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# Understanding the Benefits of Graspable Interfaces for Cooperative Use

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**Abstract:** Although graspable interfaces are often developed as support for cooperative (design) activities, there is still little research on cooperative use aspects. This paper explains the concept of graspable interfaces and analyses their potential as tool for cooperative design. It presents a theory on positive effects of graspable media on cooperation and supporting evidence. After examining effects, the paper presents a model how these effects relate with key characteristics of graspable interfaces. This model is sustained with empirical evidence from video analysis of cooperative design using paper as graspable medium. Results stress the importance of parallel manipulative activity and of non-verbal activity for involvement and active participation. Gestures, talk and visible artefacts interact in producing meaning. The analysis suggests issues for further research. and demonstrates that video analysis is a fruitful method for analysing use of graspable design media.

***Keywords:*** *CSCW, Graspable Interfaces, Tangible Interfaces, Theoretical Study, Semi-Realistic Field Study, Video Analysis, Cooperative Design, Interaction, Participatory Design Tools*

Graspable interfaces are a new type of human-computer interfaces, diverging from the visually-centred tradition of interface design. Although still in a state of prototypical implementation and exploration of design alternatives, this new approach receives increasing recognition and interest in HCI. Research on graspable user interfaces has focused largely on describing prototypical systems, categorising them, and investigating usability issues. Researchers share a rather intuitive belief that graspable interfaces are a valuable tool for collaborative design, being less intrusive, easier to handle and more amenable to cooperative interaction than graphical tools. This belief has been supported by user reactions to demonstrations and informal experiments with users [43, 44, 16, 40]. Yet closer investigation of this phenomenon is sparse (exceptions are e.g. [2, 41, 10]).

If we want to exploit this potential, we must know what constitutes it. Otherwise system designers risk hampering properties of graspable interfaces accidentally, which are valuable for cooperative use. The goal of my research project is to contribute to an understanding: why and how graspable interfaces support cooperative design, which characteristics contribute to this and how these can be consciously exploited in system design.

As the concept of graspable interfaces is still rather new, an extended introduction addresses some of the most often asked questions. After characterising graspable interfaces, presenting the state of research contributing to a theoretical understanding, and explaining ‘cooperative design’, the main part of the paper starts. It presents (the heart of) a theory on the effects of graspable media on cooperation. I will give an overview of positive effects of graspable media for cooperative use and relate these effects to properties and characteristics. This overview summarises main results of existing research about the influence of physical environments and artefacts, which can be held to apply to graspable interfaces as well. Many valuable results about functions of tangible (resp.

Graspable) objects for cooperation and coordination can be found in ethnographic workplace studies. But these predominantly focus on affordances of paper as an artefact (e.g. the role of flight strips in air traffic control) and on cooperative tasks different from cooperative modelling (office environments, control centres). Thus empirical studies of cooperative design with graspable objects are necessary to support the theory and to concretise it. The last section of this paper presents results from a video analysis of a design session with scraps of paper (interpreted as a graspable medium). This evidence supports most elements from the described theory.

## 1. Basic Concepts

### 1.1. Characterisation of graspable interfaces

The concept of graspable (resp. "tangible") interfaces evolved in close association with Augmented Reality from growing dissatisfaction with traditional HCI. Researchers searched for alternatives to desktop metaphor and Virtual Reality. The physical (life)world should retain its role as central reference, augmented with digital capacities. Soon research efforts differentiated into different directions, one of them being graspable interfaces.

Fitzmaurice, Ishii, and Buxton [14] introduced the concept of graspable interfaces.[1] It is pursued e.g. in MIT's tangible media projects [23, 43], Rauterbergs BUILD-IT system [15], the Envisionment and Discovery Collaboratory of L3D in Boulder, Colorado [2, 3, 12], and the Real Reality approach in Bremen [9]. These approaches differ in implementation and focus, while sharing main characteristics. Using various technical means physical objects are coupled with digital representations. Change in the physical arrangement is recognised and interpreted as controlling action for the digital information. Either spatial configuration, topology, sequence of actions or all of these can be relevant for interpretation. In graspable interfaces the physical objects integrate functions of representation and control for digital information [43]. They have representational significance for human onlookers. This representational function of graspable interfaces distinguishes them from other interfaces which are based on visual representations. Often additional information, e.g. results from simulation, is visually projected onto the physical work space. People thus can interact with physically *and* digitally represented aspects of the model. Input and output space coincide in the physical interaction space, the distinction between input and output devices is eliminated.

#### *1.1.1. What does it mean for an object to be 'graspable'?*

It means that it is of material nature, following physical laws, is situated in an environment and can be experienced by the living body. One interacts directly with graspable objects, touching and feeling them. The word *tangible* expresses the doubleness of touch -- being touched by the same thing that one touches, being active and passive at once. From an anthropological viewpoint (or phenomenological), the sense of touch reminds us that we are embodied beings and forms the permeable border between outside and inside, enabling our primary experience of the world. Touch reassures us of our existence. In addition to the phenomenon of touch, the term *graspable* emphasises interaction with the hands. Whereas touching can be done with any part of the body, grasping refers to the act of enclosing something with ones digits, however partial. Our hands are the most sensorised part of our body and their representation occupies a rather large part of our brain. They have been our foremost and most versatile, creative instruments for ages until technology reduced their utilisation to clicking and pointing.

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1 To be specific, the idea of using graspable building blocks or construction kits as an input medium to create virtual models (for CAD or simulations) is older. Frazer and Aish [1] experimented with it in the early 80s. But the idea did not get publicity in the HCI community and was not taken up by other researchers at that time.

*Graspable interfaces,* incorporating both real and virtual artefacts, are more than mere "physical props", which augment virtual environments to improve immersion. The real world is augmented and coupled with virtual structures, while remaining locus of control and activity. Different from the concept of token-based access [19] they are more than access points to digital information. Incorporating access, they enable the creation and modelling of structures or systems, thus creating new information.

### 1.2. Examples illustrating the concept of graspable interfaces

The EDC environment (Envisionment and Discovery Collaboratory) has been built for participatory neighbourhood development [2] and utilises a touch-sensitive white-boards as horizontal workspace. Illuminating Light of MIT's Tangible Media group [44] is a learning environment for optical experiments and augments plastic model pieces laid out on a table with a projected, simulated light trajectory. Urp [43] supports planning processes of architects or urban planners and allows the interactive evaluation of design consequences on shadows, reflections and wind flow. BUILD-It [15] supports factory planning. Different from other graspable interfaces, the system relies on a few graspable elements only, which are temporarily bound to projected elements and serve as graspable "handles". Because physical blocks have little representational function, BUILD-IT should be interpreted as a combination of Augmented Reality with ideas from graspable interfaces. The 'Real Reality' concept [8, 9, 36] concentrates on the idea of synchronous modelling in real and virtual worlds. The virtual model can be used for simulation and gives access to complementary representations. 'Real Reality' places emphasis on the physical functionality (behaviour) of real models. The approach thus focuses on domains where functional models do exist, e.g. in factory planning, where small models allow execution of programs, or in the domain of pneumatics, where small versions of valves and pistons are regularly used for training.

It seems that most projects up to now focused on domains with an obvious one-to-one representation of domain elements. This might be attributed to this straight-forwardness and to the existence of a long tradition of small scale models in many domains. Experience up to now indicates that design of graspable interfaces is easier if only standardised elements are used, known in advance and only slightly adapted.[2] Some projects indicate that graspable interfaces can also be used for interaction within abstract domains. For example the MediaBlocks system of MIT [43] offers functionality of video cutting and sequencing. The earlier LogJam [10] supported groups in logging and categorising videos. Triangles [16] supported interactive story-telling by connecting triangles. As this approach to Human-Computer-Interaction is rather new, its scope has not been fully explored yet. Therefore it would be premature to conclude on its limits.

### 1.3. Steps towards a theory of graspable interfaces

Many implementations of graspable interfaces have scenarios of cooperative or participatory use (urban planning, learning optical experiments or pneumatics, participatory neighbourhood development, engineers and workers doing layout and configuration of factories). Most researchers report favourably, but only few case or field studies have been reported (e.g.[2, 10, 40]). Up to now, most research on graspable interfaces focused on implementation, although work contributing to a general understanding increases. This concentrates on defining concepts, building category systems [43], evaluating usability [15] or potential interaction metaphors. The focus is on single user interaction, questions of cooperative use are largely left out of consideration. As requirements for cooperative use are not identical with usability requirements for single user settings – often they are

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[2] Standardised objects can be retrieved from an object library. Non-standardised elements complicate e.g. consistent coupling of real and virtual elements, recognition of real and production of corresponding virtual objects, and require sophisticated interpretation mechanisms for recognising users intentions.

complementary or even incompatible (see e.g. [17]) – a deeper understanding seems essential in order to deliberately design for cooperative use. This motivated the research project described here.

Two proposals [43, 7] seem most promising for an understanding of the characteristics of graspable interfaces. Both are relevant for my work presented here. Ullmer and Ishii [43] stress *seamless integration of representation and control*.

a) The physical objects serve as interactive physical controls.
b) The state of the ensemble of physical objects embodies key aspects of the systems digital state. Inspecting the physical representation only enables inferring a rough picture of the entire system state.
c) Physical objects are computationally coupled with the underlying (digital) information and
d) perceptually coupled to digital representations, which is often projected into the workspace.

Whereas Ullmer's characterisation focuses on issues of representation and its computational coupling, Brauer's [7] perspective is one of human-computer-interaction, comparing GUI interaction with graspable interfaces. Brauer [7] defines as special qualities of graspable interfaces the following two key characteristics:

a) *Physical spatiality* describes the co-presence of user, objects and other users in *one* interaction space. This space is a hybrid. Physical objects have a double affiliation to real/physical and virtual/digital space, but must still obey laws of the physical world. Real and virtual parts are each enhanced by the other. Because of co-presence of users and objects, interaction takes place *IN* the user interface. Therefore input and output space coincide. The user experiences a bodily shared space, his/her body is in the same space as the interaction objects. Following [17, 22, 35, 41] physical spatiality, by preserving physical laws and sharing of space, results in well-understood visibility of objects and of gestures. Strictly speaking this characteristic is a prerequisite for the next characteristic.
b) *Haptic directness* denotes direct manipulation where the physical, graspable objects themselves are the interface. The user has direct contact with the interface elements and has an embodied experience of manipulation, using his/her hands and body movements. Interaction is unmediated and intuitive, leading to 'direct engagement'. Because hands interact directly with interface elements, two-handed or parallel interaction is possible. Unmediated, direct manipulation results in isomorphic and structure-preserving operations.

### 1.4. Cooperative Design

The cooperative use scenarios mentioned above can be characterised as being processes of design, planning or model building. The term *cooperative design* is used to denote the common type of cooperation in these scenarios (independent from the particular medium used).

Planning or designing in groups benefits of drawing from different expertise, comparing perspectives, developing shared views and putting arguments under close scrutiny. All participants learn from each other, exploiting the "symmetry of ignorance" [3, 34] and in result produce something that no-one alone could. *Cooperative design* is shared making of something that is new to participants. It is a creative and constructive activity, often concerning open-ended design issues. Because of differing perspectives and stakes it bears conflict potential. These conflicts must be handled constructively. Thus processes of developing understanding for different perspectives, evaluation of arguments, agreement and settlement are necessary in order to develop shared understanding and shared solutions. The process can be considered successful if participants agree on an "informed compromise", feel "shared ownership" and do understand the reasons (rationale) underlying decisions. In cooperative design there is no model monopoly of persons or subgroups, as all members contribute actively and scrutinise ideas. [3]

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[3] Model monopoly [6] occurs when a subgroup dominates process and result, either because of political constellation or because of a head-start. The others are forced or tempted to adopt the given model and its inherent perspective, having

This description denotes an ideal or special quality of cooperative processes and highlights differences to other cooperation types, which emphasise coordination, routine and division of labour. It focuses on conflict resolution and development of shared understanding in highly interactive and argumentative design processes. Cooperative design is related closely to participatory design. In PD, users and system designers build a shared practice of design, often using non-linguistic tools which allow for hands-on exploration and evoke tacit knowledge [13, 28]. The use of mock-ups in PD methods resembles cooperative design with graspable interfaces. Cooperative design is also related to the concept of collaborative knowledge building [38] and attempts for a dialogic theory of learning [27] in CSCL.

Crutzen [11] argues that information systems tend to support routine activity. The notion of interaction held widely in computer science (and also CSCW) still relies on the information-transfer model and focuses on routine action. She describes another notion of interaction, situated, relying on human involvement and commitment in a situation, taking place in processes of constructing *new* meaning. Irritation and break-downs are a chance to interrupt routines and habits, generating doubt, leading to new understanding and the *activity of change*. Crutzen calls for information systems to enhance the visibility of differences and to support us in reviewing and changing our believes, creating new meaning and giving up routines. Cooperative design relies on accepting irritations caused by different perspectives or by the problem domain and on constructing new meaning. Without irritations routine, custom or habit will govern thinking.

## 2. The positive effects of graspable media on cooperation

Whereas many studies show important characteristics (often termed ‘affordances’) of paper media due to its physicality (e.g. [29, 4]), only few explicitly investigate use of 3D objects. Nonetheless a lot of findings can be transferred, delivering several lines of argument explaining the positive social effects of graspable interfaces. I will now give an overview of these argument lines and present a model of how these effects relate to characteristics of graspable interfaces. Much interesting work is done in ethnographic studies, influenced by distributed or situated cognition and activity theory. Due to the space limitations**,** it is not possible to give reference to this multitude of research.

*A comment in advance:* Graspable interfaces do not steer the structure of interaction. They are a tool or medium which supports cooperation, but does not guarantee for its success. Thus mediation, moderation or facilitation may be necessary, which uses graspable media as a tool, whenever appropriate.[4] Often the most important part of a meeting is free debate, building new understanding. Graspable interfaces do not interfere in this discussion, but support it.

### 2.1. Description of effects

Concrete graspable models allow for playful, intuitive and experience-oriented ways of interaction [8]. This is especially important for heterogeneous groups and people without abstract domain knowledge. This holds for learners as for workers, whose tacit knowledge is concrete and not abstract. One can discern two levels. *Intuitive manipulation* of graspable interfaces eases first access, reminding of children’s play with bricks. Users do not need to concentrate on manual manipulation and feel less inhibited by low-tech manipulation [30, 13]. Intuitive manipulation concerns simple operations of manipulating objects. *Experience-orientation* refers to a higher level of semantic meaningful, complex and intentional actions, which depend on users’ prior experience. In many

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no chance to produce independent ideas. The problem space is already framed. Because of too little discussion, scrutinising, evaluation and cross-fertilisation, design results often are poor (see for evidence [33])

[4] Existing technical systems supporting group processes concentrate on brainstorming techniques, voting and rational argumentation structures. But the expertise of a moderator is to judge *if and when* such methods are appropriate.

domains where users have concrete experience in the real world, physical models help in expressing and eliciting tacit knowledge [28, 13]. E.g. factory workers are able to show complex movements or process patterns manually, using spatial tacit knowledge, whereas they may not be able to explain it verbally.[5] Thus active participation and contribution of knowledge by all participants is supported. Graspable interfaces can be manipulated by several people in parallel, not interfering with habituated interaction patterns. Social synchronisation/negotiation e.g. usually prevents people from grasping the same object. *Parallel manipulation* can also speed up modelling processes, as it allows interactive interaction and simultaneous work on subparts of the model.

Experience in participatory design, especially with design games, shows that graspable models give *focus* to discussions [2, 30]. Abstract arguments must be concretised in face of the model, thus getting disputable. Discussions do not get stuck in abstract arguments and repetitions because the objects are a steady visible reminder of the problem. Many contradictions and problems are easily visible. This fosters consensus and pragmatic resolution of conflicts. The *visual, public availability* of physical objects makes them function as reminders and can heighten commitment. The physical environment constrains actions (via spatial layout, physical laws, embodyment of domain specific constraints) and enforces focus on the unconstrained remainders. These constraints are all well understood by the participants, because they are visible and familiar.

Gutwin and Greenberg [17] analysed properties of physical workspaces (versus virtual ones) supporting *awareness* of partners and environment. Most properties are valid for graspable interfaces as well. In physical space and through size of the workspace peripheral perception is eased, supporting coordination of actions. People see announcing movements, the actions themselves and results of manipulation. *Deictic actions* [35, 18] augment oral communication, supplementing additional information or directing attention. Objects serve as shared visible reference for communication and resolve ambiguities [35]. In physical space embodied actions are visible for communication partners and thus have *performative meaning* besides manipulating objects [22**,** 35**,** 41]. Body movement can be used as familiar resource of interaction control [41, 18]. Sharing a space bodily also contributes to a feeling of social nearness and raises willingness to cooperate.

Graspable models are *visible externalisations*. They act as anchor, as graspable symbol to point onto and to show something with. Graspable models serve as externalisation for both actor and listener. To the actor, they have two functions. Used as markers, they help in following a line of thought and visualising things to oneself, supporting individual cognition [32]. One interacts with the representation, using the "backtalk" as feedback [37]. While a mental image cannot be separated from its interpretation, externalisations can cue new interpretation and offer the possibility of doubt and ambiguity [26]. Graspable models also relieve the individual from some of the effort of verbalising, thus extending expression ability. At the same time artefacts (and gestures referring to them) are available to communication partners [41], enhancing understanding, often more easily understood than complicated verbal explanations. Graspable models thus can be a medium of communication across the borders of (professional) languages and can be understood before a common vocabulary is developed. Through shared experience of usage and showing things, meaning is associated with and ascribed to the artefacts, forming a new "language-game" [2, 3, 13]. In Susan L. Stars terms graspable models can serve as "boundary object" [39] in developing a common language.

### *2.1.1 What are the effects of the integration of virtual and physical ?*

Up to now I have described effects which hold for graspable interfaces due to their physical parts. But they integrate and blend real and virtual elements. The physical space of the interface is augmented with digital information and controlling abilities. For one physical model there may be many

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[5] What is experience-oriented thus differs between people of different experience. What is abstract to beginners may be very concrete for experts, who can augment the representations by imagination and experience. But to experts things on a higher level will be abstract again and thus be in need of being made concrete.

virtual representations associated. This offers additional transitions (or translations) in-between representations, where each kind of representation may serve different purposes or highlight different aspects. Augmentation can also “add attributes” to models, e.g. colour or behaviour. The digital part of the system can archive models and enables reconstruction of their evolution. Thus alternative solutions and design rationales can be analysed more easily [3]. Simulations allow analysis of results from the complex interplay of decisions and visualise behaviour of the resulting system. The virtual part of graspable interfaces thus compensates for some of the drawbacks of (non-functional) physical models [2]: adding behaviour and attributes which can not be manipulated as easily in the physical world.

Properly designed, graspable interfaces may offer many of those facilities and positive effects which are usually attributed to computer support. Open questions concern which features of real and virtual environments can be integrated into one system without counteracting each other and how to balance this. It is naive to assume that a blend of real and virtual elements automatically brings all positive effects added up. As one needs kind of a ‘zero point’ (or ‘backdrop’) for comparisons, I chose to start by establishing an understanding of the effects of physical 3D interaction with objects for cooperation in order to know ‘what not to destroy’, before expanding the investigation onto mixed configurations of real and virtual components.

### 2.2. Relating effects to key characteristics of graspable interfaces

From published research I extracted a non-comprehensive list of positive effects of graspable models and physical environments (see excerpts above). A closer look, searching for factors enabling these social effects, reveals that many result from common properties. This seems a promising solution to explain which properties make graspable interfaces a valuable tool for cooperative design. Constant visibility, bodily shared space, haptic direct manipulation and parallel access were the most frequent enabling factors. These factors obviously relate to the key characteristics of graspable interfaces (from Brauer [7]). The following graphic shows a subset of this net of relations. At the top are the key characteristics, in the middle the enabling factors, concretising characteristics, below some effects, connected with enabling factors.

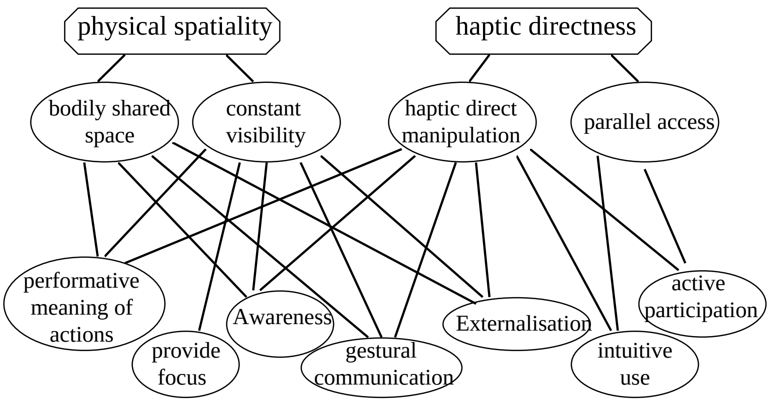



Figure 1. Relation of effects to enabling factors and key characteristics.

*Performative meaning of actions* is enabled through bodily shared space (of actors and objects). Embodied actions [35, 18] are publicly available, meaningful actions that people rely upon in interaction. The living body is at the same time perceiving and being perceived. Thus constant visibility (in physical environments direct result of shared space) is a prerequisite for performative actions and *gestural communication*. Constant visibility also facilitates keeping *focus*. The objects act as steady reminder and invitation to experiment with alternatives. They ground communication and give shared reference; everything said can be compared with the visible model. *Awareness* relies on bodily shared space, constant visibility and haptic direct manipulation. Bodily shared space simply provides the physical properties of air and material. Constant visibility facilitates peripheral awareness. Haptic direct manipulation in bodily shared space makes actions on objects visible, that is announcing movements (opening the hand, moving the arm), the action itself (manipulating objects) and the final result. Because haptic directness implies isomorphic interaction, all of this can be interpreted easily. *Externalisation* heavily relies on constant visibility and haptic direct manipulation. The latter supports the actor by enhancing expression abilities, offering a medium of manipulation and supporting thought [32]. Constant visibility also supports individual cognition as objects serve as external memory aid [26]. For watchers and listeners constant visibility enhances understanding by grounding communication and ensuring availability of performed actions and representations. Artefacts are reference of communication, or medium of demonstrations. Gestures and performative actions can be interpreted as representations [11]. *Intuitive use* is facilitated by haptic direct manipulation, lowering thresholds for active participation. Parallel access and manipulation of the workspace ease *active participation*, because there are fewer time constraints and no artificial synchronisation procedures.

This consideration of the relations between effects and enabling factors needs to be continued and sustained with evidence and empirical support. To achieve a deeper understanding of cooperative modelling, I started analysing videos of groups working with graspable interfaces.

## 3. Analysis of cooperative design with graspable media

As mentioned before, there exist few studies of cooperative design using 3D material which can be manipulated. Most studies focused on design interaction with sketches. The empirical part of my project therefore consists of an investigation of design situations with different kinds of graspable media. As the examples illustrating graspable interfaces have shown, a variety of combinations of real and digital components – that is decisions about the design of these interfaces – is possible. Which elements are real, how they are coupled with virtual ones, which augmentations are made, which manipulations are possible, how the virtual components are controlled and accessed – all of this changes the properties of the graspable interface and affects interaction patterns. I will refer to this as ‘configurations’ of real and digital components. The methodological approach chosen can be described as triangulation across different configurations of real and digital components.

Up to now one video analysis is fully completed, from which results are presented here. It examined a design session using a graspable, but purely physical medium – that is scraps of paper. Analysis confirms some of the claims made earlier about the positive effects of graspable media on cooperation. Starting with analysis of a purely physical medium may be questioned as research approach. But the aim is to explore the possibility and potency of graspable interfaces, not the limitations of current prototypes and systems. This study, by focusing on the effects of a purely physical medium allows a glimpse of this potency and a back-drop against which to compare phenomena in other configurations resp. prototypes of graspable interfaces.

A second study is mid-way. I observed a weekend course on robotics using LEGO-Mindstorm™, which is related to graspable media (although not being one) because it is a combined real-virtual construction kit. A semi-realistic field trial of the EDC [12] has been conducted and is now being evaluated. These studies allow for comparisons and generalisations in the long run.

The approach chosen for analysis of video data is oriented by Interaction Analysis as described by Jordan and Henderson [24]. The analysis of moment-to-moment interaction is deliberately kept free from pre-existing category systems, led by general questions (as explained in [24]) like: the structure of events, temporal organisation, turn taking, participation structure, use of space, influence of artefacts.... Through repeated viewing invisible phenomena become apparent and questions crop up (e.g. on how the design space orientation was negotiated), as repeated viewing alienates the familiar. All findings and hypothesis were cross-checked against the rest of the tape, as hypotheses and conclusions need to be based on evidence on the tape or on explicit knowledge about the context situation. Analysis was pragmatically restricted to topics relevant for the study context and in depth, not focusing on the ethnography of a specific setting, but on general behaviours and phenomena.

### 3.1 Paper prototyping as a graspable medium

In a workshop on PD methods a group of six women used the design game PICTIVE [30]. PICTIVE is a low-tech prototyping method for participatory design of user interfaces, based on paper scraps, pens, scissors and transparent foil. Thus it can be considered a graspable medium of physical material only. The group designed the user interface (touch-screen) for the local transportation ticket machine. One person was assigned the role of technical expert, the others of users. Before starting, they only had ten minutes to get acquainted with the task and the fare structure. These six people sat around a table whose middle was reserved as design space and captured on video. On one side of the table the video tripod was mounted, taping the table in a birds eye view. The video is part of the design method and produces a design record. Material with some potential elements of the user interface had been prepared and distributed on the rim of the table. I transcribed about 40 minutes out of 50, including all visible gestures (about ten missing minutes due to changing the tape). The resulting paper prototype was used to disambiguate some of the verbal interaction and to check the content of unreadable text on scraps of paper.

#### *3.1.1. Types of gestures and frequency distribution*

In comparison with prior studies of face-to-face design sessions which used paper primarily for writing and sketching [42, 31, 5], additional types of actions were found due to the possibility of manipulating the material (cp. Robertson [35]). There are gestures and actions

- *on the rim of the design space*: cutting, scribbling, searching, sorting. These were rarely mentioned yet.
- *referencing the design space* (mostly identical to those in interactions with sketches): simulation of interaction with the system (“kinetic, mimicking” gestures or “enactment” [5, 42, 35]), pointing, indicating an area by circling or waving, and communicative gestures.
- *manipulating the design space* (rare when using paper as drawing surface only): laying scraps of paper, removing scraps, fastening them, rearranging them.

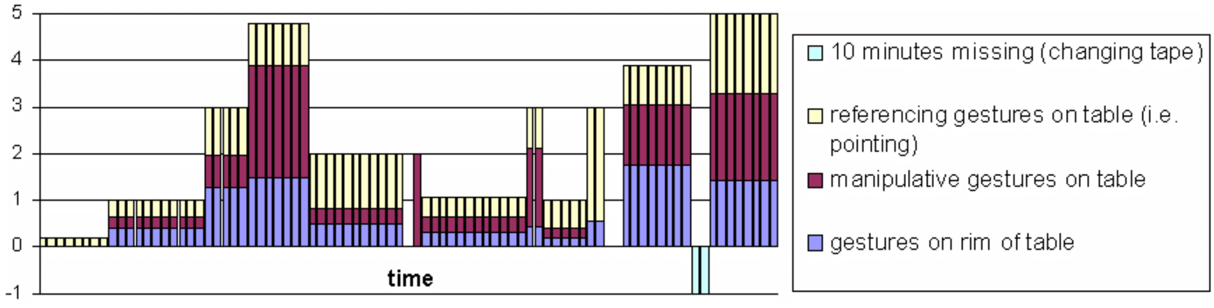



Figure 2. Frequency of gestures over course of the 50 minutes of session
(1 bar represents 30 seconds, 10 minutes of tape change shown as negative value)

I analysed frequencies and types of gestures (averaged per ten second intervals) for these three categories. Gesture frequency and percentage of gesture types vary greatly. After ten minutes of low gesture activity, discussing needs of different user groups, frequency of gestures referring to objects rises rapidly once the group starts designing. During quiet phases with few gestures discussion usually centres on general topics (user groups and requirements, colour choice, text, dialogue flow). In ‘burst’ phases with up to five gestures the group usually rearranges elements and implements ideas, often with several people simultaneously active and creating new elements on the rim.

*3.1.2. Parallel activity: interaction, synchronisation and orchestration*

Analysis shows that parallel activity has an important role in design activity, especially during those 'bursts' of activity when freshly developed design ideas or consensus is transformed into visible design. Besides of several instances of parallel pointing (Figure 3 a), there is parallel manipulation, which is either interactive or independent of each other, interlacing interaction, highly orchestrated, alternating interaction (figure 4) and – most of the time – parallel activity on the rim of the table (see figure 5).

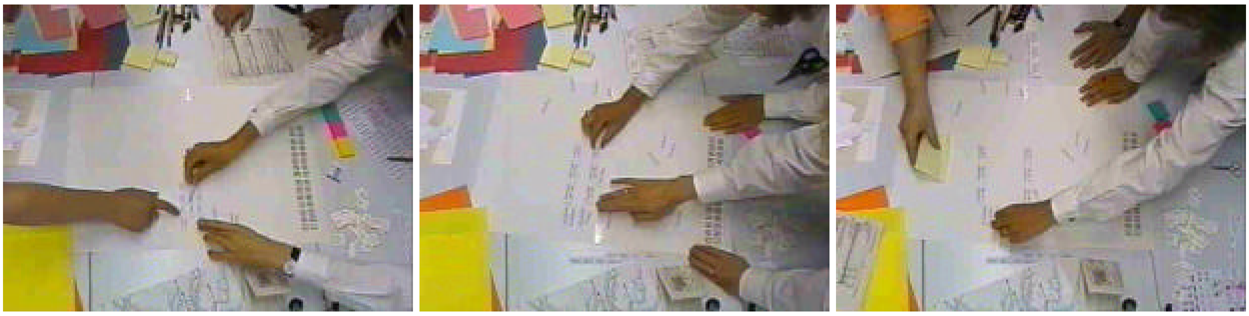


Figure 3. Parallel work: (left to right): a) parallel pointing b) parallel, interactive manipulation, c) parallel but independent synchronous manipulation

Seven scenes show *truly parallel manipulation* (Figure 3 b & c). Four times two persons *interact* in rearranging paper scraps, manipulating highly interactive and synchronous. This seems to occur especially when there is some consensus (shared vision) about design. Usually one person begins to rearrange scraps and a second person assists. This is illustrated with transcript Nr. 1. Three times people *independently but synchronously manipulate* objects in different areas. In addition there are four scenes of almost parallel, *alternating manipulation*, which may either be interpreted as turn-taking with artefacts and bodies (comp. [24]) or as just by accident not parallel executed. There are also several situations with *interlacing* interaction. While one person cuts off paper scraps and lays them into the design space, the other person positions them.

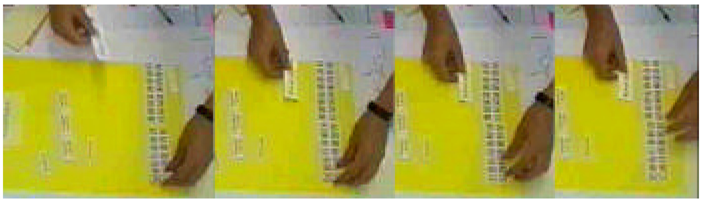


Figure 4. Example of almost parallel, but alternating manipulations (see frames from left to right)

Researchers working on interactive white-boards (personal communication) report no problems from the constraint that touch-sensitive white-boards can only be manipulated by one person at a time. They rarely noticed an impulse to work interactively. This may be due to the higher threshold of intruding into other people's personal space when standing. The results presented indicate that a horizontal workspace produces different interaction patterns. The table promotes parallel activity, because actors' bodies remain on the periphery of the table while only arms and hands reach into the middle. In recent publications Arias and Fischer [3] mention breakdowns due to the use of a touch-sensitive white-board for the EDC system, which enforces a turn-taking and modal interaction. We could observe such breakdowns during our field trial of the EDC [12]. Jordan and Henderson [24] note that group problem solving before a screen differs from groups positioned around a flat table, as the physical arrangement strongly influences the structure of interaction.

Analysis demonstrates the importance of parallel manipulative activity for quick and intuitive interaction and highlights its intricate social orchestration. If the technology used in implementing graspable interfaces prohibits parallel manipulation, these fast and effective social mechanisms are endangered. Technical constraints would destroy peoples ease, produce overhead work of coordinating interaction, and breakdowns would interrupt the flow of interaction.

Transcript Nr. 1 gives an example of parallel, highly interactive manipulation while developing design ideas and testing them at the same time (scene similar to figure 3 b). In this scene U and S interact and cooperate in rearranging scraps and thus in developing design ideas. The ideas evolve in interaction with each other and with the design materials, exploring and extending vague ideas.

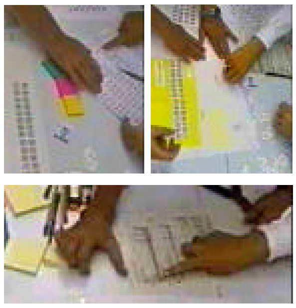


Figure 5. Examples of parallel activity on the rim

Transcript Nr. 1 (lasting from 11.55 to 12.19) (talk translated)

11.55 *Several 'buttons' have been laid down; discussion concerns what kinds of tickets do exist*

**U:** "But the 7-day ticket exists for several price levels ? " *(points to the fare rates information)*

**B:** "That, because" / *(lays new scrap onto ist place)*

**U:** "There is not just <u>one</u> 7-day ticket "

**S:** "That's true??? "

**U:** "Yeah, there are several. " *(points onto fare rates info)*

**D:** "Yes, it should anyway "

**B & S:** "Ah " --

*(**S** points to the middle, rearranges scraps and pulls them down, **U**'s hand approaches)*

**U:** "Then I would, would do it like that -- price level 1

*(**U** pulls left part of upper line (price level 1) further up, while **S** is still busy)*

and then *(**S** now pulls away hand)*

*(**U** takes right part of upper line and lays it - indented - under left part)*

the 7-day ticket here under it. "

**S:** "And then – here " / *(puts hand in middle again, shoves second line of text down while **U** is still busy with upper line)*

**D:** (*interrupts*) " (....) this smaller? " -- --

*(E points to left edge of the upper line and touches it → now 3 hands visible)*

**E:** " We have this one in big, too, I believe "

### *3.1.3. Gesture and talk in interaction*

The session shows a mixture of talk-driven interaction (discussions about requirements analysis and user groups) and instrumental interaction (the concrete physical task of design) (see [24]). Ideas are formed, discussed, and interface elements created during longer phases of discussion with many deictic gestures. When a shared vision is produced, there results a rush of activity of positioning and finishing. Effects on discussion style differ. Sometimes people are busy with preparing and positioning material and almost stop talking, as final design always lags behind discussion. Talk is reduced to a few words (*organisational talk*), organising the activity (e.g. "Here we have this." "short way ticket", "I'd like this to be here"). During heavy action occurs a kind of *fragmented talk*, i.e. parallel lines of talk with organisational talk interjected by short ideas or anecdotal stories. While the group is busy with implementing, individuals sometimes seize the opportunity for longer opinion statements. At the end of the session the group manages rapid talk, involving new ideas, and finishing the design in parallel, including instant implementation of new ideas. Whether this is an effect of time running out or getting accustomed to this type of work can only be speculated.

*Interaction is very quick*. When a person states an idea or requirement and there is no objection, another person usually looks around for material and starts cutting and laying scraps into the design space, while discussion proceeds ('ratification qua execution'). Within 10 seconds, no more than 20 seconds, someone reacts (by searching, cutting, laying) to an idea stated. Thus turn-taking consists of verbal as well as action turns which relate to each other (see [24]). Usually there is no explicit discussion of division of labour. This seems extremely quick and effective. Interaction with paper scraps, which is intuitive and direct, allows implementation and *fast trial of ideas*, shifting in-between design alternatives, as can be seen in the transcript 1.

*Some decisions are pragmatic*. E.g. orientation of the two sheets serving as 'screen' is decided implicitly and pragmatic by use. At (3.30) S. simulates typing on a virtual keyboard in the lower half of the sheet (seen from her), shortly after she points to the lower edge and says "down here". Three minutes later, when scraps are laid, the screen is oriented to her without any arguments. The second screen receives the opposite orientation because D. (sitting opposite S.) makes the first manual suggestion, although not carrying it through. The group pragmatically accepts the first definition of orientation, although two persons will have problems reading text. But only once someone asks what is written on a scrap, the other times this is inferred from conversation.

*Non-verbal participation* is high. Two persons talk markedly less, but contribute almost as many ideas, questions, and objections as the rest. Regarding non-verbal action, quiet persons are active alike talkative. They react on discussion by searching material, creating and laying down new interface elements on their own accord, thus participating and *expressing their opinion non-verbally*. In one example (at 10.30) one can see how the background activity of preparing "buttons" keeps B. thinking about the fare system and what is needed on the interface, as she asks a very concrete question, interjecting it into an ongoing discussion "Is it the same fare for a bicycle regardless of being adult or student?". Non-verbal participation thus *keeps people involved*, allows *parallel activity* and *fosters active participation*.

*Gestures, visible representation and talk augment each other*. Together they produce a vivid vision of design ideas. When the design space is yet void (at 3.50), gesture and talk together produce a first vision how elements could be arranged. The following transcript exemplifies this. It also shows how an orientation of the "screen" is proposed („down here"), implicitly established and accepted by the other participants. In the end, the suggestion is immediately put into action by another participant, indicating that there is a feeling of consensus about the idea.

Transcript Nr. 2: (lasting from 3.55 to 4.10) (talk translated)

*Idea of having a keyboard on the touch-screen has just come up* ---

**S:** "But somehow, I do not know where *(moves hand across lower part of paper surface)*
down here, I can imagine " *(points to left lower edge, then onto upper part of surface)*

**D:** "can I...." / *(interrupted)*

**S:** "To cut all of this out one would go nuts. I believe, We should make a box, "
*(one hand points to sheet with alphabet printed onto it,*
*then makes a two-handed gesture of a square bracket, )*

**B:** "So, one could do that " / *(interrupted)*

**S:** "where one says – keyboard "
*(**U** takes the sheet with the printed alphabet from the table and starts to cut it)*

**D:** "she just showed it nicely, perhaps with something like this? "
*(takes a white slap of paper and lays it where **S** made the bracket gesture)*

*after some arguments about the slap being too small, **U** directs attention to the printed alphabet she is cutting out and suggests cutting it into 2 pieces to form a keyboard (as alternative to producing one from scratch)*

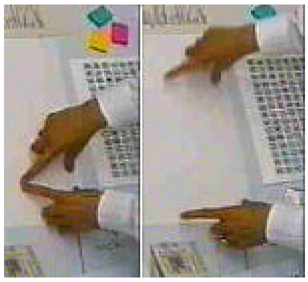


Figure 6.: Bracket-gesture by S.

Further on, this area is referenced to as keyboard area, even before anything is laid down. The same happens for other areas, which e.g. will hold a list of buttons. Verbal and non-verbal suggestions come in one, gestures indicate place and space synchronously with talk, producing a vivid image. Deictic references augment talk and ease expression ("these letters here", "grouping these here", "I want to see the output over there").

*Simulations of user interaction with the system* (enactment) serves either the *summary of results or for clarification*. In total there are eleven simulations, rising in number after the first 15 minutes and occurring usually when a design is partly or fully implemented. Only one occurs when no scraps have been laid yet, demonstrating how the virtual keyboard will work. Simulations usually mix a simulation of user actions (typing, clicking), the systems reaction (dialogue flow, output) and referencing objects and areas of the screen with gestures. Other simulations serve as clarification of results (indicated by words like: "Do we agree that...", "Did I understand correctly, that..."), while summarising and delivering a vivid image.

In simulatory use, *misunderstandings quickly get visible* (e.g. taking a ticket from the screen itself). Because there was no time to simulate the final flow of dialogue along several 'dialogue screens', simulations were restricted to referencing gestures. In final enactment of dialogue flow they would need to include replacing sheets or writing on post-its to indicate change of screens. In other domains one can imagine earlier manipulative gestures during simulation.

Instantly seeing designs results leads to concrete questions (at 11.10: "But the seven-day ticket costs differently for adults and kids?") caused by irritation about the mismatch of knowledge and visible design. Visibility and concreteness of design *offer irritations, evoking questions and objections* (at 16.50, very decisive: "When I already said I'm adult, I do not want to see these parts on pupils!") and *stimulate imagination* about the use situation.

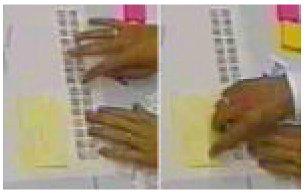
### *3.1.4. Further observations: role of artefacts, nested activity, process and product quality*

There seems to be *shared ownership*, as all participants are allowed to change the design alike and do touch and change scraps. Distribution of labour develops only insofar as the *fare information* exists only once and by size is accessible for two or three people only. It thus *acts as a restricted display* (compare [22]). Only the two people sitting next to it use it as resource, giving information to the rest of the group and checking hypotheses and design ideas. They often cooperatively analyse it. The fare information and prepared other materials serve as reminders (of what is not yet included in the design) and as stimulation. *Prepared material both opens and closes a space of design ideas*, stimulating some ideas, suggesting one trajectory while occluding another.

The session can be interpreted as consisting of *two nested activity systems* (in Activity Theory terms). The outer activity is the workshop on PD methods, the inner activity is the design of an interface with one PD method. In the course of the session the design issue moves to the foreground, as participants take it seriously. Nevertheless there are several focus shifts, when participants ask about the sessions goal, suggest skipping detailed design, or announce the closing of the session. These focus shifts are handled very fluently.

*Quality of both process and product of the session are good.* While still in need of discussing requirements, a quite reasonable proposal was developed within 50 minutes. Discussion covered possible user groups like foreigners, inhabitants and regular commuters, plus different kinds of knowledge (station-name vs. map area). A great deal of controversy covered how to reconcile these

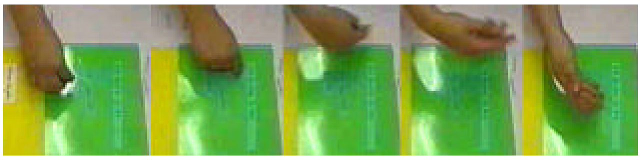
**S:** " I thought, when I type here *(types)*



then I want to see what I type in this output window here, just above it."

Figure 7: Simulation of usage as explanation (at 19.30)

**K:** "Do we agree that when I click here *(taps)*



then this screen is replaced with the other menu? "

Figure 8: Simulation as clarification and summary (28.30)

competing requirements. The first design trial was given up when the group decided to distribute everything on two screens, for better overview and minimising button-pushing. The virtual keyboard is always visible, allowing to type stop names. Touching a map sign opens a map on which to select the area wanted. Help is available for all ticket types. The resulting design proposal is superior in comparison to most ticket automata in German public transportation and would make a good start for detailed design. The video enables recollecting arguments as input for further requirements analysis. As in participatory design prolonged design sessions may discourage prospective users from participating, methods which enable quick idea development and good discussions are very valuable.

### 3.2. Relating results to effects of graspable interfaces

Quality of both process and result indicate in favour of the effectiveness of modelling with graspable material. The medium of paper was used *intuitively*. *Experience-orientation* shows in how participants easily relate scraps of paper to prior experience and adopt complex meaning and usage behaviour, e.g. the possibility of having a virtual keyboard. The importance of *parallel manipulation* has been discussed in length. The *non-verbal activity* of searching, cutting and scribbling together fosters involvement and a feeling of shared activity, it allows parallel action and thus supports active participation. In the session *focus* never got lost, the participants always tried to find new alternatives and played with them. The available materials and information sheets served as reminders and as stimulation, while constraining in some respects, as e.g. the existing fare system couldn't be changed. General discussions always get interrupted by *pragmatic solution ideas* and efforts towards compromise. The *performative meaning of actions* can be discerned e.g. in how laying down scraps signifies acceptance of design ideas or is itself part of a new suggestion. Gestures, talk and visible artefacts interact in producing meaning and shared understanding. *Awareness* can be seen in the sequences of highly interactive manipulation which relies on synchronisation of actions. In addition the group almost always interprets activity on the rim correctly and notices what it contributes to. The positive effects of *externalisations* can be seen in the quick trial of ideas, consciously exploiting the back-talk of the representation. It relieves of verbalising everything, e.g. in simulations of usage, and eases listeners understanding. *Visibility* and concreteness evoke irritation, questions and objections, enforcing focus and clarifying discussion. Over the course of the transcript, the *evolution of a new language game* in which the scraps play the role of boundary objects can be discerned. Meaning is ascribed to parts of the blank surface, even before any scraps are laid down and intended meaning is shown by simulation of usage and talk. Thus understanding builds up and a common vocabulary ('keyboard', 'buttons', 'expert-mode or button', 'Back-button') develops.

## 4. Concluding remarks, Conclusions, and Future Work

The analysis supports the hypothesis of the relation between positive social effects and properties of graspable interfaces. The empirical observation also led to additional arguments and issues which need to be integrated into the theoretical framework.

Specific design recommendations can not be inferred from the reported study, except of the demand that cooperatively used graspable interfaces should support parallel manipulation. Nevertheless the study points to several issues. As background activity keeps participants involved and contributing productively, enabling such background activity might be a valuable design goal. But there are some indications that activity on the rim can distract from ongoing talk, making people miss new ideas (there are two incidents, one needing clarification). How much background activity is positive, at which point do negative effects dominate? The study also indicates that one should design to support non-verbal and non-textual participation, which enhances less talkative peoples chances. Systems should also support the use of gestures (compare [5, 42]). But it is neither technically possible nor sensible to catch *all* details, to mirror the physical world and to interpret everything. This maintains opportunity for social synchronisation and spontaneously evolving group-specific procedures, resp. improvisation (compare [10, 21]). For designing graspable interfaces, we also need to get a better understanding of how the given design space, the representations and materials constrain the design process and the evolving distribution of labour.

The transfer of results from this study ought to be carefully reflected, as the paper prototyping setting took place in physical space, not in hybrid space. The other parts of Brauer's key characteristics of graspable interfaces [7] hold for the observed setting. This can be taken as a shortfall of this characterisation, as it doesn't seem to include enough issues particular to hybrid settings. From the other proposal [43], the paper prototyping setting weakly fulfils two out of four characteristics. The physical objects serve as interactive controls, but there is nothing to control except themselves. They also embody key aspects of the underlying system state, as looking at the physical workspace allows some insight. But there is no underlying digital state, only the groups design vision.

A systematic overview of which characteristics hold for certain systems will be done in the future. More studies of design with graspable interfaces have been conducted [12], resp. are planned. With more empirical studies of graspable media comparison of results across different configurations of real and digital components and relating effects to characteristics will be possible. This research approach will enable structured evaluation of systems regarding cooperative use and the attribution of effects to different design decisions. It will contribute to closing the knowledge gap between single-user interaction and human-human interaction with graspable media and lead to design recommendations. The results show that video analysis of design sessions with graspable media is a fruitful method and motivates further research using similar methods.

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