions (F) derived from the design requirements (R) into detailed descriptions of the design (D). The transitions between these design issues are design processes and are represented by the eight design processes of: F→Be: Formulation, Be→S: Synthesis, S→Bs: Analysis, Be – Bs: Evaluation, S→D: Documentation, S→S: Reformulation 1, S→Be: Reformulation 2, S→F: Reformulation 3, see [12]. The design issues R, F and Be fall under the problem space of design (P_S), and the design issues S, Bs and D fall under the solution space of design (S_S) [25, 26]. The P-S index is calculated by taking the ratio of total occurrence of P_S and of S_S. An illustration of how this scheme will be applied is given in Table 1.

Table 1. Illustration of FBS coding scheme

Segment from Protocol data	Design issue	(P_S)-(S_S)
”Let us discuss about the heating coil”	S	S_S
“It should heat the water”	F	P_S
“Up to x degrees”	Be	P_S
“It will consume x watts of electricity”	Bs	S_S
“The machine needs to be resource efficient”	R	P_S

2.2.2 Coding scheme to capture level of systems perspective and integration

The following coding scheme is proposed and applied to capture level of systems perspective within the protocol data. It is inspired from the work of Gero and Mc Neill [19], originally developed to investigate the hierarchical or systems aspects of the process of designing. In this research, it is contextualized to analyse the levels of application of systems perspective and the level of interaction between the various elements of the system during PSS designing by experienced practitioners, with and without the use of the simple design support. The proposed scheme has three primary levels of design abstraction: i) discrete elements (D): designers focus on a discrete element in a segment (ex. product or service or stakeholders (ex. suppliers, environment, users etc.) or other elements); ii) interactions (I): designers focus on an interaction between two or more discrete elements; iii) systems (S): designers address problems / solutions as an integral system (ex. PSS) involving various discrete elements to provide value, meet requirements (ex. resource or cost efficiency). An illustration of the coding scheme is presented in Table 2.

Table 2: Coding scheme to capture systems perspective and integration

Segment from Protocol data	Criteria
”Let us discuss about the coffee machine”	D
”The coffee machine should remotely indicate when it needs to be serviced”	I
”A regularly maintained coffee machine can increase resource efficiency”	S

3 Results

3.1 FBS Results

Two independent coders were used to generate the coded protocol. They have an average agreement ratio of 81% with the third independent arbitrator, with a standard deviation of 5.52% for this coding scheme. The results of the distribution of the FBS design issues from the control and experiment group are reported in Table 3.

Table 3: Design issue distributions

	Control group (G1) [%]	Experiment group (G2) [%]	Ratio (G2/G1)	G1 without ‘D’ [%]	G2 without ‘D’ [%]	Ratio (G2/G1)
Requirement (R)	1	1	1.00	1	2	2.00
Function (F)	22	26	1.18	24	32	1.33
Expected Behavior (Be)	20	17	0.85	22	21	0.95
Behavior of structure (Bs)	31	16	0.51	34	20	0.58
Structure (S)	18	20	1.11	20	25	1.25
Design description (D)	8	20	2.50			

The results indicate that there are noticeable changes in Bs and D between the experiment and control groups. Frequency of occurrence of Bs has almost halved and D has increased by around two-fold in the experiment group compared to the control group. F and S also show small levels of increase in frequency in the experiment group. The results of distributions of the design issues considered without the frequency of occurrence of D, show the highest increase in occurrence of F, closely followed by S and the design issue with the lowest frequency as Bs. The P-S index of the control group is 0.75, while the P-S index of the experiment group is 0.78. These are very close to each other.

The graphical representation of the dynamic design issues of the control and experiment groups are presented in Images 1 and 2, respectively. These figures are generated using LINKODER a publicly available software (see linkoder.com).

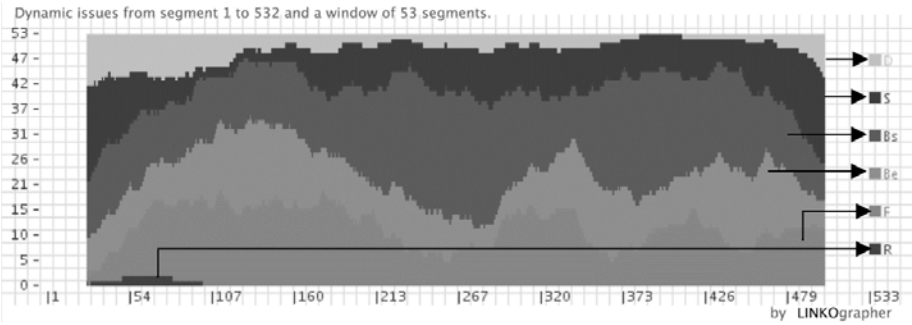

Image 1. Moving average of cognitive effort expended on design issues, control group

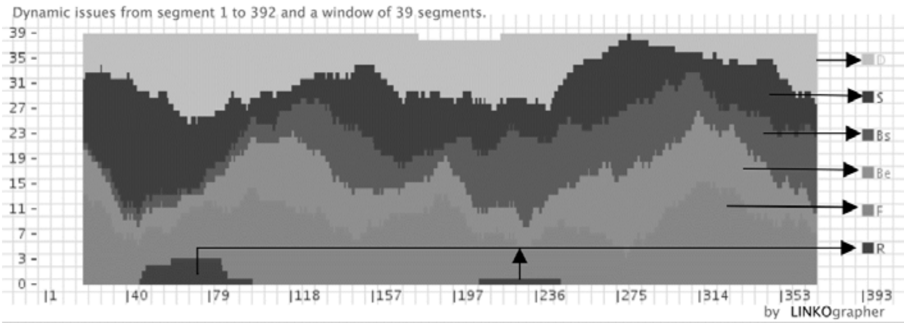

Image 2. Moving average of cognitive effort expended on design issues, experiment group

The results of the distribution of dynamic design processes of the control and experiment group are presented in Table 4.

Table 4: Syntactic design process distribution

	Control group (G1) [%]	Experiment group (G2) [%]	Ratio (G2/G1)
F→Be: Formulation	10.8	13.8	1.27
Be→S: Synthesis	9.0	9.4	1.04
S→Bs: Analysis	12.2	10.1	0.82
Be – Bs: Evaluation	36.9	18.8	0.50
S→D: Documentation	8.1	13.0	1.60
S→S: Reformulation 1	8.1	13.0	1.60
S→Be: Reformulation 2	5.9	10.1	1.71
S→F: Reformulation 3	9.0	11.6	1.28

3.2 Results from systems coding scheme

The two independent coders have an average agreement ratio of 87.3% with the third independent arbitrator, with a standard deviation of 3.49% for this coding scheme. The systems coding results from the control and experiment group are presented in Table 5.

Table 5: Distribution of design criteria of systems coding scheme

	Control group (G1) [%]	Experiment group (G2) [%]	Ratio (G2/G1)
Discrete (D)	54	37	0.65
Interactions (I)	38	36	0.94
Systems (S)	8	27	3.37

The results indicate that there is around a 3-fold increase in the occurrence of systems level abstraction, with balanced distribution of focus on discrete elements and the interactions between them, in the experiment group.

4 Discussion and conclusion

The results are utilized to answer the research question "How do the characteristics of PSS designing vary with and without the use of a design support?". Three main characteristics that are expected to be specific to PSS designing are investigated in this research: design issue and design process distributions, extent of systems perspective and level of integration of the elements within the system. The design support provided to the experiment group is a set of procedural recommendations consolidated from the state of the art of PSS design methods. Among other things, the support suggests designers assign functional unit at the begining of the design, to identify and integrate various elements that fulfill the requirements and corresponding functions, and to balance them from the systems perspective. As expected, the results of the experiment group reported a significantly higher degree of systems level abstraction and a balanced focus on discrete elements and the interaction between them. The earlier work of the authors [18] reported that almost half of the cognitive effort spent by designers during PSS designing is on behavior and high degree of effort on evaluation. The current results indicate a noticeable reduction in behavior of structure and evaluation, as a result of the application of the design support. It also shows an increase in the occurrence of design description, with small increases in function, structure and the majority of the design processes. The major changes could potentially be attributed to the increase in systems level abstraction and resulting in the balanced focus on discrete elements and their interactions within the system being designed, potentially caused by the introduction of the design support.

The results of this exploratory case study, provide an early indication regarding the effects of the design support on the characteristics of PSS designing. It suggests that the use of a design support can increase systems level abstraction and modify the focus on discrete elements and their interactions, while potentially reducing the cognitive effort spent on behavior, which otherwise is a dominant design issue in PSS designing. This preliminary insight can be used as a basis for generating hypothesis. However, this study is based on minimal data, thus limiting the external reliability of the results. The immediate future work of the authors will involve hypothesis building and the corresponding testing with statistically significant data sets and the use of a higher level of granularity for the proposed systems coding scheme to obtain richer data.

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Insights from an EEG study of mechanical engineers problem-solving and designing

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Abstract

This paper presents results from an experiment to determine brain activation differences between problem-solving and designing of mechanical engineers. The study adopted and extended the tasks described in a prior fMRI study of design cognition and measured brain activation using EEG. The experiment consists of multiple tasks: problem-solving, basic design and open design using a tangible interface. Statistical analyses indicate increased activation when designing compared to problem-solving.

Keywords: design neurocognition, problem-solving, designing, mechanical engineers

1 Background

The study described in this paper is part of a larger research project whose goal is to correlate design cognition to brain activation of designers across disciplines. Preliminary results from bringing neuroscience methods to design research is contributing to a better understanding of human behavior in designing. One of the questions that design research has studied is whether designing differs from problem-solving and if design specific characteristics make it independent of any domain of application [1, 2]. The study reported in this paper elucidates the design neurocognition and brain behaviour of mechanical engineers when designing and problem-solving. Non-invasive tools have provided access to brain behaviour through objective measurements of various aspects of brain neurophysiology producing the field of neurocognition [3]. This has opened the way for the first steps in understanding design neurocognition – the neurocognition of designing. Functional magnetic resonance imaging (fMRI)-based design studies are at the exploratory stage with one well-controlled experiment published [4] and others that focus on design related behaviours rather than the acts of designing [5]. Results show higher activation of the dorsolateral prefrontal cortex consistently for design tasks and ill-structured problems and recruits a more extensive network of brain areas than problem-solving [4, 6]. fMRI has very high spatial resolution which helps in narrowing to very specific brain regions that are activated during any task, but it has low temporal resolution. Designing is a temporal activity. EEG's high temporal resolution during cognition can help elucidate the stages of designing while providing the temporal basis for information processing [7]. Averaging the measurements yields a measure of the EEG voltages that are consistently related to the sensory, perceptual and decision-making processes [8]. By taking advantage of the electroencephalography (EEG) method's high temporal resolution, we focus on the investigation of time-related design tasks. Design neurocognition EEG-based studies are emerging at an exploratory stage with a few reported domain-specific studies on engineering design, architecture and industrial design. Results from controlled experiments of engineering-design based studies identify the relationship between neurophysiological EEG signals to study effort, fatigue and concentration and problem statements and cognitive behaviors in conceptual design [9, 10]. Time-related neural responses during problem-solving compared to design tasks are as yet unknown. The study reported here is based on the analysis of participants' brain waves using an EEG headset in the context of performing problem-solving and design tasks in an experimental environment. The objective of the study is:

- investigate the use of the EEG technique to distinguish design from problem-solving.

In this study, we adopted and then extended the tasks described in a previous fMRI study of design cognition reported in the literature [4]. With this study we aim to answer the research question: How far EEG can help distinguish design from problem solving? We postulate the following hypotheses:

Hypothesis 1. Design neurocognition of mechanical engineers when problem-solving and designing are different.

Hypothesis 2. Neurocognitive temporal distributions of activations of mechanical engineers are significantly different across design tasks.

2 Methods and approaches

We have adopted and replicated the tasks described in Alexiou and Zamenopoulos et al. [4], augmenting their results with EEG high temporal resolution. We extend the experiment to a third task. The set of three tasks is preceded by a pre-task so that the participants can familiarize themselves with the physical interface. The three tasks are followed by a fourth open design task where the tangible interface is replaced by free-hand sketching. The replication of the experiment tasks of Alexiou and Zamenoupoulos et al. [4], with EEG brain wave data is supported with the analysis of data from video and audio recording.

2.1 Experiment Setup

A tangible interface for individual task performance was built based on magnetic material for easy handling. The Mikado game was given to the participants to play in the breaks between tasks as this action helps them with the tangible interface of the magnetic and movable pieces during the tasks. A pre-task was designed so that participants can familiarize themselves with the use of the EEG headset, maneuvering the magnetic pieces that make up the physical interface and prevent him/her from getting fixated in Task 1. The block experiment consists of a sequence of 3 tasks: problem-solving, basic design and open design, as depicted in Image 1. For the present study we have matched Tasks 1 and 2 with the problem-solving and design tasks from Alexiou et al. [1], in terms of difficulty, number of constraints, stimuli and number of instructions. Task 3 provides an enlargement of the problem and the solution space. The third task provides the opportunity of evaluating and reformulating the design solutions. In Task 4, the participants are asked to propose and represent an outline design for a future personal entertainment system.

Table1: Description of the tasks.

Task 1 Problem-solving	Task 2 Basic design	Task 3 Open design
In Task 1 the design of a set of furniture is available and three conditions are given as requirements. The task consists of placing the magnetic pieces inside a given area of a room with a door, a window and a balcony.	In Task 2 the same design set of furniture is available, and three requests are made. The basic design task consists of placing the furniture inside a given room area according to each participant notions of functional and comfortable using at least three pieces.	In Task 3 the same design available is complemented with a second board of movable pieces that comprise all the fixed elements of the previous tasks, namely, the walls, the door, the window and the balcony. The participant is told to arrange a space.

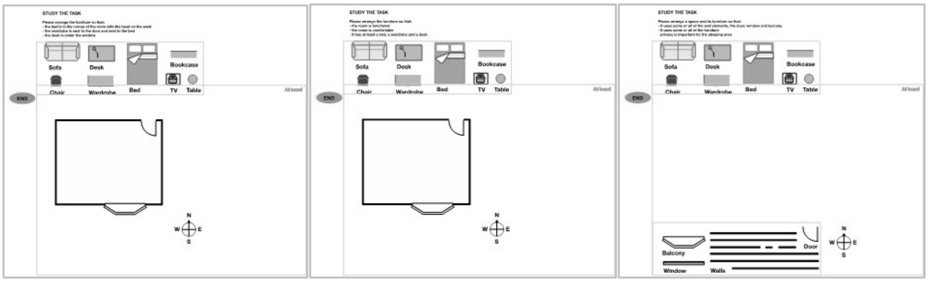

Image 1: Depiction of the problem-solving Task 1, basic design Task 2, and open design Task 3.

The movable pieces were placed at the top of a vertical magnetic board to prevent signal noise due to eye and head movements as tested in the physical magnetic board. The EEG activity is recorded using a portable 14-channel system Emotiv Epoc+. Electrodes are arranged according to the 10-10 I.S, Image 2. The subjects performed the tasks on a physical magnetic board. The two video cameras for capturing the participant face and activity and the audio recorder were streaming in Panopto software (https://www.panopto.com/), Image 3. One researcher is present in each experiment episode for recordings and instructing the participant. A period of 10 minutes for setting up and a few minutes for a short introduction are necessary for informing each participant, reading and signing of the consent agreement and discussing the experiment. The researcher sets the room temperature and draws each participant's attention to minimize neck movements, blinking, muscle contractions, rotating the head, horizontal eye movements, pressing the lips and teeth, and silly faces in particular during the tasks, as these affect the signal capture. Electromagnetic interference of the room was checked for frequencies below 60Hz.

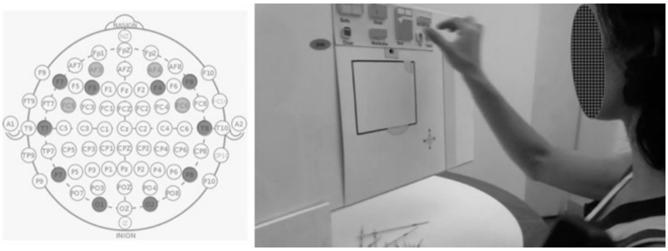

Image 2: Emotiv Epoc+ electrodes arrangement (10-10 I.S.) and experiment setup using the headset.

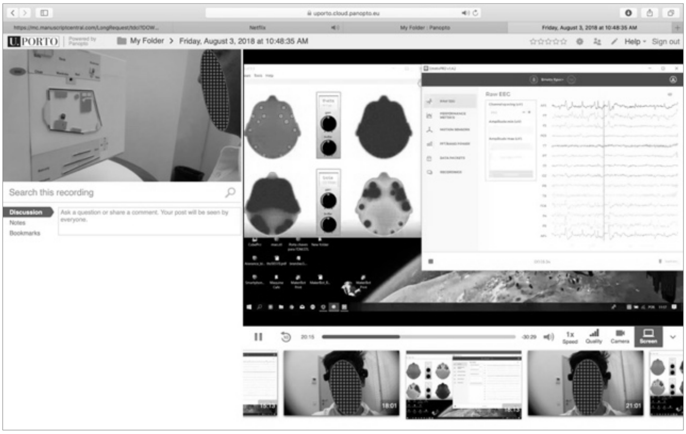

Image 3: Audio, video and screen captures streaming in Panopto.

The researcher follows a script to conduct the experiment so that each participant is given the same information and stimuli. Before each task, participants were asked to start by reading the text which took an average of 10s of reading period. Then the subjects performed the sequence of five tasks previously described with breaks in between where they play Mikado. The experiments took a total of between 34 to 61 minutes. The experiments took place between March and July of 2017 and June and September of 2018 in a room with the necessary conditions for the experiment, such as natural lighting from above sufficient for performing experiments between 9:00 and 15:00 and no electromagnetic interference. The researcher positioned the participants at the desk and checked for metallic accessories for electromagnetic interference.

2.2 Participants

In this paper we describe the analysis of 18 mechanical engineers. Results are based on 18 individuals aged 25-40 (M = 28.9, SD = 4.2). The sample include 10 men (age M = 29, SD = 5.3) and 8 women (age M = 28.7, SD = 2.5), all right-handed. This study was approved by the local ethics committee of the University of Porto. Each participant was reminded to use the bathroom and spit out any gum before the start of the experiment. The researcher sits each participant at the desk, asks him/her to untie hair and remove earrings and other metallic accessories of electromagnetic interference, check if they are using contact lenses as these may cause to much blinking and interfere with data collection. Time was given to the participants, in particular in Tasks 3 and 4 so they could find a satisfactory solution.

2.3 Data Processing

For the present analysis all the EEG segments of the recorded data were used for averaging throughout the entire tasks, from beginning to end. In this research we adopt the blind source separation (BSS) technique based on canonical correlation analysis for the removal of muscle artifacts from EEG recordings [11, 12] adapted to remove the short EMG bursts due to articulation of spoken language, attenuating the muscle contamination on the EEG recordings [13]. The fourteen electrodes were disposed according to 10-20 I.S, 256 Hz sampling rate, low cutoff 0.1 Hz, high cutoff 50 Hz. Data processing includes the removal of DC offset with the IIR procedure, and the previously mentioned BSS. Data analysis included total and band power values on individual and aggregate levels in MatLab and open source software.

In the short interviews conducted at the end of Tasks 3 and 4 the researcher asks participants four open questions. A 5 Factor Personality Test was given to each participant after the experiment. Results of the interviews and the personality tests will be reported elsewhere.

2.4 Data Analysis

A total of 26 experiments were conducted with mechanical engineers. Due to EEG recording issues two experiments were excluded. The analysis then proceeded based on the EEG data recorded and processed for each of the 24 remaining experiments, and each of the 14 electrodes used for averaging, for each of the tasks. For the analysis of the transformed power (Pow) across tasks per participant a z-transform was conducted to determine outliers. The criteria for excluding participants were based on the evidence of 6 or more threshold z-score values above 1.96 or below -1.96 and individual measurements above

2.81 or under -2.81. This resulted in a further six experiments being excluded leaving 18. We focus on the overall activation per channel, per task, per participant as the study aim is to determine how far results for problem-solving and designing can be discriminated. The task-related power (TRP) is typically calculated taking the resting state as the reference period per individual. We analyzed the EEG recordings of the resting periods prior to the experiment of a few participants and their results vary considerably, some participants showed signals that can be associated with the state of being nervous and expectant and their cognitive effort and activity is unknown. As the focus of the present study is to determine how well designing can be distinguished from problem-solving we take the problem-solving Task 1 as the reference period for the TRP calculations. Thus, for each electrode, the following formula was applied taking the mean of the corresponding electrode i, in Task 1 as the reference period. By subtracting the log-transformed power of the reference period (Powi, reference) from the activation period (Powi, activation) for each trial j (each one of the five tasks per participant), according to the formula:

$$TRP_i = \log(Pow_i, \text{activation})_j - \log(Pow_i, \text{reference})_j$$

By doing this, the negative values indicate a decrease of task-related power from the reference (problem-solving Task 1) for the activation period, while positive values express a power increase [14]. TRP scores were quantified for total power and temporal analysis was initially carried out by dividing each experiment session into halves per task across domains (power and activation refer to brain wave amplitude).

3 Analysis and Results

Preliminary results of total task-related power (TRP) across the 18 participants indicate that the tasks can potentially be distinguished from each other using the TRP values.

3.1 Task-Related Power of Mechanical Engineers

The analysis of task-related power (TRP) allows a preliminary comparison of differences across the tasks. Results between the tasks for the mechanical engineers are depicted in Image 4. To compare the TRP of mechanical engineers we performed an analysis by running a 4x2x7 repeated-measurement ANOVA, with the within-subject factors task, hemisphere and electrode. From the analysis of the 18 participants we found a significant main effect of task, $F(1.87, 31.81)=4.57$, $p=.02$, $\eta 2partial=.21$) (corrected for Greenhouse-Geisser estimates of sphericity, $\varepsilon=.62$). None of the other factors showed a significant main effect. No two-way interactions were found to be significant or close to significant at this level of analysis.

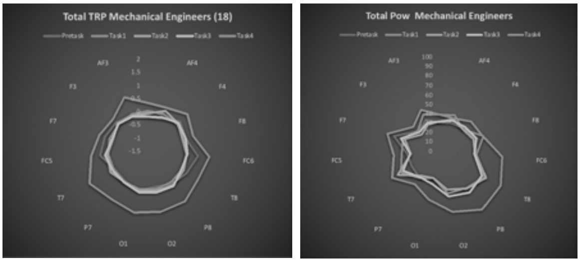

Image 4: Task-related power (TRP) and Transformed power (Pow).

In addition, we conducted pairwise comparisons to check for differences among mechanical engineers comparing them for electrodes, hemisphere and task. The pairwise comparisons revealed that Task 4 differs significantly from the Pretask (p=.03), Task 2 (p=.03) and Task 3 (p=.02). The transformed power (Pow), was calculated for each of the 5 tasks and 14 electrodes.

Temporal Analysis

The transformed power (Pow) was calculated for each fifth per task. Results across the 18 participants are depicted in Image 5. At this stage amplitude values above 200 µV/m were excluded leading to 2 standard deviations from the mean as thresholds.

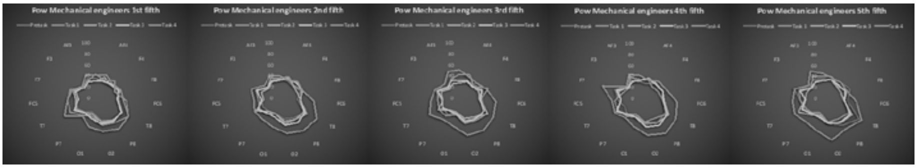

Image 5: Mechanical engineers and tasks divided in fifths.

To compare the Pow scores for the fifths of mechanical engineers we performed an analysis by running a 4x2x7x5 repeated-measurement ANOVA, with the within-subject factors task, hemisphere, electrode and fifth. From the analysis of the 18 mechanical engineers we found a significant main effect of hemisphere, $F(1, 17)=23.44$, $p<.001$, $\eta 2partial=.58$; electrode, $F_{GG}(3.65, 61.97)=3.33$, $p=.02$, $\eta 2partial=.16$) (corrected for Greenhouse-Geisser estimates of sphericity, $\varepsilon=.61$), ($p=.034$); and fifth, $F_{GG}(2.53, 42.98)=3.58$, $p=.03$, η2partial=.17) (corrected for Greenhouse-Geisser estimates of sphericity, ε=.63). No significant main effect was found of task, $F_{GG}(2.81, 47.78)=1.82$, $p=.16$, η2partial=.10) (corrected for Greenhouse-Geisser estimates of sphericity, ε=.70). Further, the ANOVA revealed a significant interaction effect between the factors hemisphere and electrode, $F_{GG}(2.32, 39.35)=3.31$, $p=.04$, η2partial=.16) (corrected for Greenhouse-Geisser estimates of sphericity, ε=.39). No other two-way interactions were found. In addition, we conducted pairwise comparisons for hemisphere, electrode, fifth and task. Below we report on significant ($p\leq.05$) pairwise comparisons. The pairwise comparisons revealed that the second fifth differs significantly from the fourth ($p<.01$) and fifth ($p=.02$) fifths, and the third fifth differs significantly from the fourth ($p=.01$) and fifth ($p=.04$) fifths. The pairwise comparisons also revealed differences comparing hemisphere, the 7 electrodes and tasks within each fifth. Below we report on the significant ($p\leq.05$) pairwise comparisons found mainly between Task 1 (problem-solving) and Task 4 (free hand sketching). For the right hemisphere, electrodes FC6(p=0.05) in the second fifth, FC6(p=0.03) in the third fifth, P8(p=.04) in the fourth fifth and O2(p=0.03) in the fifth fifth are significant. For the left hemisphere, electrodes O1(p=0.04) in the second fifth, O1(p=0.03) in the third fifth, T7(p=0.04) and F7(p=0.04) in the fourth fifth and electrode O1(p=0.01) in the fifth fifth, are significant.

Cohen's d was calculated for each electrode, per fifth using a comparison between sequential tasks. This revealed medium (.50) and large (.80) size effects between Task 3 and Task 4, as shown in Table 1.

Table2: Cohen's d for eight electrodes between Task 3 and Task 4 per fifth.

T3/T4	FC6	P8	O2	O1	P7	T7	FC5	AF3	Fifth
									1st
	.66	.56		.53					2nd
d	.68	.67	.71	.78	.62	.64	.51		3rd
	.57			.56				.52	4th
	.60		.80	.65	.54		.57	.63	5th

Dynamic Average

Statistical analysis indicates increased activation of the left and right occipitotemporal cortex when designing compared to problem-solving. Electrodes P8, O1, O2 and T7 Pow values differ significantly for design Task 4 from all the other tasks. These electrodes corresponding Brodmann area (BA) are BA37 (P8), BA42(T7) and BA18 (O1 and O2). It is known that drawing activates right BA37. In the frontoparietal cortex, electrodes FC6, F7 Pow and FC5 Cohen's d values differ significantly from the design Task 4 to all the other tasks as well. The dynamic average was calculated for electrodes FC6, O2, O1 and FC5 for Task 1 and Task 4 as depicted in Image 7.

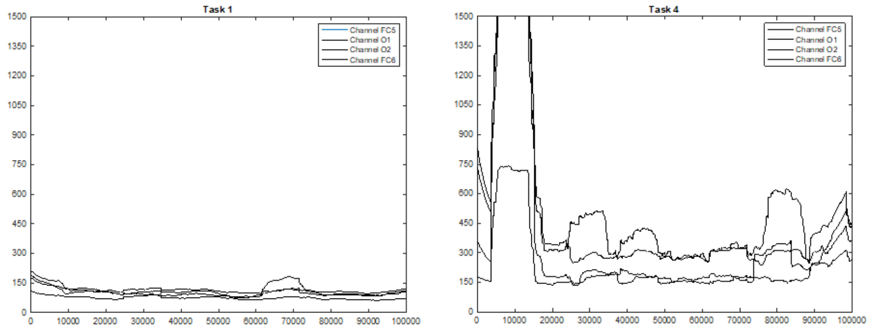

Image 6: Dynamic average of FC5, O1, O2, FC6, Tasks 1 and 4.

4 Outcomes and Discussion

Results from this study demonstrate that it is possible to address the overall objectives of this research: investigate the use of the EEG technique to distinguish design from problem-solving. The results of this preliminary analysis of the EEG data of the 18 participants show differences in the design neurocognition of mechanical engineers across tasks and provide initial support for Hypothesis 1: the design neurocognition of mechanical engineers when problem-solving and designing is different, particularly in Task 4. Mechanical engineers show higher transformed power (Pow) and distinct TRP differences from Task 4 to the problem-solving tasks. The neurocognitive temporal distributions of activations are non-uniform, providing initial support for Hypothesis 2: as mechanical engineers show variation in the Pow and TRP between the problem-solving and design tasks, across the fifths, particularly in Task 1 and Task 4. On a qualitative level the current study shows evidence of a distinct characteristic of increased Pow and TRP of Task4 from the reference problem-solving task for mechanical engineers. No evidence for higher activation of the dorsolateral prefrontal cortex across design tasks [4, 6] is provided.

Further detailed analyses are being carried out to provide a more comprehensive understanding of the neurophysiological differences between the tasks.

Such analyses include using a finer temporal division and bandwidth studies. Once a comprehensive articulation of the brain behaviour derived using EEG becomes available, we will be in a position to correlate that behaviour with cognitive behaviour.

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Improving Decision Making by teaching Debiasing Approaches - motivating Engineering Students with Reflection

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Abstract

Engineers constantly make decisions and run the risk of being negatively influenced by cognitive bias. For teaching students existing debiasing approaches, there is a lack of possibilities to create awareness and motivate them. The aim of this paper is to investigate how knowledge about cognitive bias can be taught to engineering students so that they can make reliable decisions in their work. A study was conducted with mechatronics students. The Test Group, which reflected on behaviour in a first task, showed a higher motivation compared to the Control Group without reflection. The Low-Performers of the study had particular difficulties in identifying strongly disconfirming observed data and rejecting hypotheses with strongly disconfirming evidence.

Keywords: Decision Making, Debiasing, Motivation, Reflection

1 Introduction

Many decisions are made in product development, regarding the development goal as well as the design of the solution. During the design phase, decisions are made minute by minute [1]. Thus, designers must have knowledge about how human behaviour influences their thinking and decision making in order to avoid effects of cognitive biases. Cognitive biases are systematic errors in human information processing. One of the main causes of cognitive biases are heuristics [2]. The effects of cognitive biases have already been examined extensive in psychology; the examination of effects on product development are still in their beginning [3]. One of the most prevalent and examined biases is the confirmation bias [4]. The confirmation bias „is a tendency to seek and interpret evidence in order to confirm existing beliefs" [5]. As a significant influence of heuristics [6] and confirmation bias on decision making in product development is shown by HALLIHAN et al. [3], it is important to consider the impact of the biases on decision making processes of engineers.

According to LEWIN, three steps are necessary to undergo a change of behaviour in order to achieve a higher performance. Firstly *Unfreezing* - the habitual and biased behaviours must be recognized and discarded. In the second step - *Moving* - procedures are learned which cause less or no biases. Finally, these procedures are strengthened in a third step *Refreezing* through adequate practice [7]. According to FISCHHOFF, debiasing requires personalized feedback and coaching [8]. In today's lectures with several hundred students, such extended coaching is not possible. From our point of view, it is therefore necessary to draw students' attention to human behaviour in decision making, to train debiasing methods and to motivate them to learn more about human behaviour in design, leading to better decisions. We think these aspects can be supported by self-experience of cognitive bias and a following reflection. Especially for *Unfreezing,* the reflection could be helpful, because it can have a motivating effect. Trained and motivated students can give each other feedback and refreeze their debiasing approach in future project work.

One method to reduce the confirmation bias is Analysis of Competing Hypothesis - ACH. ACH is a method to make decisions that entail a high risk of error in reasoning. The core of the method is a matrix where observed data is rated with respect to relevance and diagnostic value, thus preventing the acceptance of an unlikely hypothesis [9]. That ACH can reduce confirmation bias in product development was demonstrated by HALLIHAN et al. [3]. However, they also describe that the effort required for the application of methods is a deterrent [10]. Other challenges that product developers may face when applying this method are not described.

Research question and research goal

To prevent students from using biased heuristics we want to motivate them to learn more about cognitive biases and debiasing methods. We also want to identify challenges that arise when students apply debiasing methods. We therefore conclude on the following research questions (RQ) and hypothesis (H):

RQ1: How can we impart knowledge about cognitive bias to engineering students so that they can make reliable decisions in their work?

- H1.1: Reflection improves the motivation to learn more about cognitive bias.
- H1.2: Reflection improves the quality of evaluating hypotheses for observed data.

RQ2: Which challenges encounter Low-Performers when evaluating hypotheses for observed data compared to High-Performers?

2 Materials and Methods

Specific tasks are needed which provoke bias to make it possible for participants to experience it. Additionally, a comparison between participants reflecting their experience of bias and those who did not reflect their experience takes place. This leads to a division of participants into two groups – a *Test Group* and a *Control Group*. To address the presented research issues, a between-subject study was conducted that took place in a mechatronics bachelor course. The participation was voluntary for students taking part in the course. The group size varies because the sessions were carried out one after the other and the students were free to choose the session. In addition, data collection was voluntary which lead to different numbers of data sets within the groups. The following chapters describe the study's procedure, data acquisition and analysis in detail.

2.1 Study design

Procedure differed between groups as shown in Image 1: In the *Test Group*, participants performed *Task 1* to experience confirmation bias and reflected under supervision on their results. Afterwards the participants took part in a training on theoretical basics of confirmation bias and its mitigation by using the ACH-method before processing *Task 2*. Participants of the *Control*

Group received the training before working on the two tasks. Besides, participants of the Control Group did not reflect on their results in either of the tasks.

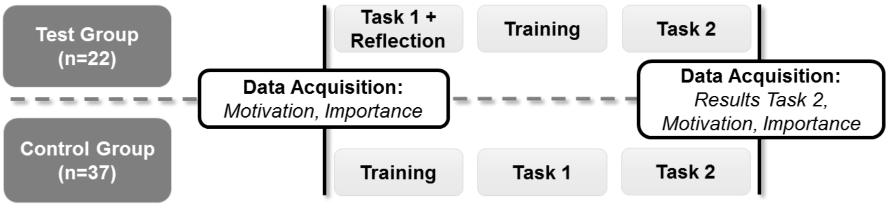


Image 1: Study procedure of Test- and Control Group

Using a survey, the motivation to learn about and the importance of cognitive bias for both groups was recorded at the beginning and the end of the study.

Task 1 consisted of a decision problem: Participants should impersonate a team leader in industry who was confronted with a technical problem with one of the company's current products. Firstly, an introduction to the product was given by presentation. Then participants received a hypothesis on the cause of the technical problem. Afterwards eight different sets of observed data in form of pictures, videos and explanatory notes were presented. The observed data covered various topics: component wear, frequency of defects and test results. The information had been chosen so that some sets of data supported the hypothesis and others disconfirmed it. Information not related to the problem was also presented. The participants' task was to rate those sets of observed data on their diagnostic value for and against the hypothesis. On this basis, the participants should make a decision whether they accepted or rejected the given hypothesis. The sets of observed data were rated on the following scale:

Table 1: Rating scale for observed data

--	-	0	+	++
Strongly disconfirming evidence	Disconfirming evidence	Neutral data	Confirming evidence	Strongly confirming evidence

After Task 1 both groups were informed which decision was correct. Task 1 was used to enable the Test Group to experience and reflect on confirmation bias. No data was collected. The Control Group also processed task 1 to compensate for training effects of the Test Group.

Task 2. The second task was similar to the first one but differed in two aspects: Firstly, participants received three different hypothesis and should rate each of the eight sets of observed data for each hypothesis. Secondly, the participants should use the ACH-method to come to a conclusion.

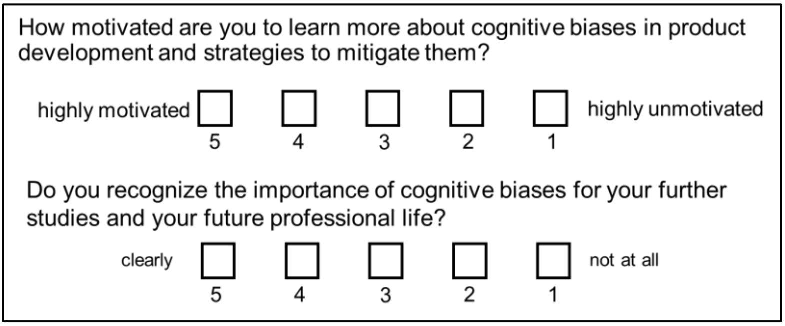
Reflection. After completing Task 1, the *Test Group* reflected on their results. A moderator guided this Reflection by discussing the results with all participants. Questions for discussion included: (1) If they rejected or accepted the given hypothesis, (2) which set of observed data confirmed or disconfirmed the hypothesis in their opinion and (3) why they rated it this way. The moderator discussed with the participants which rating is correct. Additionally, the participants were told in which cases their answers showed aspects of confirmation bias and why this particular task was chosen.

Training in theoretical basics and ACH. Both groups received the same training but in different sequence (see Image 1). The training started with an introduction to cognitive biases and especially the confirmation bias. Followed by introducing a shortened version of ACH developed by HEUER [9]. The participants did not have to develop any hypotheses and were also given the observed data. It was the task of the participants to rate the data in relation to the hypotheses and to fill in the given matrix. They were then asked to evaluate the probability of the hypotheses on the basis of the matrix. In the training, participants learned that it is most important to consider strongly disconfirming evidence because it has more diagnostic value than confirming evidence. The training closed with a practice of the shorter version of ACH.

2.2 Data Acquisition and Analysis

Motivation and importance. The participants' motivation to learn more about cognitive biases and on the importance of the matter was recorded by using a short survey at the beginning and the end of the study, as shown in Image 2.

To identify the impact of Reflection on participants' motivation and importance, the Mann–Whitney *U* test was used to find differences in the ratings of motivation and importance of the *Test Group* and the *Control Group*.


How motivated are you to learn more about cognitive biases in product development and strategies to mitigate them?

highly motivated ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 highly unmotivated

Do you recognize the importance of cognitive biases for your further studies and your future professional life?

clearly ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 not at all

Image 2: Motivation & Importance Survey

High- and Low-Performer. During *Task 2* participants wrote down their decision whether they rejected all or accepted one of the given three hypotheses on a form with an optional explanation for their decision. In the given case of *Task 2*, all of the presented hypotheses were false, so participants showed a high performance when rejecting all hypotheses. They are called "High-Performers" in the following while "Low-Performers" are the participants who falsely accepted one of the given hypotheses. By comparing the numbers of High- and Low-Performers in *Test Group* and *Control Group* using Pearson's chi-square test, effects of Reflection were made visible. Participants who did not document a decision were excluded in the following analysis.

Rating of observed data. During *Task 2* all participants' ratings were documented in a given matrix (see Table 2). The presented eight sets of observed data in *Task 2* contained one strongly disconfirming evidence for each hypothesis in order to make the rejection of all hypotheses the single correct solution. The ratings of those sets of observed data were collected and reviewed on their correct rating of the strongly disconfirming evidence. The number of correct and false ratings of High-Performers and Low-Performers across both *Test Group* and *Control Group* were compared by using Pearson's chi-square test.

Table 2: Matrix to rate observed data

	Hypothesis 1	Hypothesis 2	Hypothesis 3
Observed Data 1	Rating (e.g. "+")	…	
Observed Data 2	…		

Evaluating hypotheses on rated data. The decisions of the Low-Performers were examined more closely. Using the ACH method, hypotheses with strongly disconfirming evidence should be rejected. Therefore, it was determined which participants accepted a hypothesis despite rating observed data as strongly disconfirming evidence.

3 Results

In the following analysis a significance level of p=0.05 is used.

3.1 Motivation & Importance

Before and after the study, the participants were surveyed. The participants rated their *motivation* to learn about cognitive biases and whether they recognized the *importance* of cognitive biases for their later professional lives.

Table 3 shows the results of the Mann-Whitney-U-Test using the surveys' data:

Table 3: Participants' rating on Motivation & Importance
(differing sample sizes due to not submitted questionnaires)

		Test Group Median (n=21)	Control Group Median (n=35)	U	p
Before the Study	Motivation	4	4	293	n.s.
	Importance	5	4	328.5	n.s
After the Study	Motivation	5	4	222	0.009
	Importance	5	5	261	0.034

Before the study, there is no significant difference between the test and Control Group regarding their rating on *motivation* and *importance*. It is apparent that both groups start with high motivation (4 out of 5).

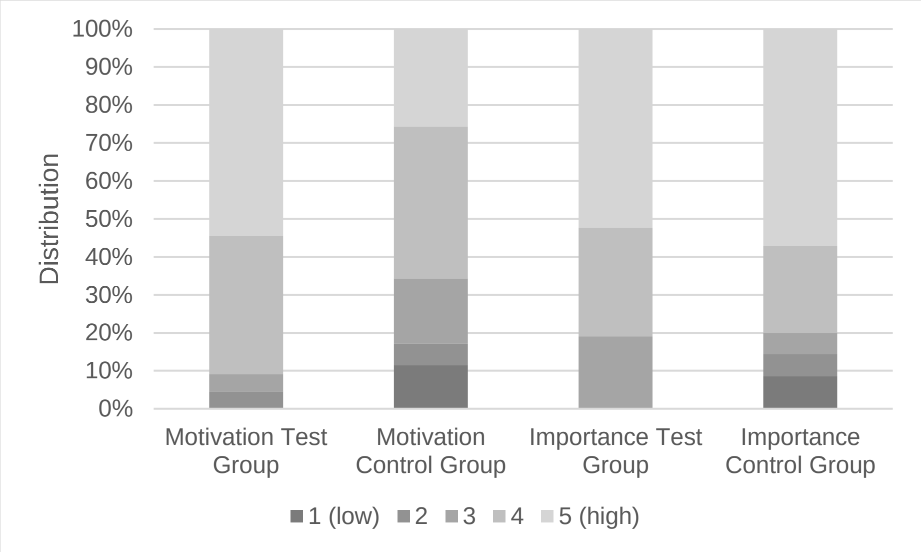


Image 3: Distribution of participants' rating on motivation and importance after the study

After the study the Test Group rated both their *motivation* and the *importance* of cognitive biases significantly higher (p<0.05) than the control group, see also Image 3.

3.2 Quality of evaluating hypotheses

Of the forms that could be evaluated, seven participants in the *Test Group* (n=22) correctly rejected all presented hypotheses. In the Control Group (n=37) eight participants rejected the presented hypotheses. The Pearson's chi-square test did not show any significant differences between the quality of evaluations between the test and Control Group (p>0.05). There is no significant evidence that Reflection improves the quality of evaluating hypotheses for observed data (H1.2).

3.3 Challenges in evaluating hypotheses

For the application of the shortened ACH method in this study, the subjects had to rate the observed data and evaluate the probability of the hypotheses based on their rating. The evaluation of the probability results in the acceptance or rejection of the given hypotheses. The challenges in rating and evaluation are compared in the following between the High-Performers (15 participants correctly rejected all hypotheses) and Low-Performers (35 participants falsely accepted one hypothesis).

Rating. For each hypothesis observed data was presented, which was strongly disconfirming. Table 4 shows how often participants correctly identified the strongly disconfirming evidence.

Table 4: Number of ratings with correct and false rating of the given strongly disconfirming evidence for each hypothesis

	Low-Performer	High-Performer
Correct Rating	54	34
False Rating	51	11

The Pearson's chi-square test shows a significant (p=0.006) difference between the Low- and High-Performers. High-Performers have recognized the strong disconfirming evidence more often (75 %) as such than low performing participants (51 %). Low Performers rated the strongly disconfirming evidence to positive.

Evaluation. For the correct application of the ACH method, hypotheses with strongly disconfirming evidence should be rejected. 18 Low-Performers have mistakenly accepted a hypothesis although they had identified strongly disconfirming evidence. The other 17 Low-Performers failed to identify strongly disconfirming evidence for their accepted hypothesis.

4 Discussion

Effect of reflection on Motivation & perceived Importance. As results given in 3.1 show, reflection significantly improves the participants' motivation to learn more about cognitive bias and subjective importance of the matter for their professional lives. The experience and reflection of biased human behaviour encourages students to learn more about cognitive biases. Unfreezing, the first step of debiasing, should therefore be supported by experiencing cognitive bias within an exercise and instructed reflection.

Reflection improves motivation to learn more about cognitive bias and correlates with a higher perceived importance of the human behaviour in design.

Effect of reflection on the decision quality. As there was no significant difference between *Test Group* and *Control Group* regarding the quality of evaluated hypotheses, we could not find evidence for hypothesis H1.2. This result may be explained by the fact that the initial motivation of both groups was already high. The additional motivation through reflection could therefore not be clearly seen in better learning and performing. Moving, the improvement to a debiased behaviour, could not be directly improved by the increased motivation. To what extent the increased motivation leads to a subsequent self-directed learning process of the students should be investigated. It can be assumed that the increased motivation is beneficial for moving and refreezing a debiased behaviour.

There is no visible short-term effect of Reflection on the quality of evaluating hypotheses on observed data.

Rating of observed data. When comparing the results on ratings of High- and Low-Performers (see Table 4), we see that High-Performers correctly rated observed data as strongly disconfirming evidence more often than Low-Performers. A general method such as ACH by HEUER cannot give specific information as to whether observed data should be considered strongly disconfirming. This requires detailed and discipline-specific training, as well as training in practice-oriented tasks in which problem causes have to be identified.

Correct rating of observed data as strongly disconfirming evidence leads to a better quality of evaluating hypotheses.

Evaluating hypotheses on rated data. Looking at how many Low-Performers used the trained ACH-method correctly – which in short means rejecting hypotheses with strongly disconfirming evidence – shows that 18 out of 35 Low-Performers did not use the method correctly (see 3.3). The acceptance of a hypothesis with strongly disconfirming evidence is an indication of the confirmation bias where the importance of disconfirming evidence is underestimated. The results show that even debiasing methods like ACH cannot prevent the appearance of cognitive bias.

Despite the use of a debiasing method, there remain signs of confirmation bias, which leads to incorrect decisions.

5 Conclusion & Outlook

This study showed that reflection leads to a higher motivation to learn more about cognitive bias. This is an important aspect, but is not described in existing debiasing approaches. Even if an effect of reflection on better decisions has not yet been shown, we assume that more motivated students will learn more about debiasing in the long term and thus make better decisions.

When evaluating observed data using the ACH method, we identified two challenges. The Low-Performers had difficulties in correctly identifying strongly disconfirming evidence. In addition, they found it difficult to correctly apply the ACH method and to reject hypotheses with strongly disconfirming evidence. In order to support the Low-Performers we recommend an additional specialized training to analyse observed data and logical reasoning. During exercises, students should receive direct feedback in order to recognize and avoid errors quickly.

The findings show that motivation is only the first step to teach students how to make reliable decisions in their future work. However, new insights could be found which show, that it is important to combine a correct rating of observed data with a correct evaluation of the rated data to come to a correct conclusion.

Acknowledgement

We would like to thank all participants who took part in this study enabling this work.

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Human needs as the crux of the matter in product-service systems development

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1 Motivation

In the recent years, the conception of humans has shifted from *homo economicus* to *homo ludens*. As a result, there is an agreement about the necessity of a holistic view on humans incorporating emotional and subjective aspects as well – there is no cognition without emotions. In product development, this paradigm is mirrored by the concept of product experience or user experience, defined as the entirety of psychological reactions of any human-technology interaction [1]. This includes purposive and physical, but also non-purposive and non-physical interactions, anticipated, actual and reflected as well as remembered interactions. All these interactions influence human product experience and hence have an impact on human judgement and behaviour towards any product, service or product-service system [2, 3].

The human experiencing of product-service systems is influenced by its function, attributes, appearance, characteristics and behaviour. These can be addressed in the development process. But the same attention has to be paid to the use context, the use task and the human. Humans have different knowledge, skills, competences, goals, values, expectations, experiences and they have different psychological needs. All these aspects need to be considered in the development of product-service systems. Particular attention can be paid to the psychological needs and their fulfilment in order to gain positive user experience. While this approach has been developed for interactive consumer products [4], it can be transferred to product-service systems and to professional domains.

2 Approach

Recognising that hedonic and emotional factors are part of any human decision and judgment process, the relevance for human-technology interaction even in professional domains must be accepted. The particular approach of addressing specific psychological needs of the users is highly relevant. The fulfilment of needs and positive experiences have positive impact on “good work”, resilience, motivation, involvement, but can also reduce absenteeism and staff turnover.

The focus on psychological needs in the development of product-service systems does not only need a specific mind-set, but also adapted processes and specific methods. Depending on industrial sectors, organisational structure, staff expertise and other constraints, the solution must be tailored accordingly. This contribution presents two case studies on how such user experience design approaches with a strong focus on psychological needs can be adapted for product-service system development in large companies.

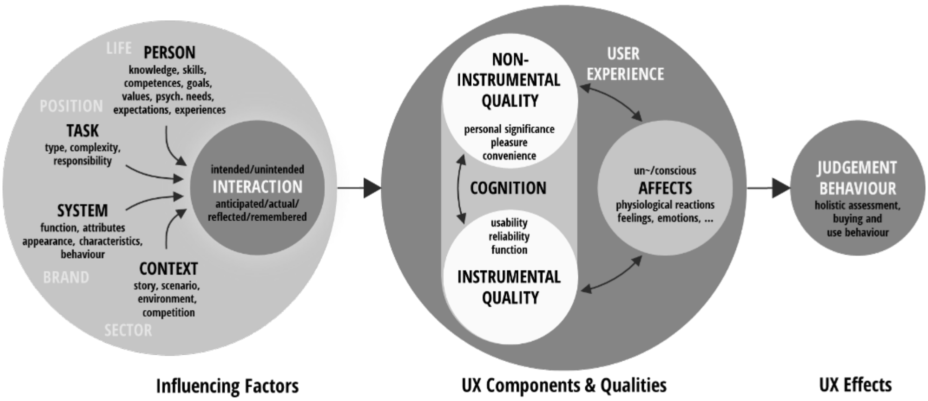

Figure 1: Situative Model of User Experience

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Researching users or chasing miracles

Designing user research designs for systematic user involvement in requirements engineering

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Abstract

Technical innovations should support people in their everyday activities. The development of these systems requires corresponding insights into user practices, contexts and needs. The insider knowledge of users as experts concerning their living conditions is highly valuable for innovating technical systems. For this purpose, research designs for user participation in development processes are required, with which not only the data collection, but also their preparation and evaluation are adapted to the research objective. Engineering designers see themselves confronted with a broad spectrum of instruments for user participation, often without concrete help in deciding what to choose what for. The paper presents a research guideline, with the help of which the influencing variables of the respective research question can be identified, described and translated into an empiric research design.

Keywords: user-centered design, user participation, user involvement, design methodology, design research ,empirical research, research designs

1 Introduction

Although user involvement has a long tradition in new product development, surprisingly few guidelines exist describing concretely how users should be integrated into development processes of technical systems. Influences from various disciplines characterize a conceptual landscape in which the analytical boundaries become blurred and the conditions of certain principles are characterized more by a soft character than by systematic specifications. As theoretical concept, user involvement has reached a degree of maturity that, in addition to further developing the theory, requires tangible efforts concerning the implementation and adaption in design practice.

The article at hand transfers the process logic of empirical investigations to the dimensions of product development and thereby identifies those junctions, at which user participation decisions should be made, which in turn can be translated into concrete process steps for setting up user-centered study designs. Thereby, implicitly, this article contributes to the question of how communication across disciplinary boundaries can be promoted. Taking account of the various degrees of user involvement in development processes, the next section will briefly outline the evolution of user roles in the context of design (2). The analysis of user-centered design practice (3) is followed by the presentation of a research logic by which emirical user research designs can be put together in a process-oriented manner for achieving adequate user involvement in product development (4). Eventually, a guideline by the help of which suitable research designs for adequate user involvement can be designed will be presented (5).

2 Perspectives on the user

Interactions with users in the early stages of development go beyond simple needs identification. Studies have found the importance of having users involved closely in design and development. Several works have discussed that frequent and intimate user involvement is important for improving product concept, as well as for improving innovation capabilities and product market performances [1, 2]. Whereas user engagement in the latter stages as test and launch is now common practice in product development, more and more modern techniques focus on the fuzzy front end of innovation as well as on design and development itself [3].

User involvement, which is interchangeably named user participation or user involvement, has the potential to improve the quality of technical systems by providing more complete assessment of user information requirements [4, 5]. The nature of participation depends significantly on the objective of user involvement. This is not only a question of the extent to which the users life and action situations can be depicted, but also which results can be expected from.

Therefore, one of the core questions of user involvement is asking for the development stage that users are to be involved in, which is directly linked to the actual purpose of the design task.

Product development is divided into four essential phases: planning, conception, design and detailing. During the planning phase, product ideas are identified and decisions are made, as for example, which products are to be developed. In the concept development phase, the requirements for these product ideas are to be concretized and concepts for the products are to be derived, which in turn have to be detailed in the design phase. The detailing phase aims at product finalization by integrating subsystems to an overall system. If users are to be involved into development processes, they can essentially assume three functions: identify, define, validate. These functions are generally needed in every development phase but not equally in each phase. As a result, different data and information requirements are expected from users, depending on their function. Of course, this must also reflect itself in the selection of the user involvement methods and instruments as well as in the overall design of the user research study.

3 Research Approach

At a first glance, user involvement remains a rather abstract concept without much empirical development. As a concrete definition is missing, the main research objective is to understand how user participation is methodically supported and which challenges engineering designers do face in practice. This can be operationalized by the following research questions:

1. *Which concepts of user involvement do exist in design practice?*
2. *Which are main practical challenges of user involvement?*
3. *Which kind of guidance through these challenges is needed?*

Accordingly, the analysis consisted of two research steps. Firstly, a literature research has been conducted. Journal articles, papers and books were obtained from Springer Link, Web of Knowledge, Google Scholar and Google. The investigation concentrated on publications that included at least one of the following keywords „user involvement“, „user participation“, „user-centered“

and „user integration“ in the context of „product development“ and „engineering design“ in English and German.

A qualitative content analysis was done using MAXQDA software. It mainly focused on the challenges and limitations discussed within the data material, including reflections and open questions concerning the process design of user involvement studies. The analysis followed the coding scheme from a higher concept back to the data-generated concepts, which ultimately condensed in a conceptual network. This approach primilary should reflect the perception of engineering designers concerning their own capability of selection, adaption and application of user involvement methods and the co-creation process with users. These findings are condensed into pressing questions regarding user involvement. This approach follows the assumption that if practical challenges can be formulated as questions, it might be easier to identify viable solution concepts.

3.1 Descriptive research findings

In the underlying body of literature, user involvement is understood as both, theoretical explanatory approach and conceptual framework, in which the degree of user involvement varies depending on its objectives. These considerations seem to be done rather randomly, however. Searching for methods for user involvement in development and design, surprisingly, the findings turned out to be rather research approaches or concepts using different survey methods to gain user insights.

The majority of articles uses different survey methods for user research from various disciplines, while the design perspective and engineering methods seem surprisingly missing in this part. It is hardly answered what it means to involve users and into what users are to be involved from a design perspective. It is described how user involvement can be achieved, but not what it implicates for the design process. Most methods seem to be adopted without being adapted and applied to different development tasks.

Table 1 summarizes the identified concepts dealing with value creation through user involvement after being linked to their origin domain, main objective and most frequently mentioned methods, techniques and instruments used. Common to all approaches is the emphasis on active exchange with users and other stakeholders to achieve the objectives pursued. Even though netnography and innovation communities might be subsumed under co-creation, here they are listed separately because they are not dyadically organized between engineering designer and user, but they function network-based.

Table1: Concepts of user involvement

Conception	Overall Aim	Methods, Instruments
Co-Creation [economic sciences]	requirement analysis (based on empathy and inspiration), collaborative value-creation (Prater, 2009), personalized customer experience (Prahalad & Ramaswamy, 2004)	workshops, design techniques, personas, scenarios, lead user method, card sorting, toolkits, innovation contest, design challenge, serious play, observations, surveys, acting scenes
Design Thinking [software/ mechanical engineering]	empathize–define–ideate– prototype–test, (= understand, explore, materialize), sharing interdisciplinary knowledge in creative collaboration (Brown, 2008; Lawson, 2006; Rowe, 1987)	workshops, personas, brainstorming, user stories, point-of-view, sketches, prototyping, mock-ups, observation, survey, concept testing, serious play, empathy map
Experiental Research [social sciences]	any research where conclusions of the study are strictly drawn from concrete empirical evidence, and therefore "verifiable" evidence (Flick, 2014)	surveys, ethnographic and observational methods, content analysis, experiment, grounded theory, action research, case studies, focus groups
Innovation Communities [eoconomic sciences]	observation, evaluation and establishment of virtual communities working on innovation tasks (Jeppesen & Frederiksen, 2007; Sawhney & Prandellini, 2000),	complaint management, innovation circle, monitoring, focus groups, design challenge, observations, walkthrough, storytelling
Nethnography [cultural studies]	web-based passive research into consumer behaviour (Kozinets, 1998, 2002; Bartl et. al, 2009), network-based	ethnographic evaluation of virtual discussion forums, surveys, content analysis, observations
Participatory Design [systems engineering]	actively involve users and other stakeholders in the development process, survey and increase of acceptance (Bødker & Iverson, 2002; Namioka & Schuler, 1993)	interviews, observations, future workshop, thinking aloud, scenarios, probes, storyboard, cartographies, prototypes, brainstorming, role play, walk through
User Experience [human computer interaction]	includes functional and emotional needs, before as well as after use, going beyond questions of effectiveness and efficiency, (Garett 2011, Hassenzahl, 2008, Mooshagen & Thielsch, 2010)	personas, card sorting, eye tracking, observation, depth interview, storytelling, user diaries, focus groups, meCUE, AttrakDiff2, UEQ, VISAWI, UMUX

Overall, it can be summarized that the topic has thus far experienced little systematic development work with regard to process models, methods used and conceptual frameworks. This reveals the lack of a common understanding of the process logic of a suitable research design. Without this context knowledge, however, there is a tendency to isolate methods, transfer them to a new object, and attempt to adapt this object to the method. The opposite should be the case: A method is to be selected based on the goal, which is to be realized by its application. Only then adaptions of methods can be made appropriate to the object. In contrast, most of the articles analyzed here neither point out clearly what is understood by user involvement into product development in general, nor do they explain the selection criteria of the method(s) used in their particular user-centered design process.

3.2 Qualitative research findings

User-centered design is strongly connected to insights of human-oriented research disciplines. Methodological support origins in cultural, social and cognitive sciences mainly. In each discipline, methods are defined by their epistemological interest, scope and objective. This positioning is crucial to assess the outcomes to be expected if applying them. Mostly, methods adress specific issues and when applied to new contexts, they need to be adapted accordingly. In the field of user-centered design, this need seems to be ignored to some extend. The most used method for user involvement in design was „interviews“. An interview is no more or less than an empirical survey technique by which user data can be collected. After processing, this data still has to be analyzed and synthetized. Herefore, data analysis methods for transforming user data in technical requirements are needed. Within the articles analysed here, this is still perceived as challenging issue.

One main result of this analysis is that technical disciplines are mainly lacking in awareness for the logic of empirical social research and the design of experiments. For example, although qualitative empirical research methods are well known for their suitability in exploratory studies, gaps exist concerning their reliable selection and application. Even in publications that tackles different innovative approaches of user involvement for deeper user understanding, the terms research methodologies, -methods, -designs, techniques, -tools and instruments are often used interchangeable. This mistakenly gives the impression that these terms describe equal, independent and alternative empirical research methods. This fuzziness, in turn, cause biases in the analysis and, consequently, uncertainties concerning the implementation of the results. Assuming that an inadequate research design is related to bad data quality, which in turn is related to an inadequate description of user requirements and, therefore, related to misdeveloped products, rise the question, how engineering designers can be supported in the design of empirical user studies.

All challenges identified or situations perceived as problematic in connection with user involvement in practice were coded as open questions with regard to the underlying dimension of user involvement, as Table 2 illustrates by way of example.

Table2: Dimensions of user involvement

Perceived challenge	**Dimension**	**Question**
When is it most beneficial to get users engaged?	process/phase	when
Which factors influence successful user involvement? How much time and resources must be planned for user involvement?	objects/objectives time/costs	what
How can users be effectively integrated into development processes? What is the most efficient way to engage users with a given development task?	methods/tools techniques	how
How to identify and recruit the right participants?	provider/user	who

Most questions towards practical implementation of user involment reported in the studies analyzed here can be condensed into the dimensions of „what“, „when“, „how“ and „who“. This research approach concurrently provides empirical evidence for the previous assumption that answering these questions can guide user involvement practice [6]. This assumption aimed to support the challenge of holistically understanding user descriptions and translating them into concrete design practices and, therefore, deriving how the user can be adequately integrated into product development. It intended to show to what extend asking the five questions „what“, „when“, „who“, „how“ and „whereby“ can support the selection of the respectively suitable participation methods and tools for involving users into development tasks.

The research presented here worked the other way around: By analysing current reports of user-centered design actictivities focusing on practical challenges towards the design of user involvement, main stressing points were condensed into questions. It can be shown that these questions indeed play an important role for systematic user involvement activities. Moreover, the analysis undertaken here reveals challenges in practically deadling with the interdependency of these questions: for designing adeaquate research designs to the development task given, these questions need to be posed in an systematic order. The considerations undertaken in the next section reflect the logical steps of empirical research designs and integrate them into a guideline by the help of which the realization of research designs for user participation can be supported.

4 Designing user involvement

While process models define which steps are to be carried out, methods define how this is to be done and with what result the steps are to be carried out. Tools can be used to facilitate the application of specific methods. Similarly, a technique can be defined as a way of doing something by using specific knowledge or skills or as practical way of performing a particular activity, such as using specific questioning techniques. Thus, the label „methods of user involvement" falsely seduces to the assumption that these methods guide the involvement of users into design tasks. Actually, methods for involving users into product development are not sufficiently defined as analytical term yet. Such a definition must also reflect the perspectives of at least all disciplines from which user-centered design adopts methods. In contrast to this, this paper is focusing on design practice. As kind of an answer to the widespread but also defective use of empirical social research methods, it offers a guideline for setting up empirical research designs helping to gain that user data that leads to the targeted answers.

4.1 Empirical research methods

Empirical methods explain relations for phenomena, which can be observed in reality. These methods are differentiated according to qualitative and quantitative methods, which depends on the underlying epistemology. Qualitative methods are based on the assumption that reality is shaped by individual perception and thus allows interpretation through observation [7]. On the one hand, due to the subject-relatedness, no high number of participants is necessary for qualitative user insights, on the other hand, this is often criticized as a lack of objectivity. Here, the objectification of the results is guaranteed by the fact that chosen methods as well as all examination and interpretation processes are documented in detail. Qualitative methods are therefore particularly helpful when real situations are to be investigated in order to identify knowledge of dependencies. They support the generation of hypotheses.

Quantitative methods serve to identify and quantify cause-effect relationships. Reality is perceived as objective and independent of the observer, whereby the socio-technical system becomes measurable and can be grasped with controlled methods. The data collection is done by measuring and counting, the results give information about the how long, how often, how much, etc. Statistical methods are used for the assessment, which requires a corresponding number of test persons. The aim is to quantify causal interdependencies, which, however, are by no means deterministic [8]. The development of structured, quantitative survey tools requires considerable prior knowledge of the field of investigation. If this is not available, as is the case, for example, in explorative studies, qualitative methods will preferably be used. Here, the quality of the relationships mentioned and their internal structure is of primary interest from the point of view of those affected [9]. This is an attempt to take account of the fact that the mere statement that a user shows this or that preference does not say anything about why he or she shows it, and thus runs the risk of being pushed into a meaning. That, in the worst case, leads to undesired innovations.

4.2 Guideline user involvement

The analysis has shown that decision-making assistance is required in order to conduct the most appropriate research design for the respective research objective. In new product development, users can participate to varying degrees in determining the functionality and design. This should be based on the fundamental dimensions of user involvement in product development: applying the questions „when“, „what“, „how“ and „who“ to the logic of empirical research systematically supports the selection of appropriate methods for data collection and analysis, as is depicted in Figure1.

Step #1: Defining and specification of the research problem

The development phase at which users are to be involved is important. This „*when*“ depends on the development task. User involvement is of crucial importance especially in the early phases of the development process: here the professional competence of the users as experts for the task at hand cannot be ignored. When it comes to the division of functions between man and technology and thus the functionality of the system to be developed, the course must be set early in the right direction, since subsequent changes to misguided concepts can only be implemented with increased effort.

Step #2: Operationalizing the research object

The question of the „*what*“ defines the expected results for involving users into the development process, such as idea generation or concept evaluation. Fundamentally, the following typology of research objectives can be used: explorative research, descriptive research, testing hypotheses and theories, and evaluation studies. At this point, the question of which decisions the users or their representatives are involved in needs to be clarified.

Step #3: Generating the study design

For product development, the question of „*how*" the users are to be integrated tackles the degree of involvement. In the case of passive participation, the user´s opinion on the system to be developed is taken into account rather deliberately in the design of the technical system. As active co-decision-makers, users, together with other responsible persons, decide on aspects of the product design, e.g. validate properties and features. Participatory design involves users directly into certain design tasks. In terms of empiric study designs, the question is how cross-sectional-, trend-, cohort- or panel data should be collected by means of a non-, quasi- or experimental design. By answering this question, also a very fundamental decision has been made, namely whether a qualitative or a quantitative survey provides the necessary data.

Step #4: Sampling and case selection

The participation process requires different capacities of the users to be involved. On the one hand, a participating user must have a fundamental understanding of his or her role in the design process. On the other hand, he or she needs not only the motivation to participate but also the corresponding professional, innovative and social skills in order to introduce and implement his or her own ideas and requirements in a development context. The question of the „*who*" thus ist o be answered by defining the target group and the information needs regarding the user context.

Step #5: Data collection

In this phase, focus should be put on potential biases caused by side effects during the investigation, which may be typical for the research methods chosen. This is important towards the generalizability of the results. For example, field and lab research settings differ in their outcomes and there are also lots of already well decribed interview effects [7] researchers have to be aware of.

Step #6: Data analysis

At this point, it is important emphasizing the main distinction between empirical logic and product development logic: In empirical research, the processing of data is followed by analysis. In product development, these steps are often already counted towards analysis and directly transferred into synthesis. The data still has to be evaluated and interpreted accordingly, however. Even though the selection of user participation methods is intended to support the subsequent synthesis, within this research step, it serves analysis purposes only.

Step #7: Synthesis

Finally, this is followed by synthetic considerations on connections, for example by inductive, deductive oder abductive conclusions.

Figure1: Dimensions of user involvement applied to empirical research steps

5 Conclusion

The paper addresses the challenge of selecting, applying and integrating different empirical research methods from the technical developing side and provides a proposal for describing and tackling the problem of method integration with a guideline that systematically supports the implemention of research design for empirical user studies.

User participation processes are dynamic and complex, and therefore more challenging than closed innovation processes. Hereby, design must be seen in a larger context: A complete participative development process encompasses not only the actual product design but also aspects of the solution of organizational and work structuring issues. The findings of this research aim contributing the objective to structure and support the application and development of user intergration methods on a systematic level. Even if this exploratory study does not involve a random and representative sample, by using an multi-disciplinary sample, it allows to depict reliably overall trends and challenges within the field. The proposed guideline aims to help design practicioners in building up appropriate research designs for user involvement studies.

The introduced research approach implies the need of thinking user involvement as a strategic programme rather than as a „just in time“ outsourcing or „add-on“ of requirement analysis. Further research activities are planned to systematically observe changes in the theoretical and empirical growing oft he user-centered design culture and impacts on the landscape of design research. Further research should be done in order to complete the collection of concepts and to define their methodical suitability and ease of use concerning different development-related assessment criteria.

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There is more than one way to skin a cat – an interdisciplinary UX review

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Abstract

User-Experience is a buzzword for many things: intuitive usage, a good design, a status symbol or just gamification. This is because several disciplines are active in this field of research at the same time. Nevertheless, a systematic transfer of knowledge between industrial-design, computer-science and product-development is rare. It is questionable whether the current methods of product-development completely master this field of research, or whether other disciplines offer alternative and possibly better strategies. In this paper, the different disciplines will be examined for their methods of achieving User-Experience and collected in the framework of a literature review.

Keywords: User Experience, Aesthetics, Usability, Design Guidelines

1 Introduction

The aim of all developments is to utilize the possibilities of technical systems in order to enable people to overcome performance limits or to maintain or expand their capabilities. The increasing interconnection of physical products with virtual systems has fewer and fewer limits. Increasing functional diversity and functional range are the results of this trend. The result is a need for ease of use that goes beyond the limits of conventional usability. The research area of User Experience tries to close this gap by placing the perception of the addressed user in the focus of the development [1]. This confronts designers with the requirements of pragmatic usability as well as the requirements of the subjective preferences of the users. The resulting paradigm shift inevitably leads to a change in the conventional product development (according to e.g. [2]), which leads to a need of adapted strategies and methods. This makes it clear that User Experience aims to create a positive experience by handling the product. This leads to a paradigm shift in traditional product development, which requires further research fields that offer solutions for user-oriented development in addition to the classical engineer. The intuitive design of interactive systems requires knowledge from different scientific fields. The main components are ergonomics, psychology, product development, computer science and design [3]. The aim of this article is to provide a literary overview of the dominant research areas of user-centred design, which we limit to product development, design, computer science and a brief insight into psychology.

2 The traditional Approach of Product Development

In order to get a complete overview of the different methods within product development for the development of user experience, it makes sense to consider the approach of classical product engineering first. If the product development process is considered according to Pahl et al., an ergonomic point of view is in the focus. A distinction is made between the workload, strain and exhaustion of an activity. Under the term Design for Ergonomics, the following three ergonomic aspects are used [4]:

Table 1: Three ergonomic aspects [5]

Ergonomic Aspects	Description
Biomechanical	Defined by the dimensions of the human body. Application: Workplace design, definition of safety measures, definition of physical forces
Energetic/ Effector	Defined by the physiological structure of the human body Application: exhaustion, maximum forces, temperature, radiation
Informational	Defined about human information processing. Application: Recognition and identification of signal meaning. Reduction of the information load.

The aim of this ergonomic design is to keep the load and strain on the user as low as possible. It refers to ergonomics methods that focus on objective parameters. The main task is the adaptation of the technical product to the human being as well as the definition of the necessary qualification of the user. However, reference is only made to functional needs. Thus only a pure usability of the product is reached. In order to achieve additional user-friendliness, the refer to the concept of usability [6, 2], which is defined in ISO standard 9241. It describes the quality of a product, which ensures a pleasant use for the user and supports the achievement of certain goals within the use. The quality of usability can be described by the definition of the characteristics that determine it: effectiveness, efficiency and the subjective value of satisfaction [7].

- Effectiveness: is the accuracy and completeness with which users achieve a particular goal.

- Efficiency: means the effort, in relation to the accuracy and completeness, with which the user achieves a particular goal.

- Satisfaction: means freedom from interference and a positive attitude towards the use of the product.

This definition focuses on the actual process of use. The usefulness and usability of the product is analysed objectively. This shows that although products can be designed with a high functional benefit, a lack of satisfaction will reduce usability. [8]. According to Göbel [9], the usability of a product is measured by the difference between potential usefulness and real usability. It is deficit-oriented. A product with optimal usability is one that has no ergonomic deficits. To support this process, DIN ISO 9241-110 provides principles for the design of usable products [7]:

Table 2: Principles for the design of usable products [7]

Principle	Description
Task Adequacy	Selection of a suitable functionality and minimization of unnecessary interactions.
Self-Descriptive-ness	Achieving comprehensibility through help and feedback.
Learning Facilita-tion	Use appropriate metaphors to achieve a minimum learn-ing time.
Controllability	Effective and efficient control of the dialog by the user.
Expectation Con-formity	Permanent consistent operation with the help of an ad-aptation to the user model.
Customizability	Customization options for the user and his work context.
Error Tolerance	The functionality of the system must be maintained even in the event of unforeseen errors.

These principles are to be seen as a development from the pure design of technology, which referred only to the technically oriented view of ergonomics, to the psychologically oriented view. However, the focus is primarily on the fundamental processes of perception and cognition [8]. Their use allows the creation of simplicity, which is mainly achieved by a product-side approach. The product is then designed to be easy to learn due to its self-descriptiveness, learning facilitation and expectation conformity [10]. Simplicity is not only defined by the product, but also by the user. [11]. A user-centred approach is hardly to be found here. The usability in ISO EN 9241-210 is broader and states that the perceptual and emotional aspects are also included [12], but this definition is not reflected by the principles described in Table 2.

3 The Dimensions of Product Design

At the human-machine interface, requirements are compared with the performance of the product within the perception process. The aesthetic and semantic dimension (communicative aspects of a design) satisfies human needs on a sensory and emotional level. The practical dimension refers to a rational level for the satisfaction of functional demands [13]. The aesthetic dimension describes the subconscious evaluation with the product. It can be described as uninterested pleasure, since its effect is immediate and unreflected. It is commonly referred to as an interpretation of the beautiful or the ugly. The forms and structures of the product defines it [14]. Within the aesthetic dimension, an attempt is made on the one hand to determine objective parameters, which are responsible for the creation of a positive perception, and on the other hand, aesthetics is described as a subjective factor, which is not defined by the product but exclusively by the human being. Both approaches are often combined in order to determine a general analysis of objective aesthetic perception [13]. The semantic dimension describes the ability to interpret content. Within the product-human interface, the semantic dimension is understood as a means of communication in which signs define the connection between form and content [15]. Furthermore, the dimension serves as a carrier of identification symbols, which both people and their environment associate with the product. These triangular relationships are used to define affiliations and demarcations to social groups, whereby products become symbols of one's own lifestyle [16]. The practical dimension can be understood as a synonym for usability. In contrast to the semantic and aesthetic dimension, the practical dimension concentrates on the objective-rational properties of the product. Oehlke [17] divides the practical dimension into the following three sub functions:

- Utility function - the practical purpose of the product.
- Operational function - adaptation to the conditions of the user
- Factibilitary function - restrictive perspective of producibility

In summary, it can be said that the product design provides user-specific important dimensions that are not included in classical usability considerations.

4 Interactive Systems as Interface

The field of computer science has taken up the concept of UX as an interdisciplinary research discipline and emphasizes the communication between the departments [3]. The term software ergonomics covers all areas involved. DIN EN ISO 9241 also offers the theoretical state of knowledge [7], which is also used in the field of product development. These are very open and can be applied generically to any problem. Due to the rapid development of such systems today, however, these standards are often behind the current findings. For this reason, so-called guidelines were applied, which set the software in its context of use and provide appropriate design recommendations. Even more detailed are often so-called style guides, which companies create to ensure a uniform appearance and interaction. Thus, software ergonomics can be understood as a summary of numerous individual results [3]. Examples of such guidelines include Nielsen [w1] and Preim [18], which were developed on the basis of the principles of ISO 9241. In these guidelines, aspects of design, perception psychology and usability can be found. In addition, the focus is set from the product to the user. Expectation conformity can only be achieved by analysing the user's experiences and abilities. Altogether, it can be stated that in the area of computer science a practice-oriented focus of the instrumentalisation of the product is in the foreground. A multitude of norms, principles and guidelines are made available, which are aimed at the direct development of a good human-computer interaction.

5 User Experience as Synergy

If one looks beyond the edge of product development, the extended concept of the user experience is understood in addition to usability. Originally, the term was used to describe all aspects of the experience of a person with a system [19]. Nowadays the concept is used in many different ways and understood in different ways. In most models, the user experience is divided into two parts. The first pillar takes the usability described above as part of the pragmatic qualities that ensure simple and intuitive usability. The second pillar is described by the hedonic qualities, which represent the sense of personal development and improvement of skills as well as the identification by means of a product to radiate a certain image [20]. The concept of UX is therefore characterized as holistic, subjective, situational, dynamic and positive.

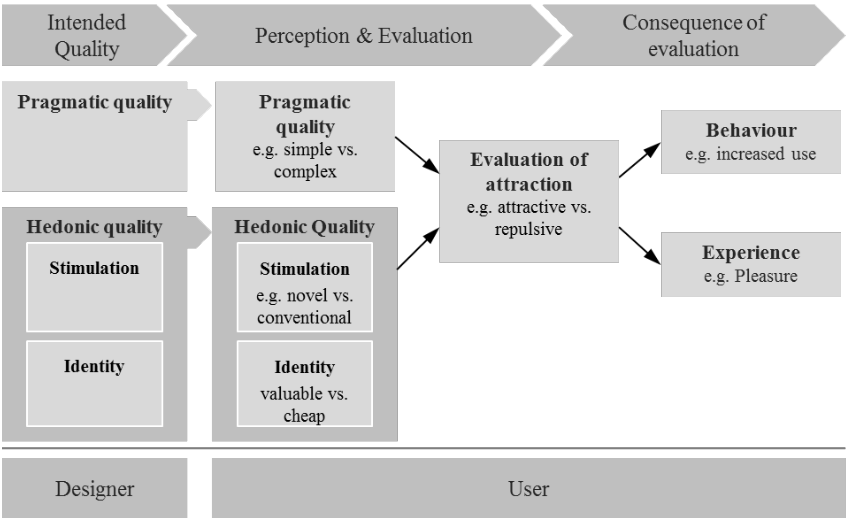

Image 1: The three qualities of UX [20]

A similar approach is the CUE model (Components of User) according to [21] illustrated in Image 2, which defines the influencing factors of the user experience. The interaction characteristic is formed by the system properties, the user characteristics and the task or context. The system properties include the look and feel of the product. It contains the optical, haptic and auditory properties of a product. They cover the functionality and representation of the user interface. In contrast, user characteristics represent the user-related characteristics, such as the demographic context, but also previous knowledge and experience with the product. The environment and goals defines the context and motivates the product interaction. Similar to Burmester [20], different dimensions result from the characteristics. On the one hand, the instrumental qualities, which can be equated with the practical qualities and on the other hand the non-instrumental qualities, which represent the aesthetic qualities. These two qualities trigger emotions with the product, whereby the user's attitude towards the system is formed.

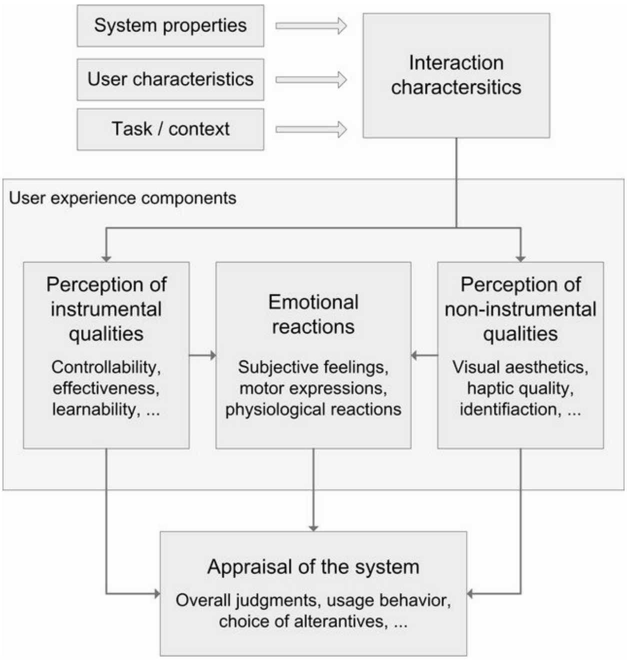

Image 2: CUE-Model [21]

Unlike the model according to [20], no distinction is made between the aesthetic and semantic dimensions. They are described in summary by the non-instrumental qualities. At the same time, Thüring and Mahlke place a greater focus on the emotional reactions of the user. However, the models shown above largely refer to the use phase of the product. For a holistic UX, the perception before and after use has to be considered, shown in Image 3. In pre-use, the user deals with the impressions of the product. Action steps are formed from earlier knowledge. These action steps are applied in the actual use. In post-use, the use is subconsciously reflected and evaluated. The user draws conclusions about himself, the product or his environment depending on his usage results. At this point, it is already possible for the user to form an opinion about the product. If it comes to a repetitive use, the user decides whether he/she will use this or a similar system in the future. If there is a system change, e.g. also a subsequent generation, the model starts from the beginning. The previous experiences will then be reflected in the pre-use [22].

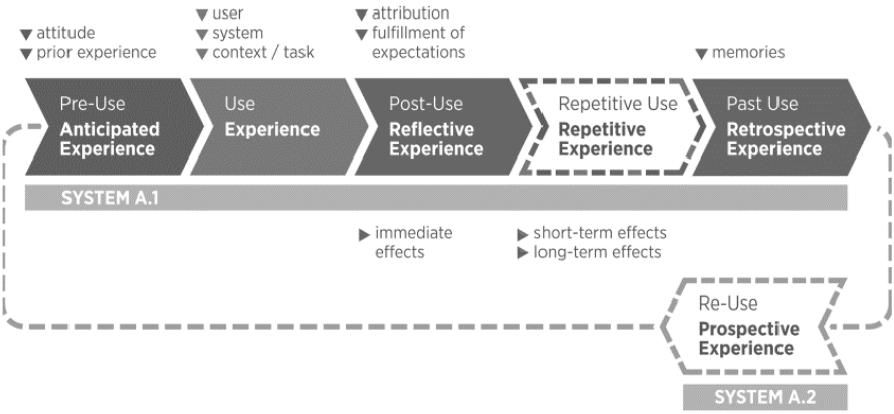

Image 3: Phases in the "User Experience Lifecycle Model" ContinUE [22]

6 A Multitude of Overlaps

In addition to the areas covered so far, numerous other research areas, methods and authors deal with the usage of products. User Experience serves as an umbrella for standardization of the different approaches. It is particularly useful to refer to the early approaches of Norman's emotional design, which focused on the user and his perception [23]. He established concepts such as the mental model, gulf of evaluation, the pursuit of affordance and the seven stages of action [18, 23]. At the same time, the user-centred design is also often mentioned, which according to definition takes into account the interests of the user or actively incorporates them [7]. However, it is not clear whether the comprehensive level of user experience can be achieved purely through a user-centred design.

Maeda and Brügger et al. provide holistic principles/laws for simplification with a focus on ease of use and thus on usability. Here, too, the core of the laws is based on the principles of usability, which have been extended with design guidelines from design and perception psychology. The emotional level can also be rediscovered here [24, 25].

7 Discussion and Outlook

In this article, an interdisciplinary literature research on the different areas of UX was carried out. It was established that UX could only be successfully achieved with the help of an interdisciplinary approach. It could be stated that the scale of a user-centred development in the different research areas is different. While product development and computer science have a largely pragmatic starting point, design focuses on aesthetics and emotions. It seems as if a purely functional view of use is no longer a contemporary concept. The demand for the design of human-machine interfaces has developed from a pure usable design to a motivational and emotional implementation. The principles of computer science form an extension of usability and have a reinforced user-centred approach, which is very function-oriented. There is an overlap between the principles of computer science and the practical dimension of design. At the same time, there is a lack of clarity in the definition of user centricity. Many areas operate decoupled from each other, giving the impression, especially in product development that they are not acting in a contemporary way. An overview of all areas dealt with can be found in table 3.

Table 3: Areas of the user centricity:

Principle	Area	Author
Biomechanical	Ergonomics	Pahl et al. Schlick et al.
Energetic/Effectoral	Ergonomics	
Informational	Ergonomics	
Effectiveness	Usability	Vajna, Pahl et al. EN ISO 9241-110
Efficiency	Usability	
Satisfaction	Usability	
Semantic Dimension	Design	Burmester, Hassenzahl
Symbolic Dimension	Design	Zeh, Eco
Pragmatic Dimension	Design	Conrady
Affordance Emotional Dimension	Perception Psychology	Norman
Principles of interactive systems Guidelines Style-guides	Interactive systems	EN ISO 9241-110 Preim, Heinecke Nielsen
Phenomenological Aspects	Perception Psychology	Norman

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Designing technical information from a sociocultural theoretical perspective

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Abstract

In the workplace, professionals use various tools, such as software, to perform work tasks. If they don't know how to use a tool, they may seek and read the technical information that was designed by a technical communicator during product development. It is of interest for technical communicators to understand how technical information can be designed to provide users with the best support possible. There is currently a gap of knowledge in the technical communication community when it comes to identifying professionals' information needs. By drawing upon sociocultural theory, the aim of this paper is to outline a view on what information needs might be and when and why they arise. The aim is also to illuminate how such a view can provide insights related to the design of technical information.

Keywords: Technical Communication, Sociocultural Theory, Information Need

1 Introduction

This paper concerns technical communicators designing technical information[1] during product development for users of industrial software or hardware devices and machines. Drawing from over 25 years of experience as a technical communicator, it is the opinion of this author that one of the most common design challenges is knowing what to write in manuals. Technical communicators designing manuals during product development seldom get the chance to come into direct contact with the users who are their target group. At the same time, technical communication research shows that users often cannot get the support they need from designed technical information when they seek and read it to learn how to accomplish a work task goal (Novic and Ward, 2006). The research in this paper bolsters the viewpoint that one way to deal with these two issues is for technical communicators to try to include the information that targeted users show evidence of needing. Such a viewpoint implies that a critical factor for technical communicators is understanding the behaviors that give rise to users' information needs—and, especially, when and why they arise, and how they can be identified during the technical information design process. Andersen et. al. (2013) note that there is a gap of knowledge in the technical communication literature when it comes to understanding user behavior. Previous research in the technical communication field has not thoroughly discussed the concept of information need. The aim of this paper is to reason how technical communicators can approach the concept of information need by situating users' appropriation of work tasks within a context of learning, and by reasoning out what the information needs might be and when and why they arise. In so doing, this paper also illuminates how such reasoning provides insights related to designing useful technical information.

The individuals of interest in this paper are those who are employed to perform work tasks in industrial, business-to-business companies, such as maintenance technicians and process operators. They will, therefore, hereafter be referred to as professionals, and are considered to be motivated to perform the work tasks within their scope of responsibility. This paper is further delimited to work tasks where a professional's goal is to achieve a result from using a tool, such as obtaining an electrical resistance reading (goal) by using an electrical measuring device (tool). The focus is on work tasks where the wrong use of a tool

[1] In this paper, technical information refers to single modes and multiple modalities across a diverse range of communication channels and media, which are designed by technical communicators during product development. Such technical information contains instructions and conceptual descriptions, as text and images, on how to use a tool and how it works, often organized into structures of chapters and sections.

does not introduce a risk of major damage or human injury. The use of a tool means that what tasks can be performed, how the tasks can be executed, and what results can be obtained are constrained by the tool design. The work tasks of interest are those where the professional does not know how to use a given tool and, driven by a need for information, seeks support by, for instance, searching and reading technical information. Such situations might arise if a professional is new to the workplace. Or, if a new tool is introduced that is different from the tools the professionals have experience of using in the work-place.

2 Methods and approaches

Technical information is regarded as a designed artifact whose purpose is supporting professionals in the process of moving from a current work task situation, where a goal cannot be independently accomplished, to a future situation where it can. Such a process is considered to be a process of learning. This author studied the literature on learning, in fields such as educational and development psychology, human factors and ergonomics, and workplace learning. This author identified and selected theoretical concepts that were found to be relevant for sketching a conceptual framework on how learning to accomplish a work task goal unfolds for professionals in an industrial setting, and how a work task goal is independently accomplished once it has been learned. Within the framework of learning, this author reasoned out what the information needs might be and when and why they arise. Based on this exposition, conclusions were drawn about how technical communicators can identify information needs and what aspects should be considered when designing technical information during product development.

First, this paper outlines the conceptual framework, then the outcome of the reasoning on the concept of information need is given. Finally, the implications on technical communicators' design practice are presented.

3 Learning and accomplishing work task goals

To depict how professionals learn to accomplish work task goals and how they later accomplish them independently, the theoretical concepts of learning and development within the zone of proximal development from sociocultural theory[2] and goal-directed task behavior within an activity system from systemic

[2] Sociocultural theory refers to the theory proposed by foremost Vygotsky (1980) about the social origin of the mind. Activity theory refers to the theory that is founded upon the sociocultural

structural theory of activity are used. These theories were found to be relevant to forming a conceptual framework for technical communication since they unite cognition and behavior while providing a view on how learning to accomplish work task goals unfolds within an activity system, where psychological and technical tools and goals are central concepts.

Professionals' work tasks take place in specific activity systems. For example, in a repair workshop where maintenance technicians perform machine maintenance. In line with Cole (1998), activity systems are viewed as cultural communities of practice, which are shaped by the individuals who have acted within them throughout their history. Anyone entering an activity system to accomplish work task goals needs to learn how the tasks are done. However, knowledge about a system is not structured in such a way that makes it objectively available and detached from human activity to be egocentrically explored and discovered in order for the individual to construct knowledge, which is also stated by Säljö (2014). A peer's knowledge about the system is mediated, which means that learning is situated within the activity system. A peer, such as a colleague, system expert, trainer, etc., denotes a professional who has developed the cognitive and motor ability to accomplish work task goals independently. They are often considered more knowledgeable, more capable and can offer guidance and support. A professional who is about to learn, is herein referred to as a learner. When intersubjectivity is established between the peer and the learner, they can collaborate; where the peer mediates the meaning of things and how to act in the system by using psychological tools (signs as language) and technical tools. The meanings of tools have been formed throughout the cultural history of the activity systems in which the tools are used. Tools have both a material and an ideal, or meaning side, and they mirror the activity system. It is the ideal side which is mediated by the peer. Thus, the ideal side of a tool does not exist in the tool itself, regardless of human activity, but is, rather, knowledge in the mind of the individuals in the system. Tools whose ideal side is signifying the ideal side of other tools or actions (thus they do not have an ideal side of their own) are in this paper referred to as information. Through the process of internalization, the learner constructs knowledge from what is mediated. Nevertheless, as Billett (2009) notes, a workplace activity system is a social world that suggests its meanings. What the learner is actively selecting to internalize, in order to construct their

theory to explain human activity, formulated by Rubinshtein, Leont'ev, Anokhin, Bernshtein, and others (Bedny & Harris, 2005). The systemic-structural theory of activity (discussed by Bedny, Seglin and Meister, 2000) explains goal-directed activity from an individual psychological perspective, where the individual is the agent.

knowledge based on what is mediated by the peer, depends on a number of factors, such as psychological needs and brute facts. Moreover, it is reasonable to believe that the peer also learns when collaborating, as Jakobsson (2012) points out.

The learning process can be initiated by the learner or by the peer. Säljö (2014) depicts a learning process in phases. In the early phase, the peer can act as a model and show how the task is done and the learner is watching and able to follow and understand what the peer is doing. Later, the learner may attempt the task by imitating the peer, while continuously relying on their support in order to progress. The peer acts as a scaffold and is utilizing different techniques, such as questioning, modeling, cognitive structuring, and feedback (Gallimore and Tharp, 1990). In the later phases of learning to accomplish the task goal, the learner can perform the task more or less independently, only seldomly asking for support. By learning and developing higher mental functions for a particular system, a professional comes to think and behave according to the system.

A learner must have a certain level of cognitive development in order to be in a position to collaborate and learn and accomplish a certain domain of work task goals. For work tasks in an industrial activity system setting, such a view is simplified in Figure 1, based on the concept of zone of proximal development, as outlined by Vygotsky (1978). A learner may be able to accomplish certain types of task goals independently (task 1 at t1). At the same time t1, there can be other tasks that they cannot accomplish independently but learn if collaborating with a peer (task 2 at t1). And yet, at t1, there can be other, perhaps more complex tasks with goals they cannot accomplish even when guided (task 3, 4 and 5). When the learner collaborates with a peer for the tasks that are within the zone, they learn and develop higher mental functions. After having collaborated, the learner can accomplish the task goal independently (task 2 enters the upper tier at t2). At the same time, some other tasks that could not be accomplished previously (task 3, 4 and 5 at t1), enter the zone of proximal development (task 3 at t2). According to this view, professionals’ appropriate procedural and conceptual knowledge. Figure 1 implies a very sequential and ordered task learning process. It is reasonable to believe that the learner may

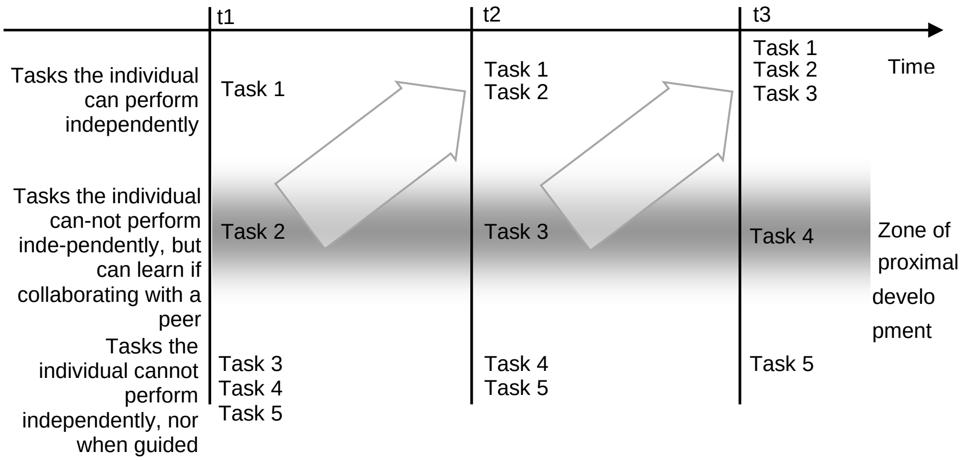

Figure 1: Simplified model of how individuals can learn work tasks in an activity system.

skip the learning of a task that was initiated, and come back to it later, or try to perform a task that is outside of the zone, for example. Nevertheless, there doesn't seem to be a "final" level of development to be reached, as implied by a Piagetian view. A professional can judge whether or not they are able to accomplish a certain work task goal independently. When they perform a work task independently, they follow a task process. Figure 2 depicts the task process, based on the systemic-structural theory of activity. The following deal with each task stage (marked in bold in Figure 2).

A need motivates a professional to engage in a work task. To satisfy the need, the professional forms a goal, which is a mental phenomenon of a future desired state of an object. The professional may decide to use a technical tool, such as a screwdriver, as a task aid in order to reach the goal. When the professional sees the tool interface, the professional recalls its possible mediated and internalized meaning. The formed thought is in this article considered to equal what, in the human-computer interaction literature, is referred to as a mental model the user is constructing out of software on how to use it and how it works (Carroll and Olson, 1988; Ehrlich, 1996). The professional use inner speech to plan out how the work task goal can be reached. The plan is a thought in working memory on how to transform an object from an initial state, such as parts of a machine, to a final desired state, such as an assembled machine.

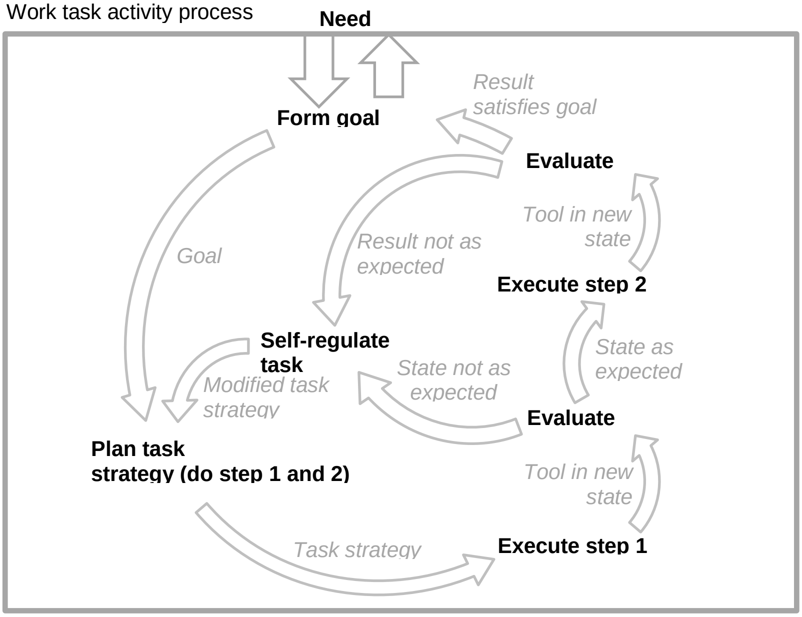

Figure 2: Simplified model of work task activity process. Text in bold indicates different task activity stages which are cognitive and motor behaviors. Text in gray italics indicates a result or decision within a stage.

The task plan is a sequence of motor behavior action steps. When a technical tool is used, the task plan involves subtasks, such as evaluating and selecting a tool, installing, configuring, and using it.

The professional executes the first planned action step with the tool. Each action step is a motor behavior, where the professional interacts with the tool by, for example, clicking on a menu in a software. The professional is formulating an action-goal and is expecting a certain outcome from the action. The tool is responding by entering a new state; for example, by displaying a software dialogue. The professional then evaluates the response from the tool (new state) and compares it to the expected outcome. If the new state matches expectations, the professional continues to the next action step. If the state is not as expected, the professional may use inner speech to self-regulate the activity by, for example, modifying the task plan. After having executed all the action steps in the task plan, the professional evaluates the final state of the object compared to the work task goal. If the final state is evaluated to be satisfactory, the professional may judge that the need, which motivated the professional to engage in the work task, is satisfied. If the final state of the object is not satisfactory, the professional may, for example, self-regulate the activity and modify the task plan.

4. The concept of information need

A professional who determines that they can accomplish a work task goal independently faces a challenge if their current developmental level is not mature enough. The professional may be able to achieve a final state of an object and determine it to be equal to the goal, but a peer could judge the result to be unsatisfactory if the quality is poor. Or, on the contrary, the professional may evaluate the obtained result to not be satisfactory enough. In the worst case, the professional gets stuck in any of the task levels in figure 2, and cannot obtain a final state of the object. Hence, the goal is not accomplished.

If they cannot accomplish a goal, the professional may be motivated to seek support. Thus, the professional initiates a learning process. When seeking support, the professional is showing evidence of an information need. An information need is defined as a professional needing to complete the thought and inner speech about forming a goal, planning the work task or evaluating the response from using the tool, since the thought and inner speech are, in some respect, incomplete. An information need is assumed to arise within a certain task activity stage (see stages marked in bold in Figure 2). The nature of the need – what type of information is needed, and in which task activity stage a professional gets stuck in, likely depends on many factors. A professional may not be able to form a goal or task plan, which could be the case for beginners in the activity system who are starting to use the tool for the first time, for example (equal to a professional performing task 2 in Figure 1). In such a case, the peer may act as the scaffold as depicted above, starting by demonstrating the tool. A professional who has learned most work tasks in an activity system, attempting to perform a more complex task (such as task 4 in Figure 2), has a larger body of prior knowledge to draw from. Such professional could get stuck in later stages of the activity, for example, the execution stage if they cannot find a specific menu in a software in the location they know it to exist.

5 Implications on technical communicators’ design practice

There are several implications for technical communicators designing technical information for the product (denoted here as a tool) which their employer is designing and manufacturing. In particular, when the intention is to include the information that the targeted professionals show evidence of needing as they learn to accomplish work task goals using the tool. The technical communicator becomes the peer who supports the professional through designed signs. One method for technical communicators to identify information needs is to observe professionals while they perform work tasks in their work environment and collect data about the needs they show evidence of. However, a complicated factor when identifying information needs during tool development is that, most often, no external company professionals have used the tool and no information needs have arisen since the tool has not yet been launched to market.

There are several aspects that technical communicators must consider and decide upon when observing professionals to identify their information needs. Firstly, who should be observed? Secondly, what needs for which work tasks goals should be observed? Thirdly, when and where in relation to product development should needs be observed? Fourthly, how should needs be observed? Each of these aspects is discussed in the following subsections.

5.1 Whose needs to observe

Manufacturers design a tool so it can fulfill a specific purpose in a certain activity system. To use the tool as an aid, the professional must accomplish a number of work task goals such as installing, configuring, and using. To learn to accomplish these goals requires that professionals have a certain developmental level. For example, to be in a position to collaborate and learn task 3 in Figure 1, which, in this case, is a task in a manufacturer's tool, requires that the professional has learned and developed the ability to accomplish tasks 1 and 2 (which may or may not be related to a tool). The design of a tool requires the ones learning to use it—the target population—to have a certain level of knowledge within the activity system. When learning the work tasks that must have been learned prior to learning the tasks in a tool, the professional will show evidence of information needs. The technical communicator must decide if the technical information should take such information needs into account, or only the needs that relate to the learning of the tasks involved in the operation of the tool.

Furthermore, a tool belongs to various activity systems throughout its life—from product development, manufacturing, marketing, and sales, to installation, use, and de-commissioning. It can be used to fulfill different purposes in various activity systems. To learn the work tasks associated with the tool within each of these activity systems, the tool design implies different knowledge levels. The technical communicator must decide which activity systems the technical information should take into account.

5.2 What needs to observe

A tool is an aid used as part of an overall work task in an activity system. Consider, for example, a tool like a computer mouse. It is used within another work task in computer software. The goal of a work task in a computer is seldom solely to move the cursor on the screen, but more often to create, for example, a document in which the movement of the cursor is one of the action steps. When observing professionals learning to accomplish goals, the technical communicator must decide if only the behaviors showing evidence of needs related to the tool they are designing technical information for, or if all needs during the learning of the work task should be observed and collected. A manufacturer can decide to support its users in becoming masters of a practice and not just masters of the tasks in the manufacturers' tool.

Furthermore, a professional in the early stages in the zone of proximal development, may have challenges when it comes to formulating goals, and show evidence of needs that the peer could judge to not be relevant. A professional may, for example, think something is possible to do with the tool, and ask non-relevant questions. The technical communicator must decide whether or not non-relevant information needs should be observed. Moreover, Lundin, Söderlund and Eriksson (2016) concluded that the type of information that could satisfy an information need will differ across work task activity systems. Such needs are a challenge for a technical communicator to satisfy when designing during product development.

5.3 When to observe

When designing technical information during product development, few professionals have begun to learn the work tasks, since the product is still being designed and has not yet launched to the market (or activity system). The technical communicator must decide if activity systems should be arranged during product development or if the needs should be identified only once the product is approved and available on the market.

5.4 How to observe

Information needs are a cognitive phenomenon and not possible to observe, as noted by Wilson (1981). The technical communicator must define which observable behaviors show evidence of information needs. The systemic structural theory of activity can be used to define such links. Lundin and Eriksson (2018) used the systemic structural theory of activity when studying the information needs that maintenance technicians showed evidence of when performing maintenance work tasks on machines in a repair center. They concluded that the observed technicians, who were experienced in their activity system, showed evidence of 50 information needs.

5.5 An approach to identifying information needs

Before starting to observe users, the technical communicator needs to decide which activity systems and work tasks within those systems the designed technical information intends to support. Next, they need to identify what behaviors to observe from a viewpoint of how they show evidence of information needs. The technical communicator could arrange the activity system and allocate professionals to observe. The professionals should have developed a task ability so that the most basic task in the tool is within their zone of proximal development. To find professionals, the technical communicator must identify the required level of knowledge for the basic work task. Once professionals are allocated, they are asked to accomplish work task goals. The professional should preferably be asked to begin with the more basic work tasks and then, as they are being learned, continue to perform more and more advanced tasks. Another peer should support the professional when they get stuck and need information, to allow the professional to accomplish task goals. The technical communicator functions as an observer and collects all behaviors that show evidence of an information need.

6. Discussion

The view put forward in this paper assumes that the learner of a work task can perceive an information need and behave in a way that is observable. It could be discussed, but learners in the early phase of learning a work task may not know what they need. In such a case, the peer becomes the one who defines what the learner needs. Through collaboration and guidance, the learner enters a point where they can start to make sense of the task, meaning that intersubjectivity is established and they can better establish what information they need. Furthermore, the approach to identifying information needs means that the technical communicator is human-centered, as they will collaborate with the professionals using the tool. In practice, however, this approach may be challenging to implement since technical communicators are often on a tight budget and the technical information must be reviewed and approved at the same time as the product is launched to a market. This leaves little room for observations that might consume calendar time. Nevertheless, as both Säljö (2014) and Billett (2009) state, learning work tasks in an activity system is not restricted to collaborating with a peer in the same physical room; it can happen via other media.

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Design influencer human

Empirical Evidence for Kahneman's System 1 and System 2 Thinking in Design

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Abstract

This paper analyses design protocols of professional engineers and engineering students using the FBS schema, testing two hypotheses related to the use of system 1 and system 2 thinking. These two modes of thinking are characterised as: one that is fast and intuitive (system 1), and one that is slow and tedious (system 2). Their relevance for design thinking has already been shown conceptually. This paper provides empirical support for the existence of system 1 design thinking and system 2 design thinking.

Keywords: Design cognition, Human behaviour in design, Design process, Dual-system theory

1 Introduction

Dual-system theory is an established model of human thinking with a long tradition in cognitive psychology [13], which has more recently been popularized by Daniel Kahneman in his book *Thinking, Fast and Slow* [8]. It is based on the concept that there are two systems responsible for different modes of reasoning: system 1 for fast, intuitive and effortless reasoning, and system 2 for slower, analytic reasoning that requires greater cognitive effort. In the last few years, a number of studies have examined how dual-system theory can explain the use of intuition and heuristics in design [1], including phenomena such as fixation and creativity [11]. One of the studies mapped system 1 and system 2 thinking onto Gero's [5] function-behaviour-structure (FBS) ontology of design, augmenting the eight fundamental processes postulated in the FBS ontology with a ninth process – representing system 1 thinking in design [9]. This process is a direct transformation of function into structure, which is a result of learning the most efficient pathway from the interpretation of requirements to a synthesised structure. The authors of that work show the use of system 1 in a number of design processes taken from the literature, including design fixation, case-based design, pattern-language based design and brainstorming. However, no empirical validation was provided to support the additional process in the FBS framework.

This paper aims to close this gap by analysing design protocols of professional engineers and engineering students using the FBS coding schema. This analysis is driven by two hypotheses:

Hypothesis H1: Design thinking comprises system 1 and system 2 thinking.

Hypothesis H2: Design professionals use system 1 thinking more often than design students.

Hypothesis H1 is based on the work cited above. Hypothesis H2 is based on the assumption that professionals have developed more experience than students, and with it a wider range of heuristics available for fast design thinking.

The remainder of the paper is laid out as follows. Section 2 introduces dual-system theory based on Kahneman's [8] account. Section 3 describes the FBS ontology and how it is extended to represent system 1 thinking. Section 4 presents the empirical studies carried out, including their coding and analysis. Section 5 shows the results of the empirical validation. Section 6 concludes the paper.

2 Kahneman's Dual-System Theory of Thinking

Dual-system theory originates from the 1970s and can be seen as well established with a large amount of experimental evidence in cognitive psychology and neuroscience. It classifies human thinking in two distinct types: one type is fast, automatic and effortless, and the other type is slow, analytic and effortful. Kahneman [8] refers to them as "system 1" and "system 2", respectively, even though they are not linked to different areas in the brain [4]. This is to enable his readers conceptualising them as two different characters with distinct "personalities" rather than as abstract concepts, and thus to facilitate understanding. In this paper, we will also use Kahneman's terms. Most of *Thinking, Fast and Slow* is about system 1. This is because it has more influence on human reasoning than many people would believe. Our beliefs, decisions and actions are shown to be systematically biased rather than to be rational and objective.

It is often difficult to use system 1 in the right "dosage". Kahneman illustrates this with a well-known optical illusion of the kind depicted in image 1. As printed on the page, the three human figures are of equal size. However, the one on the left appears larger than the one on the right. This is because the image contains cues that afford a 3D interpretation, so that system 1 automatically substitutes the question "Are the three figures, as printed on the page, of different size?" with the question "How tall are the three people?" [8, p. 101].

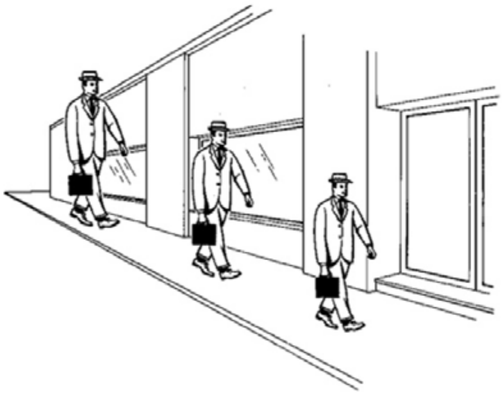

Image 1: Optical illusion: Are the three figures of different size?

This example shows that another characteristic of system 1, that it performs many computations at once, many of which are dependent on the context and cannot be consciously controlled. Kahneman [8, p. 95] uses the notion of a "mental shotgun" to describe this phenomenon.

3 System 1 and 2 in Design Thinking

Design thinking is often viewed as a complex activity that is different from other kinds of human thinking. If design thinking as an elementary process was to be classified into one of Kahneman's modes of thinking, many of its characterisations would suggest it to be system 2 thinking: It is neither associated with an effortless mode of thinking, nor can it be seen as very fast, given that most design processes in industry take place within timeframes of weeks and months, and in some cases several years. Yet, at least for parts of the design process a fast mode of thinking consistent with system 1 does play a role in design.

3.1 The FBS Ontology

The function-behaviour-structure (FBS) ontology [5] has been proposed as a design ontology that describes all designed things, or artefacts, irrespective of the specific discipline of designing. Its three fundamental constructs – function (F), behaviour (B) and structure (S) – are defined as follows:

- *Function* is the teleology of the artefact ("what the artefact is for"). It is ascribed to the artefact by establishing a connection between one's goals and the artefact's measurable effects.

- *Behaviour* is defined as the artefact's attributes that can be derived from its structure ("what the artefact does"). Behaviour provides measurable performance criteria for comparing different artefacts.

- *Structure* is defined as its components and their relationships ("what the artefact consists of").

Humans construct connections between function, behaviour and structure through experience and through the development of causal models based on interactions with the artefact. Specifically, function is ascribed to behaviour by establishing a teleological connection between the human's goals and the observable or measurable performance of the artefact. Behaviour is causally connected to structure, i.e. it can be derived from structure using physical or other causal-type laws or heuristics. There is no direct connection between function and structure. The FBS ontology defines the processes of designing as transformations between function, behaviour and structure. In a simplified view, designing consists of transformations from function to behaviour, and from behaviour to structure: $F \rightarrow B$, and $B \rightarrow S$.

In this view, behaviour is interpreted as the performance expected to achieve desired function. Usually it is unclear whether the structure produced exhibits this behaviour. It must be checked through a separate process whether the artefact's "actual" performance, based on the structure produced and the operating environment, matches the “expected” behaviour. As a result, two classes of behaviour are distinguished: expected behaviour (Be), and behaviour derived from structure (Bs). This extends the set of transformations as follows:

F $\rightarrow$ Be, Be $\rightarrow$ S, S $\rightarrow$ Bs, and Be $\leftrightarrow$ Bs (comparison of the two types of behaviour)

The observable input and output of designing include requirements (R) that come from outside the designer and a description (D) of the artefact, respectively. The FBS ontology subsumes R in the notion of function and defines D as the external representation of a design solution: S $\rightarrow$ D.

Designing is often seen as a process of iterative, incremental development that frequently involves focus shifts, lateral thinking and emergent ideas. Consequently, there are transformations in designing that reformulate previously generated design concepts. This is accounted for by the following transformations: S $\rightarrow$ S’, S $\rightarrow$ Be’, and S $\rightarrow$ F’.

The eight fundamental transformations or processes are shown and labelled in image 2:

1. Formulation (R $\rightarrow$ F, and F $\rightarrow$ Be)
2. Synthesis (Be $\rightarrow$ S)
3. Analysis (S $\rightarrow$ Bs)
4. Evaluation (Be $\leftrightarrow$ Bs)
5. Documentation (S $\rightarrow$ D)
6. Reformulation type 1 (S $\rightarrow$ S’)
7. Reformulation type 2 (S $\rightarrow$ Be’)
8. Reformulation type 3 (S $\rightarrow$ F’)

3.2 Including System 1 Thinking in the FBS Ontology

According to the FBS ontology, there is no direct transformation from function to structure. Yet, Gero [5] states that it "does occasionally exist" in the form of a "catalog lookup". Using system 1 thinking can be considered as equivalent to such a catalog lookup, because it is fast, effortless and does not require any verification of results. The only difference to the common notion of a design catalog [12] is that it is not external but internal to the designer. Kannengiesser and Gero [9] have modelled this view of system 1 by commencing with a simplified view of designing as an input-output transformation: The designer takes requirements as input and produces a design description as output. What happens inside the transformation is hidden inside the designer that is viewed as a "black box".

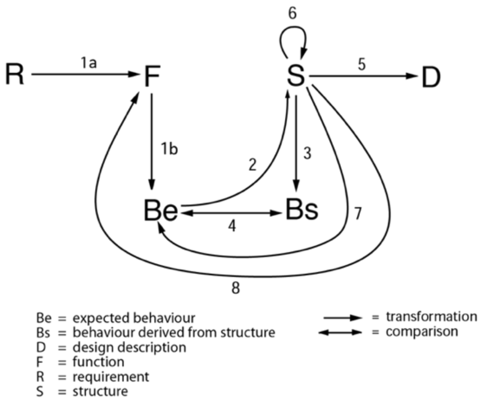

Image 2: The FBS ontology [5]

In image 3 this black box is expanded to show possible pathways from R to D, using the processes defined in the FBS ontology. The entry and exit paths of this process system are the transformations of R into F (part of formulation, process 1) and of S into D (documentation, process 5), respectively. They correspond to activities of interpretation and action that are executed by the designer. In addition to the eight fundamental processes in the FBS ontology, a ninth process (2') is depicted that transforms F into S. This additional process allows distinguishing two basic pathways between the interpretation of R and the action producing D: (1) a direct pathway provided by process 2', and (2) an indirect pathway that involves at least four processes: 1b, 2, 3 and 4.

Since process 2' establishes a direct link between interpretation and action, it can be seen as a reflex – an immediate response to a stimulus without involving any form of reasoning. This corresponds to system 1. The reflex represented by process 2' is based on learning a connection between stimulus and response through previous experiences of the designer. Whenever a pattern in the environment is interpreted that matches a previous stimulus, the associated response is executed as an instant reflex. Examples of pattern matching in architectural design include designing using precedents [3], which can be seen as design catalogues.

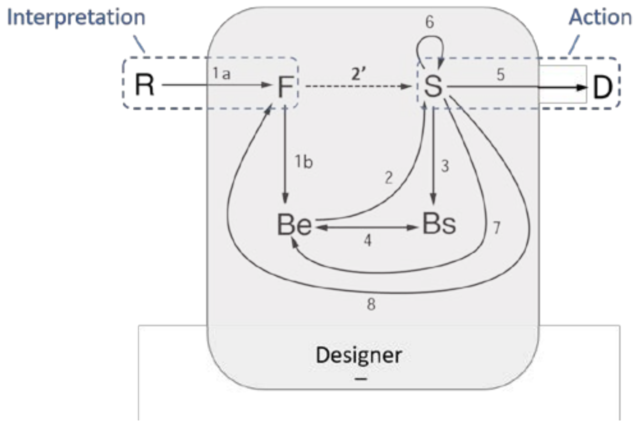

Image 3: Expanding the transformation of R into D, based on the FBS ontology [9]

Process 2' can be thought of as subsuming the set of processes 1b, 2, 3 and 4. It provides a "shortcut" for these processes, using a learned connection between F and S. This increases cognitive efficiency when performing design tasks that address similar Fs. Learning the connection between F and S involves eliminating all intermediate processes that were previously used for transforming F into S.

4 Empirical Studies

4.1 Experiments

Evidence for the existence of system 1 thinking in design (i.e. F→S) has been found when re-reviewing some previous empirical studies [14]. Here we present the results of analysing data from a complete experiment. As part of a project examining differences between professional designers and student designers, sets of design sessions were collected of juniors, seniors and professionals designing to the same set of requirements [2]. Thirteen teams of two freshmen, eleven teams of two seniors and thirteen teams of two professionals formed the source data for the resulting protocol analysis. Since they are collaborating, the team members naturally verbalized without prompting. The student participants were drawn from a convenience sample from undergraduate engineering students at Utah State University. The professionals were drawn from a convenience sample from multiple engineering design firms. Each session was videoed and the participants' utterances were transcribed. The results from this experiment form the basis for the empirical testing of Hypothesis H1 and Hypothesis H2.

4.2 Coding and Analysis

The FBS ontology is used as the basis for a coding scheme for segmenting the transcription of the design protocols and coding every segment as one of the six FBS design issues. An arbitration method was used to increase the reliability of protocol segmentation and coding. It consists of a phase of individual codings by two independent coders, and a subsequent arbitration session to resolve any disagreements in the codings. The arbitrated result, in the form of a sequence of design issues, is then taken as the input for the current analyses.

Relations between two consecutive segments are interpreted as transformations of the respective design issues. They may include design issue transformations that are not defined in the FBS ontology; for example, B→D and R→S. Given the model of system 1 and system 2 in design thinking described in Section 3.2, we are interested in the occurrence of F→S relative to two baselines in the data:

1. Syntactic baseline: Occurrence of any F→X, where X ∈ {R, F, Be, Bs, S, D}

2. Semantic baseline: Occurrence of any F→Y, where Y ∈ {Be, S}

The semantic baseline is a subset of the syntactic one, taking into account only those transformations of F that correspond to processes defined in the FBS ontology extended by system 1 thinking: F→Be and F→S. The occurrence of F→S relative to the semantic baseline is a direct measure for the distribution of system 1 thinking (represented by F→S) and system 2 thinking (represented by F→Be as part of the set of processes subsumed by system 1) in design.

The relative occurrences are then compared using ANOVA, pairwise t-tests and effect sizes.

5 Results

5.1 Occurrence of System 1 Thinking

The average occurrences of F→X, F→Be and F→S for juniors are 16.6 (std dev 5.6) 1.8 (1.5) and 6.9 (2.3), for seniors are 14.5 (4.9), 2.2 (1.6) and 5.2

(3.0) and for professionals are 12.9 (5.6), 3.5 (2.3) and 4.9 (1.6). The percent occurrences of F→S relative to the syntactic and semantic baselines are shown in Table 1.

Table 1: Percent occurrences of F→S relative to syntactic and semantic baselines (standard deviations in brackets)

	F→S relative to the syntactic baseline (%)	**F→S relative to the semantic baseline (%)**
Juniors	45.0 (15.6)	80.7 (10.4)
Seniors	33.1 (15.9)	66.0 (27.9)
Professionals	40.5 (7.8)	64.1 (17.7)

The results show that system 1 thinking, in the form of F→S transformations, is used substantially in all three cohorts. For the syntactic baseline its relative occurrence is at least 33.1% (in the "seniors" cohort). With respect to the semantic baseline, the majority of design thinking is system 1 thinking, with a minimum of 64.1% (in the "professionals" cohort).

This confirms Hypothesis H1, stating that design thinking comprises system 1 thinking and system 2 thinking.

5.2 Differences in the Use of System 1 Thinking between Students and Professionals

A one-way ANOVA shows that there are no significant differences between the three cohorts, neither with respect to the syntactic baseline ($F(2, 32) = 2.297$, $p = 0.117$) nor to the semantic baseline ($F(2, 32) = 2.519$, $p = 0.096$).

No significant differences were found between the cohorts except for juniors vs. professionals regarding the occurrence of F→S relative to the semantic baseline, using a pairwise t-test.

The effect sizes, calculated using Hedges' g [7], between the three cohorts resulted in large effect sizes between the juniors and versus seniors for both syntactic and semantic baselines, and for juniors versus professionals for the semantic baseline. The effect size was small or medium elsewhere.

Professionals use system 1 thinking less often than juniors, with an average of 64.1% for professionals against 80.7% for juniors and 66.0% for seniors for the semantic baseline. All other comparisons between professionals and students (including seniors and juniors) reveal no significant differences. These results contradict Hypothesis H2, stating that design professionals use system 1 thinking more often than design students.

6 Conclusion

The empirical results presented in this paper show that system 1 thinking is used in design and plays an important role based on its relative occurrence. It confirms previous observations and characterisations of design processes that led to the formulation of Hypothesis H1, which stated that design thinking comprises system 1 and system 2 thinking. Further analyses of existing protocols or results from new experiments are needed to have robust support these two conclusions.

Obtaining empirical evidence for system 1 and system 2 thinking in design addresses a number of research issues relevant for design researchers and practitioners:

- It fills a gap in current models of designing that do not account for, and even discourage, the use of system 1 thinking in design.
- It substantiates claims about the locations of system 1 and system 2 thinking, respectively, in the design process.
- It indicates where new methods and tools potentially to be drawn from cognitive psychology may be useful in the design process.
- It contributes to research in design expertise, by clarifying whether system 1 thinking is an effect of growing design experience.

The last issue in this list is associated with Hypothesis H2, which stated that professionals use system 1 thinking more often than students. This hypothesis was not supported by the empirical data. This is an unexpected result, because professionals are assumed to have grounded more experience that they can readily use to get from F to S by default. A possible explanation could be that the chunks of knowledge professionals build up are much bigger than students' chunks [10], in combination with the ability to generalise from specific experiences [6]. As a consequence, professionals need less cognitive processing and therefore fewer transformations including from F to S. Using Kahneman's [8] terms, professionals have a bigger "mental shotgun" with larger pellets, which might not need to be fired as often to have the same effect as that of a student. More research is needed to explain the connection between system 1 thinking and the role of expertise in design.

The research method used in this study can potentially be applied to a large set of existing design protocols coded using the FBS design issue schema. This means that new insights can be gained without having to run new experiments. Possible comparisons can be made regarding the use of system 1 and 2 thinking across different design disciplines, tasks and methods.

Acknowledgement

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Exploration of gender diversity effects on design team dynamics

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Abstract

This article introduces and applies a methodology to analyze the effect of team diversity on team design cognition. We explore team diversity in relation to team members' gender. We studied two types of teams: heterogeneous teams composed of one female and one male mechanical engineering student and homogeneous teams of two male mechanical engineering students. We analyzed 28 design protocols using the Function-Behavior-Structure ontology to code protocols and measure team cognitive design behavior. We found that male design students in the mixed teams tend to dominate the design activity. Also, we found that mixed teams showed significantly more co-design activity compared to male only teams.

Keywords: genders, design cognition, co-design, protocol analysis

1 Introduction

Design team interactions, related to designers' participation in their co-design activity, their expertise and leadership, affect the design outcome and shape the design process itself [1]. In collaborative design, the cognitive effort is not only on the design task but also on the organization of the group process to structure the activity [2]. Studies of co-design using protocol analysis [3] have addressed a wide range of concepts such as differences between individual and team design [4], co-located design versus distributed design [5], the impacts of the use of different media environments [6], [7] and the development of team expertise [8]. In this article, we propose a method to study the effect of design team characteristics on the design process. Our method focuses on the diversity in design teams and its effect on the design teams' behaviors both at the individual and group levels. To illustrate our methodology, we address the question of team gender homogeneity and heterogeneity. According to gender stereotype beliefs, men tend to display a self-directed and agentic behavior, compared to women who are associated with a more communal and cooperative behavior [9]. Although the outcomes of studies on gender effect on creativity often show a lack of differences between men and women [10], popular conception of creative thought processes related to divergent and innovative thinking is associated with masculine-agentic characteristics [11]. Personality traits have been found to affect team's creativity and the diversity of team members personalities can increase the teams' creativity performance [12]. Gender diversity can also influence individual contribution to the team mixing females' ability to be process oriented and males' capacity to be task oriented. Mixed teams performance could be improved with skills diversity although some studies showed no effect of team gender diversity on design performance [13].

In this exploratory study, we will focus on the design process itself rather than the creativity or the quality of the outcomes. We analyzed differences between two cohorts of mechanical engineering undergraduate students: one cohort consists of teams with two male members and the other cohort consists of teams with one female and one male member. To study team behavior at the individual and team level from both quantitative and qualitative viewpoints, a protocol analysis is carried out on our dataset. The protocol analysis uses the situated Function-Behavior-Structure (sFBS) ontology [14], [15] articulated for collaboration and co-creation as a theoretical framework. The significance of the work presented in this paper is two-fold: we present a method to quantitatively measure and qualitatively represent differences in the co-design activity of different teams and we provide evidence of gender diversity effects on team co-design.

In the following section of the paper we introduce our theoretical framework, the FBS ontology and the sFBS co-design model used to encode our protocols, measure and represent the co-design activity. The methodology and the experiment are also presented in that section. In the third section, we focus on the initial results of gender diversity effects on team design. Finally, we discuss the suitability of our method to study not only gender diversity effects on team design behavior but any characteristic of team diversity such as expertise, design domain or team size.

2 Design framework, data description and methodology

2.1 FBS ontology and sFBS co-design model

The framework used in this research to study design cognition is the FBS ontology [14], [15]. The FBS ontology describes concepts called "design issues" about the design artefact: a Requirement (R) includes the design brief and norms; a Function (F) represents what the design object is for; an expected Behavior (Be) illustrates design intentions in terms of how it behaves; a Structure (S) is defined by elements or group of elements of the design object; a Behavior derived from structure (Bs) accounts for how the object behaves based on an existing design Structure (S) and a Description (D) is an external representation of the design object (Fig.1). The FBS ontology also accounts for design processes that are the transitions from one design issue to another: Formulation, Synthesis, Analysis, Evaluation, Documentation, Reformulation 1, Reformulation 2 and Reformulation 3.

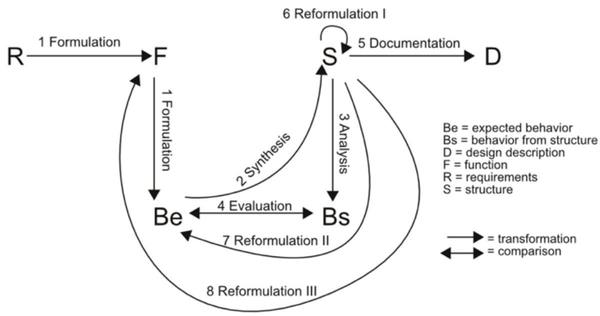


Figure 1. FBS framework (based on [14])

Design is a situated activity, at a social level and a personal level. The social level implies that the design activity is dependent on external inputs generated by other parties involved in the design process, social and cultural habits. The situatedness at a personal level implies that designers advance in the design process by referencing their past design experiences, referred to as design repertoires [16], schemata [17] or prototypes [14]. The situated FBS framework accounts for the situatedness of designing and expresses Schön's concept of design as reflection-in-action activity [19]. The situated FBS model divides the world into three (Fig.2). In the external world, the design object is represented by an instance of (R), (F), (B) and (S) and is outside of the designer. The interpreted world is personal to the designer and represents his/her own interpretation of the design object. The expected world sits within the interpreted world and represents the designer's intentions and predictions of what the design object could be. In both the expected and interpreted worlds, the design object is described by an instance of (F), (B) and (S). Transitions from one world to another is carried out by four processes. The design object in the external world is interpreted by the designer (process 1 Fig.2) and can be adjusted with existing design concepts from the designer's experience by a constructive memory process (process 2 Fig.2). The interpreted version of the design object can lead to a focus to alter design expectations (process 3 Fig.2) that can provoke an action on the external representation of the design object (process 4 Fig.2).

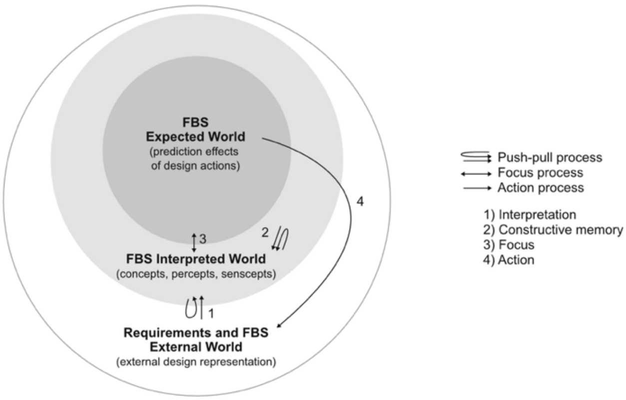
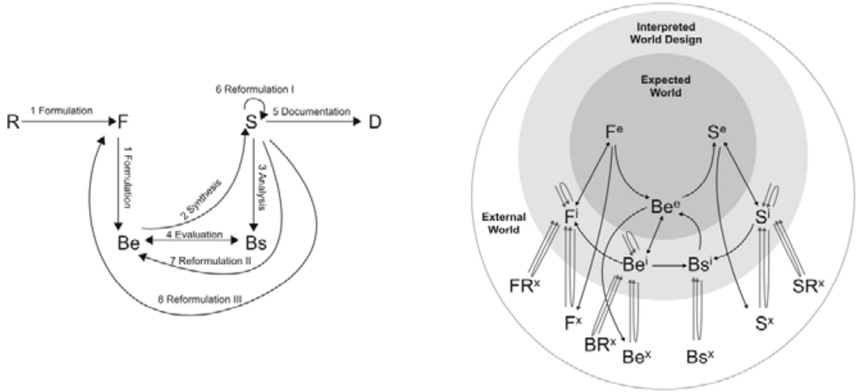


Figure 2. Situated design framework (based on [15])

Each of the eight design processes from the FBS ontology (Fig.3(a)) are mapped onto the situated design framework (Fig.3(b)). The diagram expresses situated design process of a single designer (see [15] for more details). In the sFBS framework we consider a co-design process, an FBS process that starts with a design issue formulated by one designer, followed by another design issue enacted by another designer. For instance, a co-constructed FBS analysis process would imply that designer A formulates a design Structure (S) that designer B analyzes by formulating a Behavior derived from that structure (Bs). The model is commutative which implies that designer A's actions are potentially similar to designer B's actions (Fig.4). Nonetheless, the situatedness of the design activity entails that designer A and designer B will potentially react differently to what their team mates do.



(a) (b)

Figure 3. (a) FBS framework, (b) situated FBS framework (based on [15])

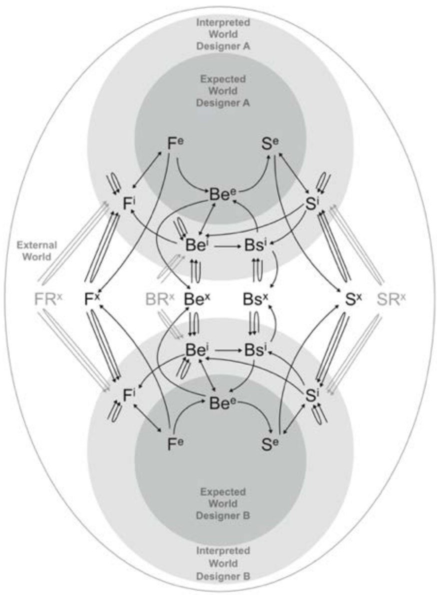


Figure 4. Situated sFBS co-design model

2.2 Data description

The source data for this study is two cohorts of undergraduate mechanical engineering students from a state university in Utah, USA, working on the same design task in teams of two: homogeneous teams are composed of two male students, and heterogeneous teams are composed of one female and one male student. A total of 10 heterogeneous teams and 18 homogeneous teams were analyzed for this study. The sample data used is taken from a wider study on mechanical engineering design (see [19]). The task was the design of a window lifter and each session lasted around one hour.

2.3 Methodology

Each co-design session was video-recorded. We ran a protocol analysis on our dataset using the FBS ontology [14], [15]. Each protocol was coded twice by two different coders who then arbitrated to produce the final coding to ensure data reliability. Rather than using Cohen's kappa we measured coding reliability by comparing each coder with the arbitrated coding which gave an average of 85% agreement. Each segment of the protocol is coded with one of the six design issues and with the speaker of the utterance (designer A male or female and designer B male). A double coding system (FBS design issues and speaker) was applied in order to measure the distribution of design process for four possible interactions: student A to student B, student B to student A, student A to himself/herself and student B to himself.

A t-test analysis and the effect size between the two teams' conditions provide statistical results of differences between the two cases. The t-test aims to test the hypothesis that our two cohort samples can come from the same sample data. For the effect size analysis, we used Cohen's D value to measure the magnitude of the significant differences we found between our two cohorts. A correspondence analysis covering the designers' interactions and the FBS design processes is carried out to provide a categorical basis for comparisons. To obtain a qualitative understanding of co-design processes for each cohort, we represent dominant processes on our sFBS co-design model.

3 Results: revealing diversity in team design cognition

For each of the 28 protocols, the distributions of individual and co-design processes were measured. Design processes are quantified based on syntactic relationship from one segment to the next, adjacent segment. A formal design process is counted when the transition from an FBS design issue to another of the FBS design issue represents one on the eight design processes defined in the FBS ontology (Fig.1). Otherwise, the transition is not considered a formal design process, although it is part of the design activity. For each design process, a speaker transition is associated from the four possible speaker transitions: student A to student B (A>B), student B to student A (B>A), student A to herself or himself (A>A), student B to himself (B>B). A co-design process is accounted to be an FBS design process co-constructed by the two students (A>B or B>A). Any other design process constructed by only one of the two students (A>A or B>B) is considered an individual design process.

3.1 Gender's diversity effect on individual design process

For each FBS design process formulated during a session, which represents between 60 and 70% of the overall protocol segment transitions, we looked at the associated designer's transitions (A>A, A>B, B>A and B>B). For the all-male teams, we observed that there is always a dominant or more involved student in the individual design participation and a less dominant one. For these homogeneous teams, the normalized distribution mean for the dominant student in individual design processes is 54.1% (SD=10.4) whereas the normalized distribution mean for the less dominant student in individual design processes is 30.4% (SD=7.9). When we looked at the heterogeneous teams, we found that for 80% of the cases, female students were the less dominant student in the formulation of individual design processes than their male counterpart. Individual design processes for female students in heterogeneous teams have an average of 34.3% (SD=11.5) whereas their male team mates' distribution mean for individual design processes is 44.7% (SD=12.1).

In order to explore if male students design behavior was different depending on the gender of their teammate, we conducted a t-test analysis between male to male design process distribution in mixed teams (mean= 44.7, SD=12.1) and dominant male to male design process distribution in all male teams (mean=54.1, SD=10.4). The p-value (0.055) supports that there is no significant difference in male students' distribution of individual design processes depending on the gender of their teammate. To obtain a more qualitative understanding of female and male students' design behaviors, we used a correspondence analysis between students' gender and individual mean distributions of FBS design processes (Fig.5). The results of the correspondence analysis cover the entire data variance (Dim 1 = 71,2% and Dim 2 = 28,8%). In our dataset, there were three possibilities regarding individuals and team mates' gender: females co-designing with males (F>M), males co-designing with females (M>F) and males co-designing with males (M>M). Each type of co-design appears in a different quadrant of the correspondence graph, that highlights relative differences concerning the design processes each individual uses (Fig.5). Females sit in the same quadrant with Reformulation 2 and Analysis. Males in heterogeneous teams and males in homogeneous teams sit in opposite quadrants on the graph. The former is in the same quadrant with Synthesis whereas the latter appears to be related with Evaluation (Be>Bs).

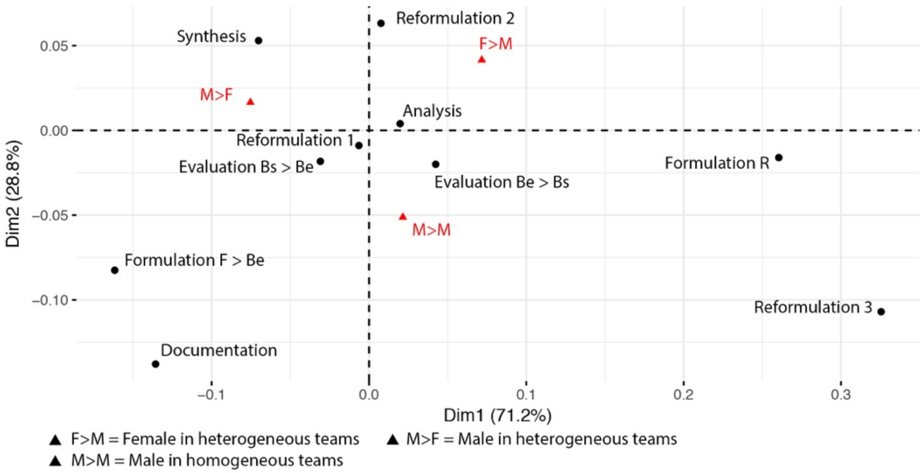


Figure 5. Correspondence analysis of design process and students' gender

3.2 Gender's diversity effect on co-designing

The normalized mean values of design processes from the two cohorts show that the distributions of individual design processes is similar for the heterogeneous teams (52.8%, SD=4.8) and the homogeneous teams (52.7%, SD=4.7). The distributions of co-design processes for heterogeneous teams is almost 1.5 times higher than homogeneous teams, (14.1%, SD=2.7, for heterogenous teams and 9.7%, SD=2.8, for the homogeneous teams). The t-test and effect size analysis on the design processes distributions show that the difference of distribution of co-design processes is significant between the two cohorts (Table 1). The p-value from the two tailed t-test on the co-design processes distribution is less than 0.05 that implies a significant difference between the heterogeneous and homogeneous teams concerning the distribution of co-design processes. The Cohen's D value of 1.6 shows a very large effect size and confirms the strength of the significant difference between the two cohorts.

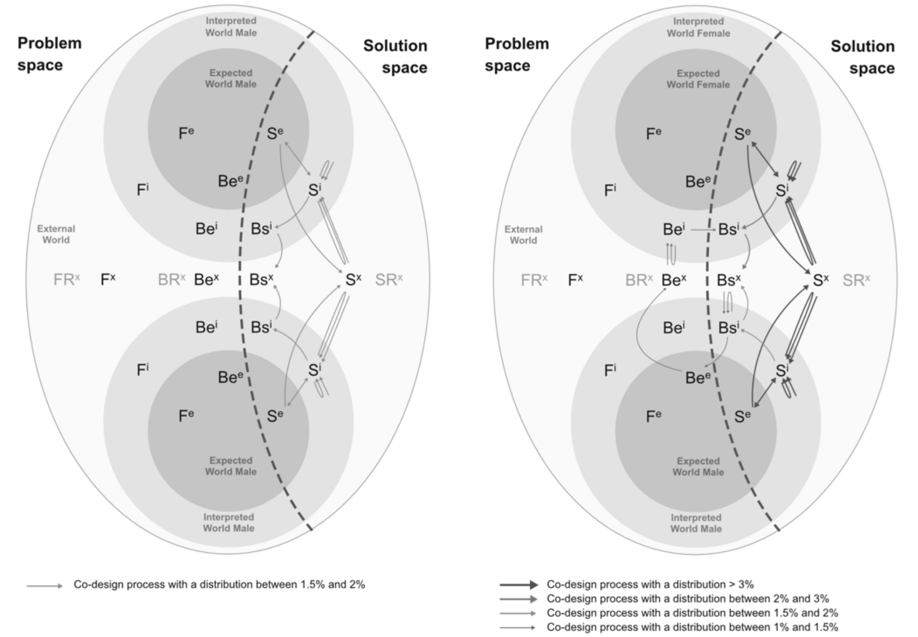
Table 1 – T-test and effect size of design processes between the two cohorts

	Significance (t-test p-value)	Effect size (Cohen's D value)
Co-design	**0.0007**	**1.6**
Individual design	0.96	0.0

3.3 Qualitative exploration of co-design behaviors

Our sFBS co-design model gives a qualitative representation of co-design processes from which quantitative data can be derived and acts as a baseline to compare diverse co-design situations. Our model accounts for 22 potential co-design processes. We used the sFBS co-design model to represent dominant co-design processes for homogeneous teams (Fig.6(a)) and heterogeneous teams (Fig.6(b)). The normalized distribution for each co-design process varies between 0.0 and 2.7% of all sFBS design processes of the homogeneous teams and 0.0 and 3.7% of all sFBS design processes of the heterogeneous teams. In our sFBS co-design diagrams, we used a threshold of co-design processes that represent more than 1.0% of all sFBS design processes (i. e., at least 5 occurrences in a session) and did not consider processes with a lower occurrence level.

For homogeneous teams, both participants (males) have identical co-design behaviors. The co-design activity is uniquely set in the solution space, where designers either analyze or reformulate existing design structures (S). For heterogeneous teams, females (represented on the top of Fig.6(b)) and males (represented on the bottom of Fig.6(b)) display a different co-design behavior. For both, the reformulation of a design structure (S) formulated by the other into another design structure (S) is the dominant co-design behavior. Co-analyzing is also a frequent process they execute. We also observe co-constructed evaluation processes that were not present for heterogeneous co-design behaviors. Evaluation is the comparison between an existing design behavior (Bs) and an expected design behavior (Be), or inversely. In the heterogeneous teams, females tend to compare expected behaviors (Be) formulated by their male teammate to an existing behavior (Bs). While males tend to compare existing behavior (Bs) formulated by their female teammate to an expected behavior (Be).



(a) (b)

Figure 6. (a) sFBS co-design processes for homogeneous teams (b) sFBS co-design processes for heterogeneous teams

4 Discussion

We introduced a tool based on the sFBS ontology that gives quantitative measurements of co-design behaviors for different design situations. One strength of this tool is its capability to reveal the effect of diversity in team design. To explore this dimension, we looked at gender diversity and found design behavior differences between two cohorts: homogeneous teams of two male members and heterogeneous teams of one female and one male member. Popular gender beliefs depict male and female with different personality traits, associating design creativity with masculine-agentic characteristics more than feminine-communal ones [9], [11]. Although our study's focus was not on design creativity, we expected to observe differences in the design processes and team dynamics between our two cohorts. At the individual design level, we found that males in heterogeneous teams dominated the activity in terms of the quantitative production of design processes. Co-designing during the design session was significantly higher for heterogeneous than for homogeneous teams. Looking in more detail at the type of co-design processes dominating the sessions, we found that heterogeneous teams display a much richer set of co-design processes compared to homogeneous teams. Our findings align in a general way with gender stereotypes, but further experiments with all female teams should be carried out and analyzed before drawing any general conclusion on gender effect on team design. Indeed, the increase of collaboration in teams with female could be because those teams are heterogeneous not specifically because there is a female in the team. The design domain in which the experiment took place, mechanical engineering design, is dominated by male students. Different design domains where the percentage of female students is higher and greater than 50%, such as architecture or fashion, should be studied as well, to provide for a fuller understanding of the effect of gender in design teams. However, the research reported in this paper provides specific results of the effect of gender diversity in teams on which to build further.

This study of team dynamics related to gender diversity was also a means to explore and assess the relevance of our methodology to reveal differences in the design process linked to the concept of diversity. Our future work will consist of deepening our understanding of gender diversity effect on design and co-design and also exploring how other diversities affect team design processes, such as design domain, team size or teammate expertise.

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Handling Human Factors in Car Interior Design

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Abstract

This research delivers - into the automotive industry - an automated pattern generating system by connecting human emotions with basic geometric elements and geometric transformation. The main task is to understand human behavior, and to model it with the goal of providing it as consumer's preference into the EmPatGen software.

Keywords: emotion design, pattern generator, automotive industry

1 Introduction

Studies introduce that product appearance has aesthetic, symbolic, functional, ergonomic, attention drawing and categorization values [1]. However, all of these are influencing the consumers choice regarding products, results have shown that customer needs are shifting into the direction of **aesthetic design** instead of functional capability [1] [2].

If we talk about products, it is essential to examine the 'product experience', that contains physical actions, perceptual and cognitive processes (perceiving, remembering, using and so on) as well [3]. Because of this, nowadays in the automotive industry it is also important to understand **psychological aspects** next to functional.

Besides that, **customization** is becoming more and more popular in the automotive design, and with configuration and customization software, this is easier and easier to accomplish. In the consumer's perspective, this connection is direct, not indirect, which can increase the user-experience.

Last but not least marketing is extending to user emotion, since "emotion can stimulate buying interest, guide choices, arouse buying intentions, and influence future buying decisions" [4].

2 Research goal and ARC diagram

This research is dealing with patterns on interior trim pieces with the goal of **helping designers to create the most suitable pattern** depending on various consumer preferences. These preferences are often hidden, however if we link human emotions to basic geometric elements and geometric transformations, it is possible to develop a pattern generating software that creates patterns according to given emotions. (Figure 1.)

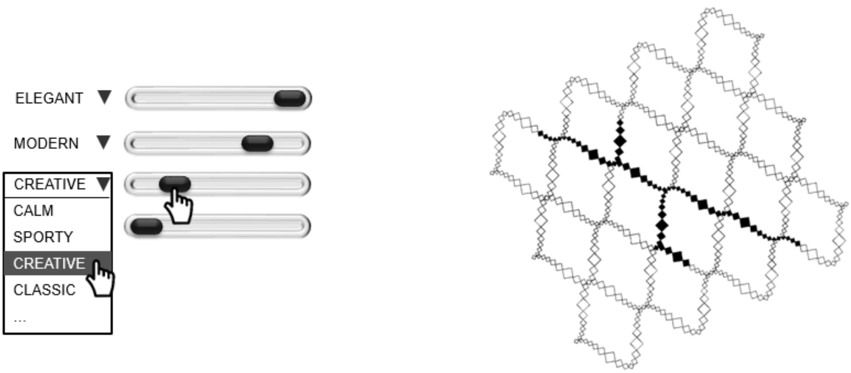

Figure 1. Usage of EmPatGen

The result of this research would give an **emotion based automated pattern generating software**, called **EmPatGen (EMotional PATtern GENerator)** in order to help designers to create the most aesthetically-pleasing pattern on car interior elements. The consumers provide preferences (emotions, feelings, moods, attitudes) - from a defined database – and rate them, while the EmPatGen software automatically generates a 2d DXF pattern according to the input data.

From the product designers view, this method is much more grounded than an intuition, that is why the **hypothesis** of this research is that product designers with this tool are able to provide more aesthetically-pleasing interior design in the car than without it. The **basic assumption** is that if product designers are supported by this system, they will be able to transform emotions into patterns on the surface of interior elements of cars in order to satisfy consumer-specific needs.

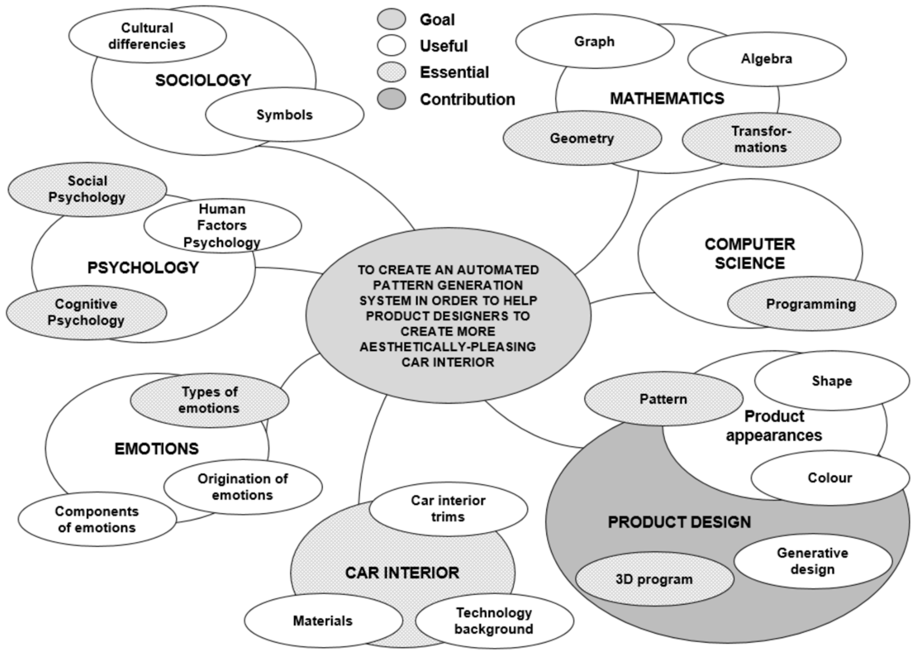

Figure 2. ARC diagram

To understand better the related topics of this research, Areas of Relevance and Contribution diagram (ARC diagram) has developed (Figure 2.). The diagram also distinguishes the directly relevant topics [5].

The research questions are: What emotions do shapes and patterns evoke? For this question qualitative and quantitative researches are already done: almost 700 survey answers and 3 focus group interviews. What are the steps of the new pattern generator process? [6] How to connect emotions with shapes and patterns? Does this tool help the designers to provide more aesthetically-pleasing car interior?

The application process has two main tasks. The first step is the usage of EmPatGen, followed by the usage of a technology that can place the pattern on the required car interior element. A possible solution for that is the laser texturing technology. For this machining only the output of EmPatGen, the 2D DXF pattern is needed, and with the laser texturing software we can easily set the depth etc. The main idea behind this is that instead of using the laser on molds, if we use it directly on the car interior panel, it could generate totally unique parts. (Figure 3.)

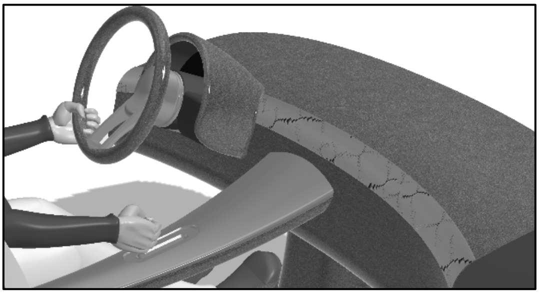

Figure 3. Application according to the pattern of Figure 1.

3 FBS model

For this research we adopted a method called Function-Behaviour-Structure (FBS) model. [7] Figure 4. shows the original concept.: Product development / design is a transformation of requirements or needs into the description of solution [7].

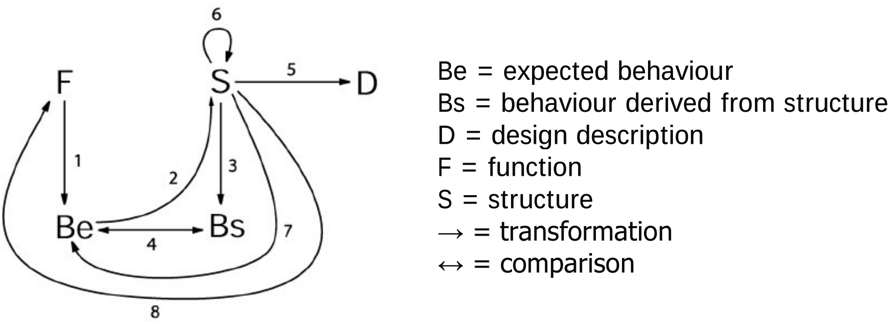

Figure 4. FBS model [7]

A few changes were applied to the model: we are using → sign for actions, and we also changed the S – structure to T – tool. In our understanding "Behaviour" is the end user's behaviour. And finally, our model is not using action 8, since there is no chance to change the basic requirements of end users. (Figure 5.)

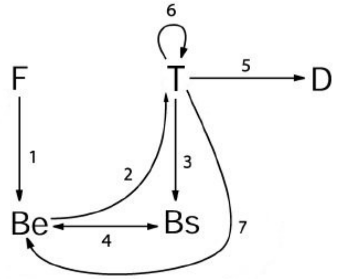

Figure 5. Modified FBS model

In this research

- The 1. action is a process of gaining data from consumers by both qualitative and quantitative research techniques, in order to discover the full picture of the study [5]. "Be" is a collection of emotions, feelings, moods and attitudes that are connected to basic geometric elements and functions.

- The 2. action is to program a mathematical model and pattern generating system. "T" is a tool that creates patterns according to the given preferences.

- The 3. action is an emotion based evaluation of shape and pattern. For this we are planning to use different types of techniques, for instance eye tracking, face detection software, and physiological signal meters. This information should be transformed into pairs ("Bs") similarly to the case of "Be".

- The 4. action is a comparison between "Be" and "Bs".

- Action 5 is the documentation process of the results.

- In action 6 it is necessary to test the program with designers, in order to improve the model according to their insights.

- In the 7. action we can modify the subdivisions of emotion groups.

4 Research, fuzzy system and pattern generator

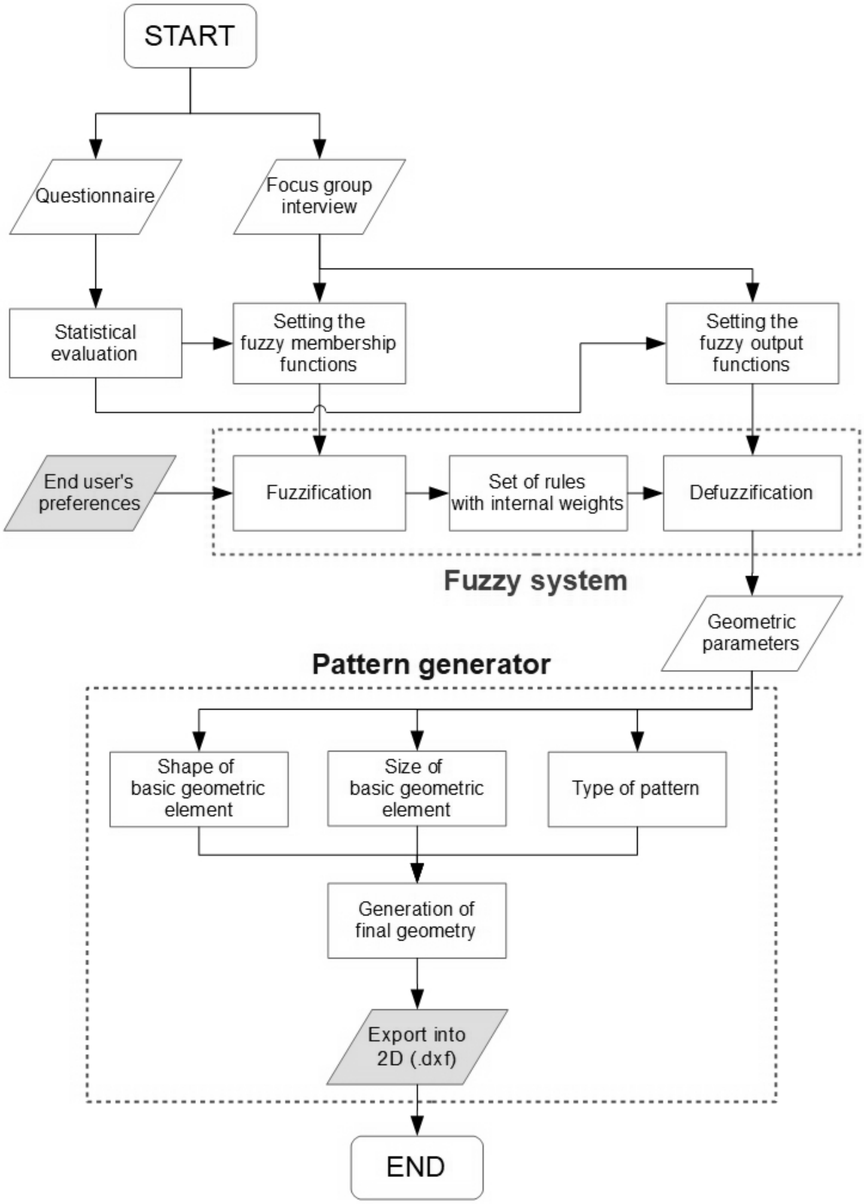

Figure 6. Flowchart

In this research one of the main tasks is to understand the human behaviour, especially the emotions caused by patterns. For this, different methods can be utilized, such as focus group interviews and questionnaires. With this information it is possible to define a fuzzy system, that is always changing according to the end user's preferences. Since we know, what type of geometries are in connection with different feelings, if we have inputs on the requirements of end users, we are able to provide outputs in the form of patterns. Figure 6. represents a more detailed flowchart about this, and that is the background theory of the “T – tool” in Figure 5.

5 Understand the human behaviour

To understand the human behaviour, first of all focus group interviews and after that questionnaire techniques were used.

5.1 Focus group interview

During the focus group interview, the participants analysed patterns in several aspects. The patterns were made with MatLab software. During the editing process, the aim was to use the simplest geometries (circle, rhombus, triangle, hexagon) and functions (sinus, tangent, absolute value). In total 14 patterns were used, which were placed on a grey notebook. (Figure 7.) (There were variations, where the diameter of basic geometry was changed, and also there were pattern with translations of basic geometry.)

1 2 3

Figure 7. A few example of the used patterns

5.1.1 Task 1.

During the first task, the participants answered the following three questions by examining the patterns one by one:

1. What is it similar to?

2. On what kind of product would you like to see the pattern?

3. In what colour can you imagine it?

The participants provide similar answers and products. A few answers of patterns of Figure 7. can be seen in Table 1.

Table 1.

1	wave, curtain, mineral water bottle, sink sponge
2	cookie coating, wheat ear, bakery bag
3	pine tree landscape, mountains, Christmas wrapping paper, tea

5.1.2 Task 2.

I would have liked to gain responses for these questions:

- What is the effect of changing only the basic geometry?
- What is the effect of changing the pattern “line” / function (with the same basic geometry)?
- What is the effect of resizing within patterns?
- What is the effect of the pattern translation?

For this, pair-comparison method was used with these questions:

- Which has bigger effect?
- Which is more static, which is more dynamic?
- What difference would you make?

There were some cases where the participants’ responses can be divided by their gender, and also in some comparison where everybody gave the same answer.

5.1.3 Task 3.

In the 3. exercise participators associated emotions to patterns.

There are so-called basic feelings [8] (sadness, excitement, nervousness, joy, anger, disgust), and more complex, higher-order emotions (e.g. social, moral, aesthetic, etc.) [9]. Emotions affect sound transfer, mimicry, gesture, however, each emotion differs from being recognized better by sound or facial mimicry [9] [10]. Based on the MPEG-4 standard [11], the basic emotions in the field of machine processing are joy, sadness, anger, fear, surprise, and disgust, which are used for facial description of virtual characters. However, in the case of automatic emotion recognition, they may also appear simultaneously or may be combined in different ways, which must also be taken into account [10].

Based on the literature research - merging the "basic feelings" and the emotions used in machine processing -, seven following emotions were determined and "emotional cards" were made from them: sadness, excitement, nervousness, happiness, anger, disgust, fear, surprise.

In this task participants provided mainly different answers, however if we divide the emotion into groups of positive and negative meanings we can find similarities.

5.2 Questionnaire

The focus group interview was the base for the questionnaire, and basically with this quantitative research method the result of the interview was verified.

In the last questionnaire, 152 people participated. It contains four types of questions, and two of them can be seen in detailed in the next chapters, since those provided adequate information.

5.2.1 What is in the box?

In this type of question indirect method was used, thus instead of asking that what people think about the pattern (for example Figure 8.), we questioned that what can be in the box, and three possible answers (here: sweets, Christmas ornaments, book) were given for that. One from them was an answer which is refer to the results of focus group research (here: Christmas ornament).

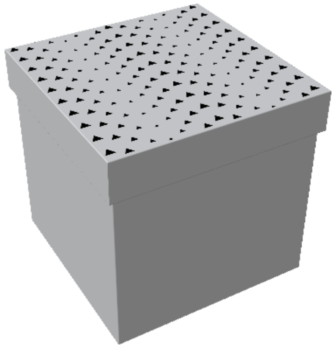

Figure 8. What is in the box?

In perspective representation unfortunately a 2D pattern sometimes loses its character, however in other cases 65-70% of the outcomes verified the result of the focus group interview.

5.2.2 Which one is more dynamic?

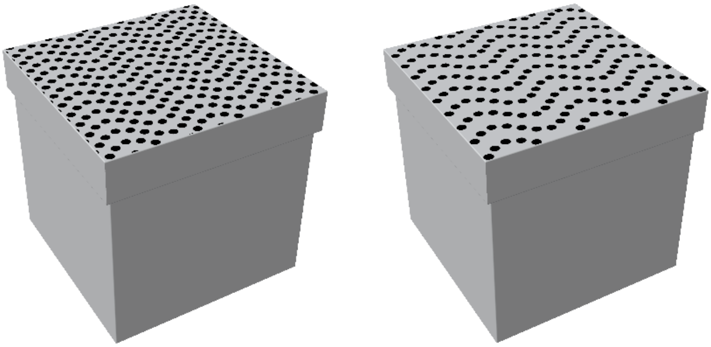

Figure 9. 1. Which one is more dynamic?

Figure 10. 1. Which one is more dynamic? - Result

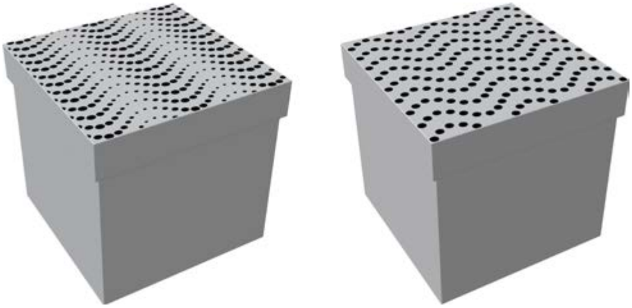

Figure 11. 2. Which one is more dynamic?

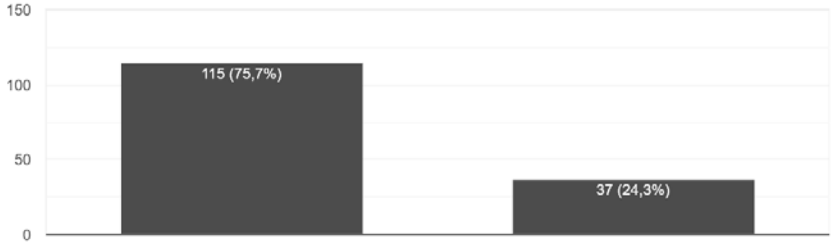

Figure 12. 2. Which one is more dynamic? - Result

In this question (Figure 9., Figure 11.), the participants should have chosen an option. It turns out that the reduction in the distance between the pattern "lines" is more dynamic, however there is not much differences. As opposed to this, the change of diameter of basic geometries is much more dynamic. (Figure 10., Figure 12.)

6 Summary and outlook

The results of the research have proved the concept, that although the motivations and experiences of the people may differ from each other, nevertheless a form or patterns can have a similar effect on them. The results are also applied for the fuzzy system, which is the next step in this research.

This idea is basically designed for individual production, but if a method becomes scalable it could be applied to serial production as well. Since in design aesthetic elements are developing, and becoming more important, this can be utilized by a car brand as a support tool which has effects on the designers and end users.

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Digitalization of society: what challenges will users meet?

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Lecture summary

The term digitization refers to the technical process through which analogue information is transformed into digital information that can be processed by digital technology ([1], [2], [3]). Meaning that the information becomes structured, searchable, and accessible through digital channels. Digitalization, however, should be regarded as manifold, socio-technical phenomena, with processes of adopting and using these technologies taking place within broader individual, organizational, and societal contexts [3].

There are great expectations and worries of the impact digitalization will have on individuals both in working life and on daily living. This involves various sectors such as industry, health and welfare, and the service sector. The challenges consist in meeting different kinds of user needs, by employees in companies and public sectors, caregivers and caretakers in healthcare, and users that are dependent on technology in daily life duties, such as paying bills etc. The presentation will discuss from a user perspective how design and design thinking can contribute to identify what the requirements are on the future technology, instead of on the user´s adaption of the technology. At a first glance, the requirements from healthcare and manufacturing industry regarding user-friendly technology seem very different, or divergent, but from a user perspective, we can identify several similarities that could be beneficial to develop from a more general approach.

Big global companies and many small and medium-sized companies are equally facing a major change due to digitalization. The transition requires investments in equipment and development, in production processes and methods, as well as new products and business models for distribution and aftermarket. New work processes and tools/support in production and production development place new demands on the competence of management and employees in the production and in R&D.

In a recently started multidisciplinary project, design thinking will be used to frame the challenges and the need for change within the companies. There is an insufficiency of knowledge both in the promotion system and in the companies in how to develop their business, their processes, products and services from a user-driven perspective. The aim is to support the project and the partners in developing their own skills in design thinking, and in improving the methods and working methods we use in the collaboration with the companies, making them more user-adapted.

New work processes and tools are also required in healthcare, a sector that is facing a shortage of employees in a near future. The ongoing discussion regarding replacement of staff by robots and other technology in healthcare has started an ethical debate and has highlighted the importance of identifying and focusing on both primary users and secondary users. The challenge in this context is that there is, and even more so in the future, an oscillation between the primary and secondary users related to the context and situation. How can design and design thinking contribute to a holistic perspective regarding framing and identification of different perspectives in designing and using of single products or systems?

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New realities for old limitations

Using Virtual Reality to match the appearance of technical installations with landscapes

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Abstract

The paper investigates the usability of Virtual Reality (VR) for the evaluation of technical installations in areas of particular natural interest, which is extremely relevant for the authors' region. The consideration of VR for evaluating the harmony of installations and the landscapes is due to impossibility to use physical prototypes to the scope. An unchanged container and three designs to disguise it aesthetically have been tested in a VR-supported experiment involving 12 volunteers. All of them were requested to evaluate the alternatives and their experience with VR by means of user experience questionnaires. The results show that the experience with VR does not affect the indication of preferences and it is therefore claimed that VR can be used beneficially in these circumstances.

Keywords: Virtual Reality, user-product interaction, technical installations, PANAS

1 Context and research question

In many circumstances, people's needs and expectations conflict with the preservation of the natural environment, which gets more and more designed. An example faced in mountainous areas is the use of technical installations, e.g. for the production of artificial snow, whose typically “mechanical” aspect might negatively impact on the perceived beauty of the surrounding landscape. Measures can be taken to change the appearance of technical systems in order to harmonize them with the environment they will operate in. This measure, besides being seemingly deceptive, gives rise to many problems in designing and testing various concepts of technical installations – resources to be spent are potentially huge. Virtual Reality (VR), increasingly employed to verify human perception in environmental planning [1, 2], can represent a supportive technology also when mechanical systems are in play [3]. The reliability of VR for this field of research and applications is the primary concern of this study.

More specifically, the authors aim to verify the usability of VR technologies for the appraisal of candidate appearances of installations positioned in a virtual mountainous environment. In particular, as VR systems might affect people’s comfort, this contribution intends to verify whether the use of VR significantly influences human behavior and consequently their choices and evaluations. More formally, the research question is the hypothesis that follows.

H0: people’s individual experience with VR affects their preferences and choices.

2 Materials and methods

2.1 Main features of the experiment and participants

The experiment designed to address the research question has involved 12 subjects, 7 males and 5 females, aged between 18 and 38 at the time of the experiment (mean 27.7, SD=5.4). Still at that time, all of them studied or did research in South Tyrol, Italy, which is a known Alpine region for which mountain tourism (both in the summer and in the winter) represents a fundamental economic driver. The relationship with the territory was supposed to motivate the interest for safeguarding the beauty and the attractiveness of mountain areas. The involved subjects participated in the experiment voluntarily with no reward. Most of them were curious to test VR for the first time, while others were willing to repeat this experience; nevertheless, none of them is used to employing VR regularly for their study or research.

The participants, while using VR (Subsection 2.2), were asked to rate and evaluate four alternative concepts for technical installations in a mountain area (Subsection 2.3). The liking of the landscape was scored before the alternatives were clearly visible – to this respect, the participants had to rate with a 4-level Likert scale the agreement with the statement “I do not like the landscape”, variable *Landscape_like*. Testers were then urged to move to different points in order to observe a scene associated with the presence of an alternative. Once the scene was sufficiently explored, testers were asked to rate 7 variables concerning their emotions and evaluations of the scene. Once the tour in the landscape was concluded, their favorite scene was indicated. Eventually, after both the landscapes had been virtually visited, 9 variables about their overall experience with VR were gathered. Details for metrics used for assessing preferences and emotions are to be found in Subsection 2.4.

2.2 Equipment

During the whole experiment, participants were immersed in two VR environments (summer- and winter-like) that were created for the scope of the study, although some elements were borrowed from freely accessible databases. The transition from the summer to the winter landscape or vice versa was created in the fashion of a virtual flight aiming at making the experience more entertaining and the tasks less boring. The used equipment, hardware and software are listed below.

- Oculus Rift, a VR head-mounted display
- 2 connected Oculus sensors and touch controllers
- A computer fulfilling the technical requirements indicated by Oculus
- The game engine Unreal Engine 4
- The software Sketchup, AutoCAD 3D and Windows Mixed Reality for the fine-tuning of the scenes and the design of the installation alternatives.

2.3 Versions of the displayed technical installations

The alternatives for technical installation included a reference solution resembling a common container as a sort of control element (indicated with 1. In Image 1) were set in two landscapes. The other alternatives aimed to resemble a similar parallelepiped shape with mirrors on the outer surface, a mountain hut and a pile of rocks. These are indicated in Image 1 with 2., 3. and 4., respectively. The selected alternatives were chosen among a set of concepts generated in a co-design session, in which the authors and a student participated. Attention was paid to generated ideas potentially non-conflicting with the technical requirements of an installation for artificial snow (e.g. inlets, outlets, transportability). The various concepts were then sketched. Subsequently, the concepts were conjointly evaluated in terms of technical feasibility, attractiveness and ease of representing the concepts with VR instruments, which led to the selection of the mentioned alternatives. Therefore, the sketches were elaborated with the support of the above software and turned into VR elements to be introduced in the two virtual landscapes. In order to facilitate the creation of VR elements, alterations of the original designs were of course allowed – just the basic idea behind the concept was necessary to be respected. A graphical example of this transformation for the mirror-like structure is provided in Image 2. Here, the two designs are different to some extent, but the concept was safeguarded of substituting the outer of the container with something mirroring the mountains and the surrounding landscape.

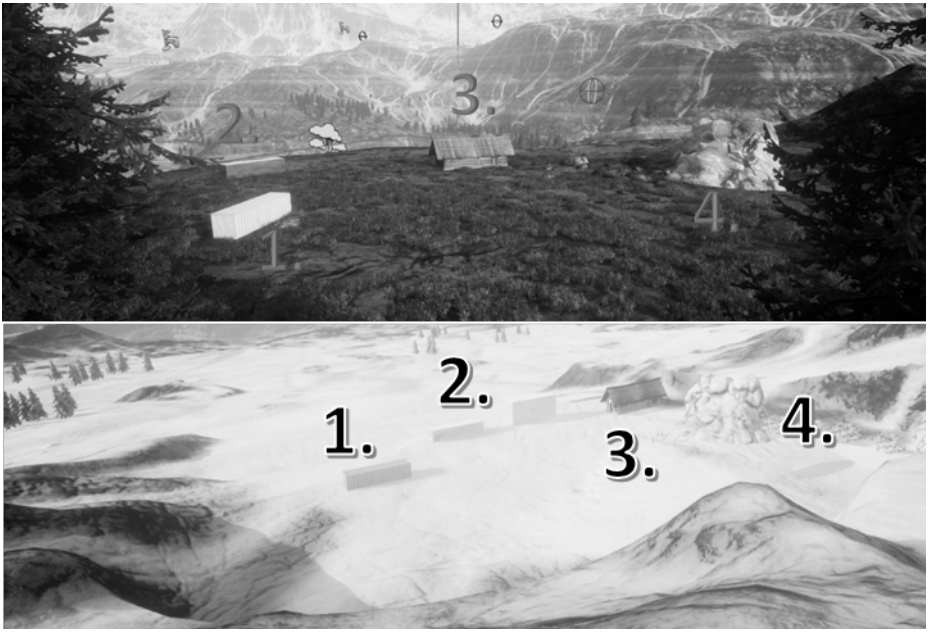

Image 1: Virtual Reality pictures of the summer- (above) and winter-like (below) scenery in which the four alternative aspects for technical installations (1. Container, 2. Mirror, 3. Hut, 4. Rock pile) are positioned.

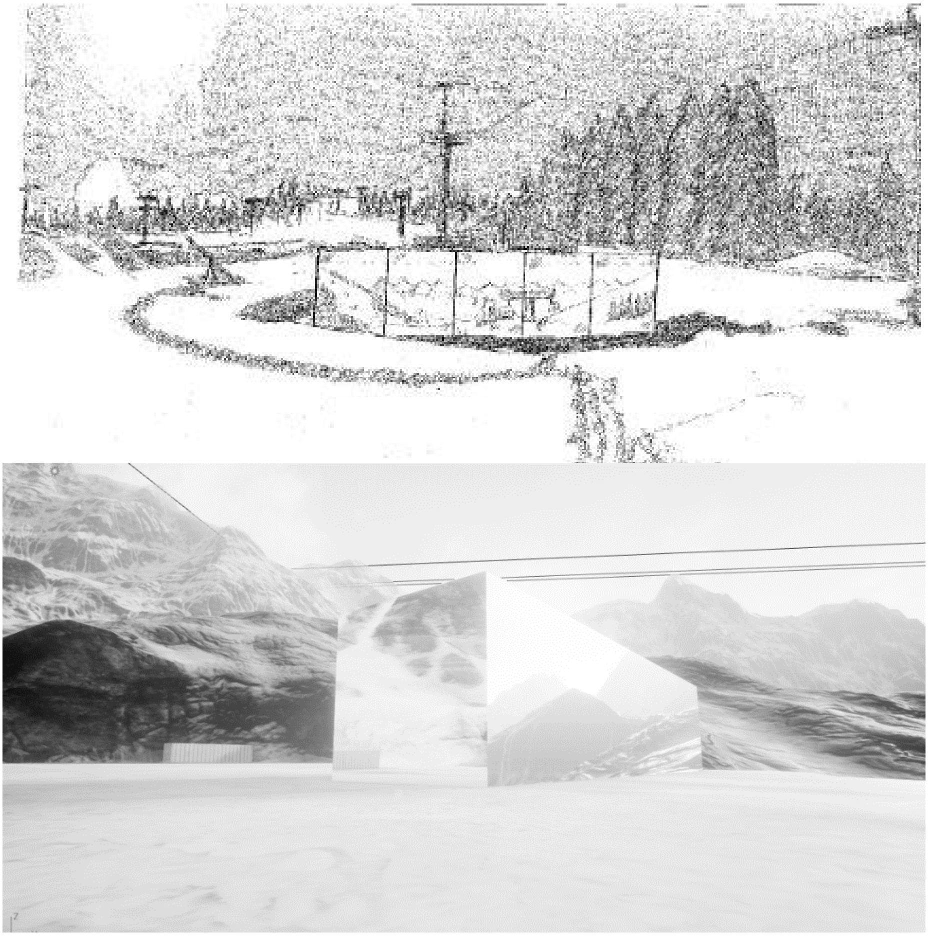

Image 2: Initial sketch (above) and Virtual Reality representation in the winter scenery (below) of the mirror-like structure alternative.

2.4 Methods used for participants’ assessment

In order to address the research question, evaluations from participants and their perception were required of both the presented scenes and the experience with VR. Given the context, the authors believed that these subjective assessments should regard emotions and experience-related dimensions. They then resorted to acknowledged instruments to pursue this objective. In particular, they individuated the chance of making reference to the Positive and Negative Affect Schedule (PANAS), a self-report questionnaire investigating people's states and reactions through 10 pairs of adjective-described emotions with opposite valence [4]. PANAS is deemed as a potentially powerful instrument also for the study of emotions in design and user-product interaction [5] and its use is starting to spread in VR studies [6]. The authors chose to use a subset of the semantic descriptions of emotions foreseen in PANAS, as triggers for the definition of the questionnaire. The reformulation was due to the need to rate aspects ascribable to the specific study. The choice of considering a part of PANAS adjectives, besides being common, e.g. [7], was dictated by the need to evaluate a large number of scenes and, therefore, the duration of participants' involvement should be limited. As a result, the following statements were assessed for each scene with a 4-level Likert scale; negative and positive statements were mixed. The questionnaire was conducted in Italian or German according to mother tongue of each participant.

- I like what I see.
- I feel irritable.
- I feel excited.
- I feel inspired.
- What I see is well integrated with the landscape.
- What I see stands out in the environment.
- What I see is disgusting.

The preference for the favorite alternative for each landscape was indicated after the completion of the visit of the winter- or summer-like scenery. By using the same Likert scale as above, the experience with VR was eventually rated through the following statements.

- I feel amazed.
- I am jittery.
- I feel impressed.
- I feel calm.

- I feel safe.
- I feel relaxed.
- I feel happy.
- I feel upset.
- I feel good.

During the experiment, the following factors were randomized in order to increase the reliability of the extracted data.

- The first and second landscape to be visited.
- The sequence of alternatives to be visualized and interacted with in each scenery when the authors supervising the experiments were left free to decide.
- The sequence of questions to rate each alternative in each scenery.
- The sequence of questions to assess the participants' experience with VR.

3 Results

3.1 Elaboration of extracted data

The extracted data can be classified into four categories, where the first one is considered as potentially affected by the other three.

1. The indication of the preferences, meant as the outcome of the evaluation.
2. The indication of the attractiveness of the landscape.
3. The set of variables for the assessment of alternatives presented in the scenes.
4. The set of variables for the assessment of the VR experience, whose potential effect on preferences is the core of the present study.

The variables concerning the rating of the scenes corresponding to alternatives were subjected with the Principal Component Analysis in order to work with a smaller number of parameters; 2 residual variables (named *appreciate* and *impact*) were extracted. The same process was followed for VR-related variables leading to the individuation of 3 main factors (*VR_pleasure*, *VR_wonder*, *VR_schock*). The reduction process was necessary due to the abundance of variables and the comparatively limited number of tests. It was deemed useful also in light of the foreseeable overlapping of dimensions included in the statements. The selection of the principal components to be kept followed the common rule of thumb of including components with eigenvalues higher than 1. The 2 (3) main factors substituting the initial variables rating the scene (the experience with VR) are accounted of the capability of describing the overall captured phenomenon to an extent of 66% (68%) according to their calculated cumulative proportion. The meaning of the principal components was extrapolated by the authors with reference to the significant loadings of the initial variables.

3.2 Individuation of the significant variables and rejection of the hypothesis

A logistic regression was then performed, where the preference was the response variable, while the regressors were constituted by variables ascribable to landscape evaluations, scenes ratings and VR experience, in compliance with Subsection 3.1. The results presented in Table 1 remark that no main dimension associated with the VR is statistically significant (p-values much higher than 0.05), so that H0 is rejected. Conversely, emotional aspects and evaluations are highly relevant for and consistent with the expression of preferences — participants tend to select alternatives that do not pass unnoticed besides being appreciated from an aesthetic viewpoint. As for the main objective of the contribution, VR has demonstrated its capability to support the evaluation of different concepts in the given conditions without visible effects on human behavior. VR can be therefore considered as a viable option to replace physical prototypes when the presence of a specific environment is relevant for evaluations.

Table 1: Results of the regression predicting the likelihood of an alternative to be preferred over the others

Regressor	Regression Coefficient	P-value
Landscape_like	-0.004	0.994
Appreciate	1.233	0.000***
Impact	0.702	0.026*

VR_pleasure	0.047	0.822
VR_nowonder	0.176	0.501
VR_shock	-0.260	0.347

3.3 Preferences and practical indications

Among the alternatives, the mountain hut resulted the one with the largest number of indications of preferences (11 out of the 24 total designations considering both the winter- and summer-like sceneries). While nobody designated the container as the favorite scene, the mirroring structure and the rock pile received roughly the same number of preferences (6 and 7, respectively). Given the relatively small size of the sample, conclusions with reference to best options cannot be drawn. Anyway, it is worth noting that the absence of preferences for the container supports the reasonableness of paying efforts to match the appearance of technical installations with the landscape better. Moreover, 5 participants out of 12 expressed different preferences for the summer- and the winter-like landscapes. This suggests that the changing appearance of landscapes is also worth taking into account.

4 Discussion, conclusions, limitations and future work

The original contribution of the paper is the investigation of VR's capabilities of supporting the study of design in terms of the appropriateness of what is designed with reference to what should surround it. This kind of research has not been conducted before based on authors' best knowledge and review of the literature. More specifically, the described experiment and the rejection of the hypothesis H0 back the usability of the VR technology for evaluating the matching between technical installations and the environment in which they should be situated. These preliminary results make it possible to extend the outreach of employments of VR in industrial, civil and environmental engineering. As for design, the outcomes encourage to consider the aesthetic dimension of technical installations, due to the methodological chance provided by VR, which seems to obviate the need for prototypes of large structures.

On the other hand, the peculiarities of the topic add little knowledge to the field of user-product interaction, since the size of the chosen installations do not allow a proper use and manipulation of the illustrated objects. In addition, the possibility to generalize the results are hindered by the following factors beyond the number, experience and the actual motivation of the participants.

- The validity of the results should be supported by assessments made as a result of illustrating the alternatives through other techniques and methods. Some feedback can be gathered by means of the hand-made sketches used as input for the creation of the VR representations.

- The results might be affected by the quality of the VR representations. During the experiment, the authors were present and asking participants to explain what they were visualizing in order to check for the comprehensibility of the designs. Although the VR representations proved to correspond to the ideas and concepts based on participants' feedback, this cannot compensate for the experiment's failing to assess the quality of the designs.

- One of the role of the authors' presence at the experiment was to support the participants in the correct visit of the landscapes and visualization of the scenes to be rated, beyond technical support. Therefore, the authors could check through a monitor that the observed scene included, at least in certain time intervals, both the installation and the background or the landscape. However, this cannot ensure that the evaluations are made with a focus on the matching between alternatives and the landscape.

- The experiment included a typical Alpine environment used as a landscape for the VR environment, but this does not ensure that the results would apply for any mountainous scenery. By the way, the participants were asked to refer to the scenes they were looking at when making evaluations. In other words, it was not possible to verify whether the participants were figuring out the relation between the VR picture and a real environment. This seems to be somehow supported by the different answers provided for the winter- and summer-like landscapes, but no conclusive answer can be provided.

The recalled limitations urge the authors to carry out future work. The evaluation of the alternative exterior aspects through different techniques represents the first step for a thorough validation of the preferences and the usability of VR in the field of the paper. As aforementioned, a critical aspect of the validity of the methodological approach is the monitoring of what is actually observed by the participants since the relationship between the designed part and the natural part of the scenery is the most relevant. To this respect, new tools that integrate VR and the eye-tracking technology represent an option. These tools, discussed in seminal studies at present, e.g. [8], make it possible to extrapolate the points that have attracted users' attention in a VR setting, as well as to measure fixations and saccades. Alternated fixations between designed products or installations and the landscape could represent an index of the attention paid to their relationships.

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Aspects of learning in virtual environments

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Abstract

This paper addresses to which extent memory performance in a virtual reality environment is similar to memory performance in the real world. The study was inspired by memory studies in the area of Subject Performed Tasks (SPT) were participants are asked to physically perform actions with different objects and afterwards recall them. Previous research shows that verbal phrases are better memorized if a person performs the actual action compared to only getting verbal instructions. The study consisted of three conditions that was expected to affect memory performance 1) VT-Verbal Tasks, 2) SPT-Subject Performed Task in the real world, 3) SPT-VR-Subject Performed Task in a VR environment. The result showed that memory performance in the two SPT conditions (VR and real life) was similar.

Keywords: SPT, SPT-VR, Memory performance, VR-environment

1 Introduction

Virtual reality (VR) applications can be used for many different purposes. Among other things they are used and can be used for different training situations. By training in VR environments dangerous situations can be avoided and the number of expensive mistakes can be reduced. There are also potential benefits of using virtual environment to train operators, for example in the process industry, to practice decision-making and to restore abnormalities. An instructor can also monitor how the trainee acts in different situations and provide real time feedback in a safe way (1, 2). Another example of where VR could be used is as a training environment for trainees in the fire service where large risks are associated with practicing in real life (3). In order to engage individuals in learning, VR can potentially be a good platform, for example to attract the growing generation (4) and using VR in training of different tasks could also make companies more attractive to employees. For example, Matsas's and Vosniakos's showed that training was more engaging and attractive when performed in a virtual environment (5).

Even though the usage of VR may have many advantages compared to a real life context, it also has some disadvantages. For instance, many aspects of the human perception (sound, touch, smell etc.) are difficult to convey in a virtual environment, and it's also not well understood how perception of stimuli in VR-environments affects memory performance and cognition. Some studies have investigated cognitive components for memory performance in VR. For example, Mania et al. (6) showed that subjects were more precise in recall in a real scene and a little less accurate in a virtual environment and least precise in a 2D-desktop scene. Another study (7), where the classical memory palace strategy was used to recall information, showed that a virtual memory palace experienced via an HMD supported memory performance better than using a display and mouse-based interaction. In another study (8) that investigated spatial performance in a virtual environment with respect to being active or passive (operating the joystick or just watching) it was shown that active participants recalled the spatial layout better than the passive participants. The suggested explanation was that critical motor information might be lost and that the spatial information was encoded in a more symbolic form when just watching.

This paper addresses to which extent memory performance in a virtual reality environment (VR) is similar to memory performance in a real world environment. The study was inspired by memory studies in the area of Subject Performed Tasks (SPT) were participants are asked to physically perform actions with different objects and afterwards recall the items. The term enactment-effect (or STP effect) was created in the early 80's to describe the fact that verbal phrases are better memorized if a person performs the actual action compared to if he/she only gets the verbal information (9,10,11,12,13). When performing a task (SPT) more information and memory cues are encoded compared to when only verbal instructions are received (VT), i.e. those who have performed the task also have motor information accessible, which enhances the recall (14).

The aim of the work presented in this paper was to investigate to which extent performing action events in a VR environment gives a similar enactment-effect as in real life settings. A study with three different conditions that was expected to affect memory performance was conducted 1) VT - Verbal Tasks, 2) SPT- Subject Performed Task in the real world, 3) SPT-VR - Subject Performed Task in a VR environment. The expected outcome of the study was that the SPT-VR context would improve memory performance in a similar way as previously shown in studies of SPT in the real world.

2 Method

2.1 Materials

The laboratory environment, which was used in the experiment, consisted of two setups; a physical table (for the SPT condition) and a corresponding virtual table in a VR environment (for the SPT-VR condition), see image 1. In total there were 24 objects included in different lists of items to be remembered by the subjects. The objects were mainly in the categories of tools, accessories for the industry, and office materials (for example hammer, wrench, scissors, tape, nails, battery, hearing protection, brush). There were long lists of 16 items/phrases and short lists of 8 items/phrases. To avoid that the order of the words in the lists would affect the outcome, different lists with varying order of the items was used.

In the SPT setup, a table with two levels was used. One upper level where the subjects could see the objects, and one lower level where the experimenter kept all objects used in the experiment hidden from the subject (see image 1). During the experiment, objects were moved, one after the other, from the lower table and placed in front of the subjects on the upper level table.

In the SPT-VR setup, subjects wore an Oculus Rift Head Mounted Display (HMD) and two Oculus Touch controllers. The controllers were represented by two virtual hands in the VR environment. Virtual objects would appear on the table, and subjects were able to interact with the objects (e.g., pick them up) by moving the controllers and clicking buttons. Realistic hand interactions has been identified as an important factor for memorizing manual tasks performed in Virtual Reality (15), and for this reason the VirtualGrasp software (16) has been used for the realization of the virtual hands.

Image 1: Scenes, left: the real environment (SPT set up), right: VR environment (SPT-VR)

For the VT setup the experimenter had a paper with the two lists (8 items and 16 items). No other materials were used.

2.2 Participants

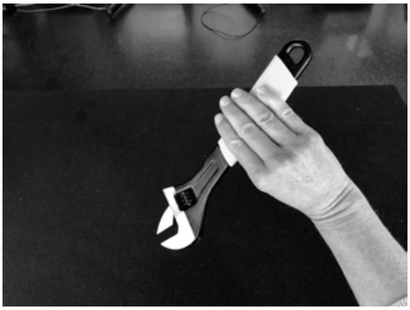
The study included 18 subjects, 8 men and 10 women. The subjects were between 17 and 58 years of age, with an average age of 35 years (m=34.7). They participants were researchers, economists and students. Only one of them had experience of using an HMD before.

2.3 Procedure

The subjects were divided (randomly) into three groups with six people in each. Group 1 performed the SPT test, group 2 the SPT-VR test and the third group the VT test. During encoding the subjects were presented with a list of items, one at a time. All subjects were presented with two lists, one short list of 8 items and one long list of 16 items. After the encoding phase all the subjects conducted a free recall task, where they were instructed to remember as many nouns as possible. The participants did not have to remember the whole action event and they did not have to recall the order of the objects.

2.3.1 SPT

In the SPT condition the subjects stood in front of the table and focused on the object presented on the table. The experimenter stood on the opposite side. First, the short list was presented to the subjects. The experimenter read action phrases from the list e.g. "lift the wrench" and then the experimenter put the wrench on the table. After that the subject actually performed the action (lift) with the object (wrench), (see image 2). Once the subject had performed the action, he/she put the item back on the table and the experimenter removed it. This procedure was repeated until the end of the list. Immediately after all the action phrases had been performed, the subject was asked to write down as many objects (nouns) he/she could recall in one minute. The same procedure was then repeated for the long list. With the long list, the subjects were given three minutes to recall the objects.



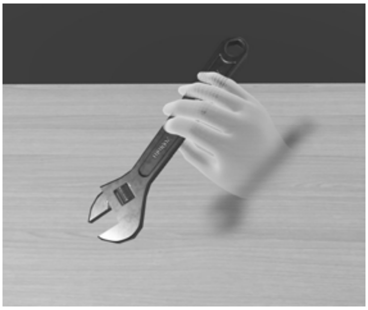


Image 2: A subject lifts a wrench.

2.3.2 SPT-VR

In the SPT-VR condition the subjects had to wear an HMD and hand controllers to interact with the objects. Via buttons on the hand controllers, the virtual hands could be used for pointing at objects, move objects around or pick them up. The subjects were given a short introduction to how to use the controllers before the actual test started. They were also allowed to practice the hand interaction using a few "example objects" that were not part of the test.

This scenario was the same as in the SPT case. The experimenter controlled the pace and order in which virtual objects were placed on the virtual table and when they were to be removed. The experimenter read an action phrase from the list and then a virtual object was shown on the table. After that the subject performed the action within the VR-environment (see Image 2). When all the actions in the list had been performed, the subject was instructed to write down all objects he/she could recall in one minute. Subsequently, the subject had to put on the HMD and the hand controllers again to perform the action phrases for the long list. The experimenter did the same scenario for the long list and immediately after all items were completed, the subject had to write down all objects he/she could recall in three minutes.

2.3.3 VT

The design for the VT condition consisted of a paper with the lists of action phrases. From this paper the experimenter read the phrases one at a time. In this condition the subjects were given the same phrases as in SPT and SPT-VR but they did not perform the tasks, they only listened to the phrases. Immediately afterwards, the subjects were instructed to write down as many objects (nouns) he/she could recall in one minute. After that the experimenter read the 16 phrases from the long list and immediately after that, the subjects wrote down the items that he/she could recall in three minutes.

2.3.4 Learning effects and subjective experiences

After the study, some of the subjects participated in one further explorative step. The aim with this was to get a first understanding of learning effects in this context, i.e. how many objects a subject recalled after each time the test was performed in the VR scenario. Thirteen of the subjects conducted the task at least two times within the VR-environment, all of them using the long list of items. The test was performed in the same way as the SPT-VR above, between each test run the subject wrote down as many objects he/she could recall in three minutes. This part of the study investigated the learning effect i.e. how many objects a subject recalled after each time the test was performed in the VR scenario.

As a last part of the test, the experimenter asked the subjects to which extent they had used memory strategies. They were also asked about their experience of using the HMD and the hand controllers for the interaction.

3 Results

3.1 Performance in the different conditions

The hypothesis was that the subject's memory performance would be better within the SPT and SPT-VR condition compared to VT. This hypothesis was supported by the outcome of the study. Memory performance was higher within the conditions SPT (SL m=7.33, LL m= 12.5) and SPT-VR (SL m=7.67, LL m= 12.5) than in the VT condition (SL m=5.5, LL m= 9.67) for both the short list and the long list. The recall rate was, not surprisingly, higher in all conditions for the short list compared to the recall rate for the long list (see table 1).

Table1: Performance in each condition. Mean value in number of correct answers and percentage.

Condition	**Short list - 8 items**		**Long list - 16 items**	
VT (N=6)	5.5	0.69	9.67	0.60
SPT (N=6)	7.33	0.91	12.5	0.78
SPT-VR (N=6)	7.67	0.96	12.5	0.78

Within the conducted ANOVAs there was a significant main effect of condition with respect to both the short list (F=8.65, p=.003) and the long list (F=11.84, p=.001), where performance on SPT-VR task and SPT task was better than with just reading the lists (VT). There was no significant difference in performance between SPT-VR task and SPT task regardless of list length. Further, there was no significant interaction between condition and list length. The different conditions had similar effect on performance with respect to list length and none of the conditions seemed to be more favourable for performance on either list length.

3.2 Learning effects within the VR-environment

Within the test group 13 of subjects conducted the task at least two times within the VR-environment, all of them using the long list of items. Performance on the first occasion was m=13.46 and on the second occasion m=15.23. Within the ANOVA (repeated measurements) that was conducted, the difference was significant (F=58.778, p=.000) with an improvement in performance between the first and second occasion.

3.3 The subjects' experience from participating in the test

Some of the participants described that they applied different strategies to remember better. In the VR condition, when conducted the test with the short list (8 items), several subjects reported that they had repeated the objects for several times before the next object became visible. With respect to the long list (16 items) the participants said it was more difficult to mentally repeat the objects, at least for all of the items in the list. Some of subjects reported that they, when trying to remember the objects in the long list, just had written down all the objects they remembered and afterwards thought about objects that were "sticking out".

In the VR condition, some subjects categorized the objects and placed them at different places on the table to remember better. Another way of categorizing the objects was to differ between heavy and light objects. Some subjects applied a strategy where they grouped objects that belonged together, for example hammer/nail and spray can/brush. Finally, another way of categorizing the objects was based on belonging to a larger main group of items, for example tools, office supplies, industry related things such as safety helmet.

Subjects that got the phrases verbally (VT) and after that conducted the test in the VR-environment described the advantages of using the VR-environment the second time. For example they said that it was much easier to remember when interacting with the objects, and that it was easier to learn when it was possible to actually see the objects. Finally, one of the subjects who also got the sentences verbally described applying the Method of Loci (17), imagining wandering around in his house placing objects in different rooms.

With respect to interaction and usage of the VR-environment, all subjects were very positive to do the test in VR. They felt that the objects looked nice and that they where similar to real life objects. The virtual hands that adapted to the objects impressed the subjects. Comments from subjects included "nice grip, not just sticking to the hand" and "Really felt real in VR, as good as in reality". Several of the subjects said they could focus better when they were doing the task in VR and wearing an HDM than when they did the tasks in the real life context

4 Discussion and conclusions

As described above, there was no significant difference in performance between SPT-VR task and SPT task regardless of list length. Although the study was conducted with a limited number of subjects, the expected enactment effect (9) was observed in the VR-environment as well in the real life context. The results also showed an improvement in performance from the first trial to the second trial in the VR-environment. This supports the assumption that effective learning can take place within a VR-environment, at least for remembering items in a sequence. This is further supported by (4), where VR training techniques were examined and it indicated that, for example, technicians could better transfer their skills from VR to reality than if traditional training methods had been used (text, video). The advantage of using a VR environment is that you can rather easily repeat the training several times, with the same conditions, and if the assembly itself is complex, it can be easier to understand it in a VR environment. VR training methods may be come more significant in the future in relation to images (in 2D) and written instructions (4).

In the discussions after the test, some of the participants revealed that they had applied various strategies to remember better. They grouped objects based on category and they used the well-known memory strategy “Method of Loci”, where items to be remembered are placed and visualised within an imaginary environment (17). The use of this strategy has also been investigated in a VR-environment. Krokos et al. (7) showed that a VR environment with an HMD provide support in memorizing information during learning to a greater extent than interacting with a 2D-display.

In Brooks et al. (8) it was argued that there may be more aspects related to the SPT effect and that the motor information might not be the only aspect. They argue that involvement of the subject and how active he/she is also contributes to the SPT effect. However, Engelkamp, Zimmer, Mohr and Sellen (14) claim that the motor information provided by enactment is a critical component of the SPT effect. In their work it was shown that regardless of whether real objects or imaginary objects were used when performing the tasks, the SPT effect was observed. Furthermore, even when the subjects performed the action with eyes closed, the SPT effect was observed (14). The SPT-VR condition was similar to when subjects performed action events by using imaginary objects in terms of not acting upon real life objects. On the other hand, within the SPT-VR condition the subjects had access to visual information.

There is an additional condition that should be addressed as well, namely, when the experimenter performs the tasks (EPT) in front the subjects. Results from research show that SPT gives better recall than when subjects watch an experimenter performing the tasks and that EPT, compared to VT, provides better memory performance (18, 19). These findings indicate that the visual component is an important aspect of the EPT encoding, but that it cannot explain the SPT effect (20). Work conducted by Hornstein et al. (21) further support that the visual component is not the crucial aspect in memory for action events. In their study they compared EPT, SPT, SPT with eyes shut and SPT in front of a mirror, and found that the subjects did not perform less well with their eyes closed, nor better in the "super visual" condition in front of a mirror. Based on these findings Hornstein et al. (21) suggest that as long as the motor memory is not affected, the amount of visual feedback do not eliminate or enhance the enactment effect.

Finally, it is also interesting to point out the similarities between the "mirror group" in the Hornstein et al. study (21) and the SPT-VR condition in the study presented in this paper. When the subjects in our study performed the actions he/she watched his/her virtual hands performing the actions as the subjects in the Hornstein et al. study (21) did by using the mirror.

To summarize, this study has shown that the enactment-effect is present also in VR environments, and that there is no significant difference between SPT and SPT-VR. The possibility to achieve successful learning of sequential tasks in VR-environments strengthen the assumption that VR-environments could be useful within for example training of manufacturing tasks, e.g. where a new employee needs to learn to perform several steps at an assembly line.

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Implications of different use cases on the ergonomic evaluation of human-robot collaboration

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Abstract

In this publication, we propose an analysis approach for ergonomics of human-robot collaboration (HRC) use cases, in order to gather information for the development of a holistic, objective and quantifiable method to evaluate ergonomics in HRC. The approach consists of three segments: Functional analysis, level of collaboration analysis and human factors analysis. Each parameter of these segments is discussed individually. We conduct this analysis for a set of use cases gathered from literature review and propose distinguishable values for the analysis parameters. Additionally, clustering possibilities for the analysed use cases are discussed.

Keywords: human robot collaboration, human factors, use cases, ergonomic evaluation

1 Motivation

Due to the trend of digital transformation, future work scenarios will rely heavily on novel technologies such as virtual reality, artificial intelligence and robotics. In the field of robotics, current developments suggest that the current state of strict separation between human and robot will be complemented by human robot collaboration (HRC) [1]. This means that both agents will interact more intensely and in different ways compared to the present situation. Thus, HRC has the potential to cover more use cases than traditional robots in isolation. However, most of these use cases are yet unclear or unknown. This is because the involvement of a human results in a multi-dimensional optimization problem. It is not easily determinable which collaboration partner should carry out which subtask, and even harder to consider the varying capabilities and needs of the individual worker, i.e. the ergonomics of HRC. This carries even more weight in applications such as service robotics, where individual human traits are the key elements of the collaboration. To gather information and contribute to a solution to those problems, we want to investigate possible use cases of HRC. In summary, this publication aims to contribute to the following research question:

"What implications on ergonomics of HRC applications can be derived by looking at the different use cases that can be considered for HRC?"

Furthermore, we base our publication on a few hypotheses that are described in the following. For the identification of use cases, we rely on publications from other authors that discuss third-party sources, under the assumption that thereby the relevance of those use cases for HRC is assured. Additionally, we assume that, due to the interdisciplinary nature of ergonomics and the various humanitarian aspects, a holistic, objective and quantifiable analysis of HRC ergonomics is not yet feasible due to a lack of reliable methods. Thus, we propose a multilateral analysis approach based on defined parameters with distinguishable values. It does still rely on subjective evaluation, however, we assume that this intermediate step contributes to the development of an objective evaluation method of HRC ergonomics.

2 Related Work

In their publication, Frey and Osborne [2] evaluated the threat of computerisation of jobs and activities. They built an algorithm that calculated the susceptibility of 702 occupations, based upon 70 occupations hand-labeled by experts. According to their findings from 2013, 47% of total US employment are automatable, and therefore at risk. While this helps to isolate use cases relevant for HRC, it does not provide further useful information for HRC ergonomics by itself.

Ajoudani et al. [3] published a review about the state-of-the-art of HRC as well as its future developments. They include many publications from the different topics that are part of HRC: human-robot interfaces, robot control modalities, as well as relevant use cases. While these topics directly relate to our research goal, the authors only state those use cases as part of their review and do not enter their analysis.

Another review that relates to our research is from Wang et al. [4]. Their review object are intelligent robots, which they define as a "...machinery system that has comprehensive improvements in perception, decision-making and performance compared with traditional robot..." [4]. They are thereby listing traits that are important for HRC as well. However, they are focused on robot systems and the technologies having the biggest impact on changing those systems, not on HRC. The publication also provides an overview of the most important robotic sectors.

Focusing on the safety aspect of HRC, Saenz et al. [5] conducted a survey of HRC application design methods. While this is mainly relevant for methodical research, it also provides use cases as examples for industrial robot applications.

3 Identification of relevant use cases

Before we can start to identify use cases for analysis, we need to define the term use case. For our publication, a use case of HRC is a singular task or set of tasks that helps to achieve a common goal for human and robot, carried out in a shared environment. In order to compile a set of use cases, we look for complete HRC applications, but also for jobs, occupations, task, activities, etc., since these can be viewed as, or translated into use cases as well.

Regarding the selection of publications we use to identify use cases, we wanted to have a scope of use cases as broad as possible. This way, we wanted to make our insights as generally applicable as possible. Therefore, reviews and publications focused on multiple use cases were preferred. Another important aspect was to limit the total amount, so that we are still able to analyse them manually. This is necessary because this publication is intended as groundwork for a method to analyse use cases automatically.

The first group of sources comprises jobs that are endangered by automation and/or digital transformation. Frey and Osborne [2] analysed which occupational domains are endangered the most by computerization. The top five domains, decreasing in susceptibility, are "Transportation and Material Moving", “Production”, “Installation, Maintenance and Repair”, “Construction and Extraction” and “Farming, Fishing and Foresting”. In order to consider these findings, we drafted use case examples for each occupation:

- “Door delivery of parcels” and “Courier services” for “Transportation and Material Moving”
- “Inspection of heavy parts” and “Complex assembly tasks” for “Production”,
- “Installation of white goods” and “Installation of furniture” for “Installation, Maintenance and Repair”,
- “Pouring of concrete” for “Construction and extraction”,
- And “Feeding of livestock” and “Milking” for “Farming, Fishing and Forestry”

A similar publication to [2] was authored by Dengler and Matthes [6]. They investigated the impact of digital transformation on the german labour market, with similar methods to [2]. Instead of occupations, they used tasks as a basis for the analysis, split into routine and non-routine tasks. They calculated substitution potentials for occupations and concluded that manufacturing, production, business management and organization, IT services and business services were those with the highest substitution potentials in decreasing order. Since they did not list specific activities, we decided against including examples for those occupations. In addition, their findings also substantiate that complex tasks will not be automated in the near future. They go further by stating that high substitution does not automatically indicate automation, but rather a high probability for that occupation to change. [6]

The second group of sources are publications directly stating use cases in their publications. Bauer et al. [7] published a paper discussing the state of research in HRC. The categorisation of the use case table in Appendix A is mainly based on their publication. They discuss healthcare, construction, urban search and rescue, tour guides, home service and entertainment as HRC application fields and corresponding use cases from third-party authors.

Ajoudani et al. [3] conducted a meta-review of human-robot collaboration, also listing some use cases from third-party authors. Since most of them were listed as benchmarking applications, they are abstract in their description. The use cases adopted from their publication are attributed to the categories healthcare robots, home service and industrial environment.

Saenz et al. [5] published a survey of design methods for HRC applications, where they also discussed three HRC use cases. While this is a small number, they discussed the differences in detail and also used their own classification of collaboration to distinguish those use cases. All three use cases fall under the industrial environment category.

The study named “Homo Digitalis” from Pollmann et al. [8] was conducted to gain insights about the impact of new technologies on different areas of life, e.g. the working environment. One part of the study focused on human-robot interaction, where, among other things, the top five activities were listed that test persons would like to do in collaboration with the robot. Since they were formulated in a very abstract way, we put them under their own category, “General work”.

Apart from a framework for levels of collaboration, Aaltonen et al. [9] also provide abstract descriptions to the individual sublevels of collaboration. Since we used their framework, we also included these descriptions as use cases for better classification of the remaining use cases. They also included use cases from different authors, however we decided against including them, to keep the amount of use cases manageable. As soon as a reliable, objective method to evaluate use case ergonomics is present, this presents a viable source of additional use cases to investigate.

4 Use case analysis

Due to the amount of use cases identified from these sources, a table was attached to the end of this publication (see Appendix A), containing all use cases taken from these sources. The use cases are assigned to the rows, the parameters to the columns. The row categorisation is based on the categories from Bauer et al. [7], supplemented by the ones from Frey and Osborne [2] (see section 3). The columns are separated into three segments: functional analysis, level of collaboration and ergonomic factors.

4.1 Functional analysis

The first column of the functional analysis, “Supported human function”, contains functions incurred by the human, which are supported by the robot. By analysing all use cases, we identified twelve supported human functions: “Navigation”, “Locomotion”, “Cognition”, “Motor function”, “Surveillance”, “Identification”, “Information transfer”, “Entertainment”, “Reconnaissance”, “Transport”, “Holding” and “Tool usage”.

“Quality of human support” refers to the supported human function column. It elaborates the quality of support through the robot. Three levels were defined: “Training”, “Supplementation”, “Compensation”. Training is the lowest quality of support, helping the human to gain knowledge, whereas Supplementation means that the robot directly helps the human to execute his tasks, just not completely. If a function is compensated, the robot unburdens the human completely of this function.

The last column of the functional analysis, “Supported robot function”, contains functions of the robot, which are aided by the human. The same functions were used as with the supported human functions, no additional functions were identified.

4.2 Level of collaboration analysis

In [9], Aaltonen et al. suggest a novel system for the classification of collaboration through different levels. Their framework was built upon similar frameworks from other authors for different terms. According to them, there is not one key factor to collaboration that can be used to differentiate between different levels of collaboration. Therefore, they defined a number of parameters that are discussed in the following, since they are represented as individual columns in our use case table.

The first parameter is called “Workspace sharing”. As the name suggests, it contains information about whether the workspace is shared and if so, how it is shared. The possible values include “Physical separation”, “Separate”, “Spatially limited sharing”, “Temporally limited sharing”, “Shared”.

The second column is called “Activity during human presence”. The possible values are “NA” (not applicable), “Robot stopped”, “Simultaneous activity”, “Simultaneous activity; hand-guided”, “Simultaneous activity; robot adaptive” and “Simultaneous activity; robot superadaptive”. Robot adaptive means that the robot is able to adapt its behaviour to the human’s during simultaneous activity, Robot super-adaptive means that the robot can adapt proactively, surpassing even a human’s standard collaboration capability.

“Joint effort” is the third column, informing about the quality of human and robot joint effort, if existent. The possible values are “NA” (not applicable), “Shared goal”, “Shared goal or object”, “Shared object, different process” and

“Shared object, shared process”. For better understanding, “Shared goal” could also be interpreted as “Different object, different process”. “Shared goal or object” is in-between “Shared goal” and “Shared object”, for use cases where both may apply or where it may change during the process.

In the fourth column, named “Physical contact”, the nature of physical contact in this use case is described. Possible values are: “Excluded”, “Possible”, “Allowed”, “Required”. We distinguish between “Possible” and “Allowed” by defining that “Allowed” implies that physical contact was intended to happen, whereas “Possible” only implies that physical contact has no consequences for the human.

The column “Specifying factors” aggregates the other parameters into what Aaltonen et al. [9] refer to as sublevels. Therefore, it does not provide new information, but helps to distinguish between the level of collaboration of two similar, but not quite equal use cases. Possible values are: “Restricted zone”, “Simultaneous; Contact OK”, “Contact excl.(…uded)”, “Contact OK; Different process”, “Contact OK; Shared process”, “Hand-guided”, “Peer-to-peer” and “Super-assistant”. We assign the values analogue to how they are assigned in Table 1 in [9].

The last column “Level of collaboration” contains the aggregated, top level of collaboration. Its possible values are: “No coexistence”, “Coexistence”, “Cooperation” and “Collaboration”. For better differentiation between sublevels, we appended an index, consisting of two numbers separated by a dot. The first number represents the top level, the second the respective sublevel for the use case, according to Table 1 in [9].

4.3 Human factors analysis

The last section of the table is used to investigate the correlations between the individual use cases and a set of abstract human factors. The human factors we use are based on those identified by Rücker et al. [10], although we aggregated their list into ten abstract human factors to make a manual analysis possible. Our suggestion for the assessment of these correlations is to distinguish between human factors that represent tools, i.e. something that can be used to improve ergonomics and those that represent aspects of the ergonomic situation by themselves. The human factors we use and qualify as tools are “Robot personality”, “Automation”, “Experience”, “Personality traits”, “Communication”, “Mutual allocation” and “Transparency”, whereas “Working postures”, “Biomechanics” and “Mental workload” are classified as aspects.

Regarding the assessment of both tools and aspects, we define three qualities of correlation for each. Tools are either used (positive correlation) or unused (negative correlation). Additionally, we added a neutral correlation for use cases where the tool either cannot be used or has no impact. Aspects are either improved (positive correlation) or worsened (negative correlation). As with tools, aspect correlation can also be neutral if the aspect is not affected or cannot be improved in a use case. In the table, the possible entries for tools are U (used), N (neutral) and UNU (unused), the possible entries for aspects are I (improved), N (neutral) and W (worsened). In the following paragraphs, each human factor is discussed shortly, with the respective control question used in the assessment to distinguish between the three qualities.

"Working postures" is the human factor in the first column of this section. Meant by that are the postures of the human, not the robot. We classify this factor as an aspect. The control question used to determine the quality of the correlation is: "Are the human postures in the collaboration better than if the human would work alone?".

The second column contains the correlations for "Robot personality", which we define as the degree to which the robot was programmed to show rudimentary human behaviour. We classify this factor as a tool. The control question used for this factor is: "Does the human benefit from pseudo-human robot traits?"

In the third column, the correlations for the human factor "Automation" are shown. We define automation as the degree of automation of the robot's task and classify it as a tool. The control question used for "Automation" is: "Does the human benefit from robot automation?"

"Biomechanics" is the fourth column of the human factor section. With biomechanics, we mean all aspects that regard the movement of the human body and the forces that it applies or that are applied on it and classify it as an aspect. The control question we used for it is: "Is human biomechanical strain reduced by robot activity?"

The fifth column contains the correlations for "Mental workload", which we define as the cognitive effort the human has to cope with. It is classified as an aspect. The control question used for this factor is: "Is mental strain reduced by robot activity?"

The sixth column informs about the correlations of the factor “Experience”, which we identify as a tool. The control question for this factor is: “Are ergonomics improved by applying human experience?”

In the seventh column, the correlations for the human factor “Personality traits” are presented. We define personality traits as the behaviour and individuality of the human, it is classified as a tool. The control question used for “Personality traits” is: “Is the human's individuality considered to improve ergonomics?”

“Communication” is the factor contained by the eighth column, by which we not only mean verbal, but also non-verbal communication. We classify this factor as a tool. As control question, we used: “Is communication used to improve ergonomics?”

“Mutual allocation” is the ninth column of the human factor section. We define mutual allocation as the assignment of tasks between human and robot and classify it as a tool. The control question we used for it is: “Does the robot help to allocate tasks in order to improve ergonomics?”

In the tenth and last column, the correlations for the human factor “Transparency” are presented. By transparency we mean whether the human is sufficiently informed about the robot’s intent to not feel threatened by it and classify it as a tool. The control question used for “Transparency of action” is: “Is the collaboration improved by explicitly communicating the robot's intent?”

5 Generation of use case clusters

In this chapter, we want to discuss the possible ways to use clusters in order to provide insights about relationships between different human factors and to other parameters.

The first way to cluster the use cases is by the supported human function. By this, it can be determined whether those functions are tied to specific sublevels of collaboration. This in turn enables to a better understanding of the individual sublevels of collaboration.

Another type of clustering considers the quality of support of human functions. In combination with the supported human function, these clusters can be used to develop prototypical use cases. Such use cases could be used to simplify the development of novel HRC applications.

Focusing on the individual human factors is another approach. Apart from the cluster containing all positive correlated use cases for one factor, the cluster with negative correlations may be of special interest. Since a positive correlation between use case and human factors is to be expected, negative correlations may provide significant information about aspects preventing the involvement of a human factor and also about unused opportunities.

Another insight gained from human factor clusters are correlations between different human factors. For example, if mental workload is worsened, can this be linked to another human factor? If such correlations are known, this knowledge can be considered during the development of HRC applications, resulting in ergonomically optimised applications.

6 Discussion

The first thing we want to discuss is how this publication contributes to the ergonomic evaluation of HRC. The first and most basic contribution is the compilation of various use cases as a foundation for further investigation, not only with ergonomics in mind, but also for different purposes.

Furthermore, we analysed each use case by means of 19 parameters divided into 3 segments, each expressed through distinguishable, albeit subjective values. Those consisted of human and robot functions that are supported by the respective partner, a level of collaboration framework by [9] and ten human factors.

We also suggested to distinguish between tools and aspects, since we determined that their role in the collaboration differed and therefore their correlations had to be expressed differently.

7 Future Work

The goal must be to develop quantifiable human factors with associated, objective values. Since the field of ergonomics is affected by fuzziness between the individual human factors, further analysis of the presented data is needed that links the human factors to certain characteristics of use cases. On this basis, distinguishable gradations can then be worked out with which the use cases can be examined objectively afterwards. Therefore, this publication provides an intermediate step in the development of quantifiable ergonomic factors.

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Appendix A – Aggregated Use Cases and their Parameters

		Functional Analysis		
Nr.	Use case names, categorized	Supported human function	Quality of human support	Supported robot function
	Healthcare Robots			
1	Guide robots for blind people [6]	Navigation	Compensation	-
2	Robotic walkers [6]	Locomotion	Supplementation	-
3	Wheelchairs [6]	Locomotion	Compensation	-
4	Elderly care robots [6]	Various, e.g. Navigation	Supplementation / Compensation	-
5	Robots for therapy of authistic children [6]	Cognition	Training	-
6	Rehabilitation robotics [7]	Motor function	Training / Supplementation	-
7	Walking assistance robot [7]	Locomotion	Supplementation	-
8	Haptic guidance cane [7]	Navigation	Supplementation	-
	Home Service			
9	Cleaning [6]	Motor function	Compensation	-
10	Home security [6]	Surveillance, Identification	Compensation	-
11	Robot in assistive kitchen [6]	Various, e.g. Motor function	Compensation	-
12	Fold a tablecloth [7]	Motor function	Supplementation	Motor Function
	Social Robots			
13	Tour guides in public domains [6]	Information transfer, Locomotion, Navigation	Compensation	-
14	Entertainment robots [6]	Entertainment	Supplementation / Compensation	-
	Urban Search and Rescue			
15	Move into collapsed building, collect data, find human victims [6]	Locomotion, Reconnaissance	Compensation	-
	Transportation and Material Moving			
16	Door delivery of parcels	Transport	Compensation	-
17	Courier services	Transport, Identification	Compensation	-
18	Installation of white goods	Transport	Supplementation / Compensation	-
19	Installation of furniture	Transport	Supplementation / Compensation	-
	Construction			
20	Pouring of concrete	Transport, Motor function	Supplementation / Compensation	Navigation
21	Carrying heavy loads [6]	Transport	Compensation	-
22	Ease handling repeating construction tasks [6]	Transport, Motor function	Supplementation	-
23	Mobile robot helper - Sharing loads and collaborative handling of loads[6]	Transport, Motor function	Supplementation	Transport, Motor function
24	Joint-action symmetrical human-robot dialogue system [6]	Information transfer	Supplementation	Information transfer
25	Robonaut - collaborative soldering and electrical measurements in space [6]	Motor function	Supplementation	Motor Function
	Industrial Environment			
26	Inspection of heavy parts	Transport, Holding	Compensation	-
27	Complex assembly tasks	Motor function	Supplementation	Motor Function
28	Feeding of livestock	Transport, Motor function	Supplementation / Compensation	-
29	Milking	Motor function	Compensation	Navigation, Transport
30	Collaborative transportation of bulky/heavy objects [7]	Transport	Supplementation	Transport
31	Collaborative assembly of a table (robot controls impedance of the table) [7]	Transport, Holding	Supplementation	Motor Function
32	Object handover task [7]	Motor function	Supplementation	Motor Function
33	Installation of heavy construction material [7]	Motor function, Transport	Supplementation	Navigation, Motor Function
34	Loading and transporting heavy wheels [7]	Motor function, Transport	Supplementation / Compensation	Motor function, Cognition
35	Collaborative assembly of homokinetic mechanical joint [7]	Motor function, Holding	Supplementation / Compensation	Motor function, Cognition
36	Collaborative assembly of cellular phones [7]	Motor function, Holding	Supplementation / Compensation	-
37	Measure and learn end-point impedance of expert welders for autonomous execution and training of non-skilled personnel [7]	Motor function, Information transfer	Training / Compensation	Cognition
38	Collaborative sawing task [7]	Motor function	Supplementation	Motor function
39	Deforming a flexible metal sheet and support payload for human handling [7]	Motor function, Transport	Supplementation	Motor function, Transport
40	Collaborative rope turning [7]	Motor function	Supplementation	Motor function
41	Collaboratively manipulating pendulum-like objects [7]	Motor function, Holding	Supplementation	Motor function, Holding
42	Machine tending [8]	Motor function, Transport	Compensation	Motor function, Transport
43	Robots in automotive assembly [8]	Transport	Compensation	Motor function, Transport
44	Palletizing robots [8]	Transport	Compensation	Transport
45	Human worker drills holes into which the robot inserts an insert; contact is avoided with capacitive sensors on the robot [10]	Motor function	Compensation	Motor function
46	Human inserts screws to holes and robot tightens them with a safe tool [10]	Motor function, Tool usage	Compensation	Motor function
47	Robot holds a part against the workpiece while the human fastens it with bolts [10]	Motor function, Holding	Supplementation	Motor function
48	Robot needs to be guided to a cardboard box by hand in a packaging operation because of deformable box [10]	-	-	Motor function, Navigation
49	Working with a robot is similar to working with a human [10]	Various, mainly Motor function	Supplementation / Compensation	Various, mainly Motor function
50	Robot “reads” the human state and acts proactively [10]	Various, mainly Cognition	Supplementation / Compensation	-
	General Work-Related			
51	Conduct an experiment [9]	Information transfer, Motor function, Cognition	Supplementation	Motor function, Cognition
52	Prepare a presentation with a colleague [9]	Information transfer	Supplementation	-
53	Gather information [9]	Information transfer, Cognition	Supplementation	Cognition
54	Select one out of multiple ideas [9]	Information transfer, Cognition	Supplementation	Cognition
55	In case of emergency, shut down the machines [9]	Information transfer, Motor function	Supplementation	-

Nr.	Use case names, categorized	Level of Collaboration Analysis					
		Workspace sharing	Activity during human presence	Joint effort	Physical contact	Specifying factors	Level of collaboration
	Healthcare Robots						
1	Guide robots for blind people [6]	Shared	Simultaneous activity	Shared object, shared process	Required	Cont. OK; Sh. proc.	Collaboration, 4.3
2	Robotic walkers [6]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Peer-to-peer	Collaboration, 4.5
3	Wheelchairs [6]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Peer-to-peer	Collaboration, 4.5
4	Elderly care robots [6]	Shared	Simultaneous activity, robot adaptive	Shared process	Allowed	Peer-to-peer	Collaboration, 4.5
5	Robots for therapy of authistic children [6]	Shared	Simultaneous activity	Shared process	Allowed	Cont. OK; Sh. proc.	Collaboration, 4.3
6	Rehabilitation robotics [7]	Shared	Simultaneous activity	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
7	Walking assistance robot [7]	Shared	Simultaneous activity, hand-guided	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
8	Haptic guidance cane [7]	Shared	Simultaneous activity, hand-guided	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
	Home Service						
9	Cleaning [6]	Shared	Simultaneous activity	Shared goal	Possible	Simult.; Cont. OK	Cooperation, 3.6
10	Home security [6]	Shared	Simultaneous activity	Shared goal	Possible	Simult.; Cont. OK	Cooperation, 3.6
11	Robot in assistive kitchen [6]	Shared	Simultaneous activity, robot superadaptive	Shared goal or object	Allowed	Super-assistant	Collaboration, 4.6
12	Fold a tablecloth [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Peer-to-peer	Collaboration, 4.5
	Social Robots						
13	Tour guides in public domains [6]	Shared	Simultaneous activity, robot adaptive	Shared goal	Possible	Simult.; Cont. OK	Cooperation, 3.6
14	Entertainment robots [6]	Shared	Simultaneous activity, robot adaptive	Shared goal	Allowed	Simult.; Cont. OK	Cooperation, 3.6
	Urban Search and Rescue						
15	Move into collapsed building, collect data, find human victims [6]	Shared	Simultaneous activity	Shared goal or object	Allowed	Simult.; Cont. OK	Cooperation, 3.6
	Transportation and Material Moving						
16	Door delivery of parcels	Shared	Simultaneous activity, robot adaptive	Shared object	Required	Hand-guided	Collaboration, 4.4
17	Courier services	Shared	Simultaneous activity, robot adaptive	Shared object	Required	Hand-guided	Collaboration, 4.4
18	Installation of white goods	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Allowed	Peer-to-peer	Collaboration, 4.5
19	Installation of furniture	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Allowed	Peer-to-peer	Collaboration, 4.5
	Construction						
20	Pouring of concrete	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Allowed	Peer-to-peer	Collaboration, 4.5
21	Carrying heavy loads [6]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Possible	Cont. OK; Sh. proc.	Collaboration, 4.3
22	Ease handling repeating construction tasks [6]	Shared	Simultaneous activity	Shared goal	Possible	Simult.; Cont. OK	Cooperation, 3.6
23	Mobile robot helper - Sharing loads and collaborative handling of loads[6]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
24	Joint-action symmetrical human-robot dialogue system [6]	Shared	Simultaneous activity, robot superadap	Shared process	Possible	Super-assistant	Collaboration, 4.6
25	Robonaut - collaborative soldering and electrical measurements in space [6]	Shared	Simultaneous activity	Shared process	Possible	Cont. OK; Sh. proc.	Collaboration, 4.3
	Industrial Environment						
26	Inspection of heavy parts	Shared	Simultaneous activity	Shared object, shared process	Allowed	Cont. OK; Sh. proc.	Collaboration, 4.3
27	Complex assembly tasks	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Allowed	Peer-to-peer	Collaboration, 4.5
28	Feeding of livestock	Shared	Simultaneous activity, robot adaptive	Shared process	Possible	Peer-to-peer	Collaboration, 4.5
29	Milking	Shared	Simultaneous activity, hand-guided	Shared process	Possible	Hand-guided	Collaboration, 4.4
30	Collaborative transportation of bulky/heavy objects [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
31	Collaborative assembly of a table (robot controls impedance of the table) [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Allowed	Peer-to-peer	Collaboration, 4.5
32	Object handover task [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
33	Installation of heavy construction material [7]	Shared	Simultaneous activity, hand-guided	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
34	Loading and transporting heavy wheels [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Allowed	Peer-to-peer	Collaboration, 4.5
35	Collaborative assembly of homokinetic mechanical joint [7]	Shared	Simultaneous activity	Shared object, shared process	Allowed	Cont. OK; Sh. proc.	Collaboration, 4.3
36	Collaborative assembly of cellular phones [7]	Spatially limited sharing	Robot stopped when human within restricted zone	Shared goal	Excluded	Restricted zone	Cooperation, 3.3
37	Measure and learn end-point impedance of expert welders for autonomous execution and training of non-skilled personnel [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Peer-to-peer	Collaboration, 4.5
38	Collaborative sawing task [7]	Shared	Simultaneous activity, hand-guided	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
39	Deforming a flexible metal sheet and support payload for human handling [7]	Shared	Simultaneous activity, hand-guided	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
40	Collaborative rope turning [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Peer-to-peer	Collaboration, 4.5
41	Collaboratively manipulating pendulum-like objects [7]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Peer-to-peer	Collaboration, 4.5
42	Machine tending [8]	Temporally limited sharing	Robot stopped when human within restricted zone	Shared object	Excluded	Restricted zone	Cooperation, 3.3
43	Robots in automotive assembly [8]	Shared	Simultaneous activity, robot adaptive	Shared object, shared process	Required	Hand-guided	Collaboration, 4.4
44	Palletizing robots [8]	Shared	Simultaneous activity	shared object, diff. process	Possible	Cont. OK; Diff. proc	Collaboration, 4.2
45	Human worker drills holes into which the robot inserts an insert; contact is avoided with capacitive sensors on the robot [10]	Shared	Simultaneous activity	Shared object	Excluded	Contact excl.	Collaboration, 4.1
46	Human inserts screws to holes and robot tightens them with a safe tool [10]	Shared	Simultaneous activity	shared object, diff. process	Allowed	Cont. OK; Diff. proc	Collaboration, 4.2
47	Robot holds a part against the workpiece while the human fastens it with bolts [10]	Shared	Simultaneous activity	Shared object, shared process	Allowed	Cont. OK; Sh. proc.	Collaboration, 4.3
48	Robot needs to be guided to a cardboard box by hand in a packaging operation because of deformable box [10]	Shared	Simultaneous activity, hand-guided	Shared object	Required	Hand-guided	Collaboration, 4.4
49	Working with a robot is similar to working with a human [10]	Shared	Simultaneous activity, robot adaptive	Shared object	Allowed	Peer-to-peer	Collaboration, 4.5
50	Robot "reads" the human state and acts proactively [10]	Shared	Simultaneous activity, robot superadaptive	Shared object	Allowed	Super-assistant	Collaboration, 4.6
	General Work-Related						
51	Conduct an experiment [9]	Shared	Simultaneous activity, robot adaptive	Shared process	Allowed	Peer-to-peer	Collaboration, 4.5
52	Prepare a presentation with a colleague [9]	Shared	Simultaneous activity, robot adaptive	Shared process	Possible	Peer-to-peer	Collaboration, 4.5
53	Gather information [9]	Shared	Simultaneous activity, robot adaptive	Shared process	Possible	Peer-to-peer	Collaboration, 4.5
54	Select one out of multiple ideas [9]	Shared	Simultaneous activity, robot superadaptive	Shared process	Possible	Super-assistant	Collaboration, 4.6
55	In case of emergency, shut down the machines [9]	Shared	Simultaneous activity, robot adaptive	Shared process	Possible	Peer-to-peer	Collaboration, 4.5

Abbreviations in Column ‚Specifying Factors'			
Cont. OK	Contact OK	Diff. proc.	Different process
Cont. excl.	Contact excluded	Sh. proc.	Shared process
Simult.	Simultaneous		

		Ergonomic Factors Analysis									
Nr.	**Use case names, categorized**	**Working postures**	**Robot personality**	**Automation**	**Bio-mechanics**	**Mental workload**	**Experience**	**Personality traits**	**Communi-cation**	**Mutual allocation**	**Trans-parency**
	Healthcare Robots										
1	Guide robots for blind people [6]	N	U	U	I	I	N	N	U	N	UNU
2	Robotic walkers [6]	N	U	U	I	I	N	N	U	N	U
3	Wheelchairs [6]	N	N	U	I	W	UNU	UNU	U	N	UNU
4	Elderly care robots [6]	N	U	U	I	I	N	N	U	U	U
5	Robots for therapy of authistic children [6]	N	UNU	N	N	I	N	N	N	N	N
6	Rehabilitation robotics [7]	N	U	N	I	N	N	N	N	N	N
7	Walking assistance robot [7]	I	UNU	N	I	I	U	U	UNU	N	UNU
8	Haptic guidance cane [7]	N	U	U	I	I	N	N	U	U	U
	Home Service										
9	Cleaning [6]	N	UNU	U	N	I	UNU	N	UNU	N	N
10	Home security [6]	N	UNU	U	N	I	UNU	N	U	N	N
11	Robot in assistive kitchen [6]	N	U	U	I	I	U	U	UNU	U	UNU
12	Fold a tablecloth [7]	N	UNU	N	N	I	U	U	UNU	N	N
	Social Robots										
13	Tour guides in public domains [6]	N	U	U	N	W	U	U	U	N	U
14	Entertainment robots [6]	N	U	U	N	W	N	U	U	N	U
	Urban Search and Rescue										
15	Move into collapsed building, collect data, find human victims [6]	N	UNU	U	N	N	U	N	U	U	N
	Transportation and Material Moving										
16	Door delivery of parcels	N	N	U	N	W	N	N	U	N	U
17	Courier services	N	N	U	N	W	N	N	U	N	U
18	Installation of white goods	N	N	N	I	W	U	N	U	N	N
19	Installation of furniture	N	N	N	I	W	U	N	U	N	N
	Construction										
20	Pouring of concrete	I	N	U	I	N	U	N	U	N	U
21	Carrying heavy loads [6]	N	U	N	I	N	N	N	N	N	N
22	Ease handling repeating construction tasks [6]	N	N	U	I	I	N	N	N	N	N
23	Mobile robot helper - Sharing loads and collaborative handling of loads[6]	I	U	N	I	W	U	U	U	N	N
24	Joint-action symmetrical human-robot dialogue system [6]	I	U	U	N	W	U	U	U	U	U
25	Robonaut - collaborative soldering and electrical measurements in space [6]	I	U	U	I	W	U	UNU	U	N	UNU
	Industrial Environment										
26	Inspection of heavy parts	I	N	U	I	I	U	N	U	N	N
27	Complex assembly tasks	I	N	U	I	W	U	N	U	U	N
28	Feeding of livestock	I	UNU	U	I	I	N	N	N	N	N
29	Milking	I	UNU	U	I	I	UNU	N	N	N	N
30	Collaborative transportation of bulky/heavy objects [7]	I	UNU	N	I	N	U	U	U	N	N
31	Collaborative assembly of a table (robot controls impedance of the table) [7]	I	N	U	I	I	U	U	U	U	UNU
32	Object handover task [7]	I	U	U	I	I	U	UNU	U	N	U
33	Installation of heavy construction material [7]	I	UNU	N	I	I	U	U	U	N	N
34	Loading and transporting heavy wheels [7]	N	UNU	U	I	W	U	N	U	UNU	UNU
35	Collaborative assembly of homokinetic mechanical joint [7]	I	U	U	I	I	N	N	UNU	N	UNU
36	Collaborative assembly of cellular phones [7]	I	N	U	I	I	UNU	N	U	U	U
37	Measure and learn end-point impedance of expert welders for autonomous execution and training of non-skilled personnel [7]	N	N	N	N	N	U	U	U	N	N
38	Collaborative sawing task [7]	N	N	N	I	N	U	U	U	N	N
39	Deforming a flexible metal sheet and support payload for human handling [7]	I	UNU	U	I	I	U	N	N	N	N
40	Collaborative rope turning [7]	N	N	N	N	I	U	U	U	N	N
41	Collaboratively manipulating pendulum-like objects [7]	N	N	N	I	N	U	U	U	N	N
42	Machine tending [8]	N	U	U	N	I	U	N	N	N	N
43	Robots in automotive assembly [8]	I	N	U	I	I	U	N	U	UNU	UNU
44	Palletizing robots [8]	N	N	U	N	I	U	N	N	UNU	N
45	Human worker drills holes into which the robot inserts an insert; contact is avoided with capacitive sensors on the robot [10]	I	N	U	N	I	N	N	N	N	N
46	Human inserts screws to holes and robot tightens them with a safe tool [10]	I	N	U	I	I	N	N	N	N	N
47	Robot holds a part against the workpiece while the human fastens it with bolts [10]	I	N	U	I	I	N	N	N	N	N
48	Robot needs to be guided to a cardboard box by hand in a packaging operation because of deformable box [10]	N	N	UNU	N	W	U	N	U	N	N
49	Working with a robot is similar to working with a human [10]	N	U	U	I	I	U	U	U	U	N
50	Robot "reads" the human state and acts proactively [10]	I	U	U	I	I	U	U	U	U	N
	General Work-Related										
51	Conduct an experiment [9]	I	U	U	I	W	U	U	U	U	U
52	Prepare a presentation with a colleague [9]	N	U	N	N	W	U	U	U	U	U
53	Gather information [9]	N	U	U	N	I	U	U	U	U	U
54	Select one out of multiple ideas [9]	N	U	N	N	I	U	U	U	U	U
55	In case of emergency, shut down the machines [9]	N	U	U	N	I	U	N	U	U	U

Abbreviations			
I	Improved	U	Used
N	Neutral	N	Neutral
W	Worsened	UNU	Unused

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