Graspable Interfaces as Tool for Cooperative Modelling

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Abstract. This article explains the concept of graspable interfaces and analyses their potential as tool for cooperative modelling. It examines positive effects of graspable models on social interaction and presents a model how these effects relate with properties and key characteristics of graspable interfaces. My hypothesis is that these effects result from the key characteristics. Results from a video analysis of cooperative modelling using a graspable medium support the hypothesis. They show the importance of parallel activity, how gestures, talk and artefacts interact in shared understanding, enforce focus and clarification, and how non-verbal activity fosters participation.

1 Introduction and Basic Concepts

Research on graspable (or tangible) user interfaces has focused largely on describing concrete implementations, categorising them, and investigating usability issues of single user interaction. Little has been published on cooperative use yet, although many applications aim at cooperative scenarios. My research project contributes to an understanding of the positive effects of graspable interfaces on cooperative use. This can provide further hints for system design. After introducing the concept of graspable interfaces, their key characteristics and the term ”cooperative modelling”, I will give an overview of positive effects concerning cooperative use and relate these effects to properties and characteristics of graspable interfaces. Then I present results from video analysis of a design session using scraps of paper (what can be interpreted as a graspable medium) which support some of the described effects.

1.1. Characterisation of graspable interfaces

The concept of graspable interfaces evolved (alike Augmented Reality) from growing dissatisfaction with traditional HCI. Researchers searched for alternatives to desktop metaphor and Virtual Reality, wanting people to remain in their natural environment. The physical (life)world should retain its role as central reference, augmented with digital properties and capacities. The concept of graspable interfaces was introduced by Fitzmaurice, Ishii & Buxton (1995). It is pursued in MIT’s tangible media projects (Ishii & Ullmer, 1997), Rauterbergs BUILD-IT system (Fjeld et al., 1999), the Envisionment and Discovery Collaboratory in Boulder, Colorado (Arias, Eden & Fischer, 1997), and the Real Reality approach (Bruns, 1993; Schäfer, Brauer & Bruns, 1997; Bruns, 1999). The latter was developed by the research group of artec in Bremen, of which I am a member. These approaches differ in implementation and focus, while, at the same time, sharing certain main characteristics. Using various technical means physical objects are coupled with digital representations. Any change in the physical arrangement is recognised and interpreted as a controlling action for the digital counterpart. Either spatial configuration, topology, sequence of actions or all of these can be relevant for interpretation. In graspable interfaces the physical objects thus integrate functions of representation and control for digital information (Ullmer & Ishii, 2000). They have representational significance for human onlookers interpreting the system state. Often additional information, e.g. results from simulation, is visually projected onto the physical working space, augmenting the physical model. People thus can interact with physically and digitally represented aspects of the model.

What does it mean for a (real) object to be *graspable*? That it is of material nature, follows physical laws, is situated in an environment and can be experienced by the living body. *Graspable interfaces*, incorporating 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 the locus of control and activity. Different from the concept of token-based access (Holmquist, Redström & Ljungstrand, 1999), they are more than access points to digital information, because they enable creating and modelling new structures.

1.2 Research on graspable interfaces

Up to now research on graspable interfaces focused on implementation, although work contributing to a general understanding increases. Research concentrates on defining concepts and building category systems (e.g. Ullmer & Ishii, 2000), on evaluating usability (e.g. Fjeld et al., 1999) or investigating the users mental models and potential interaction metaphors. Additionally to the laboratory conditions of many evaluations, questions of cooperative use are largely left out of consideration.

Two proposals seem most promising for an understanding of the characteristics of graspable interfaces in terms of human-computer-interaction. Ullmer & Ishii (2000) stress *seamless integration of representation and control*. The physical objects serve simultaneously as interactive physical controls while embodying key aspects of the systems digital state. They are computationally coupled with the underlying (digital) system state and perceptually coupled to digital representations, which are often projected onto the physical workspace. Brauer (1999) defines as special qualities and key characteristics of graspable interfaces the following

a) *Haptic directness* denotes direct manipulation where the physical, graspable objects themselves are the interface and thus allow isomorphic and structure-preserving manipulation. The user has direct contact with the interface elements, feels the resistance of the physical world and has an embodied experience of manipulation.

b) *Physical spatiality* describes the co-presence of user, objects and other users in one interaction space, where input and output space coincide. Interaction takes place IN the user interface. Strictly speaking this characteristic is a prerequisite for haptic directness.

Graspable interfaces are hybrids of real and virtual parts, with each part enhanced with the other (Brauer, 1999). Many implementations of graspable interfaces aim at scenarios of cooperative use (architects discussing urban planning, students learning optical experiments or pneumatics, neighbours discussing neighbourhood development, engineers and workers doing layout and configuration of factories). Graspable interfaces seem to lend themselves to cooperative use and researchers report favourably, while seldom investigating deeper (except e.g. Arias et al., 1997). My research project intends to examine this more closely, contributing to an understanding why graspable interfaces support cooperative modelling, which characteristics exactly contribute to these effects and how this can be consciously exploited in system design.

1.3 Cooperative modelling

Most scenarios of cooperative work with graspable interfaces can be characterised as processes of designing, planning or model building. Planning, designing or learning in groups can provide benefits of drawing from different expertise, comparing perspectives, developing shared views and putting arguments under close scrutiny. The term *cooperative modelling* will be used to denote the common type of cooperation in these scenarios (independent from the particular medium used for modelling!). Cooperative modelling is the shared production/design of something new, therefore a non-routine situation. The result may be subjectively new, as in learning processes, where the process of finding the solution cannot be prescribed. It is a creative and constructive activity, often on open-ended design issues. Because of the differing perspectives and stakes it bears conflict potential. These conflicts must be handled constructively. Thus processes of building up understanding for different perspectives, evaluation of arguments, agreement and settlement are necessary in order to develop shared understanding and solution. The process can be considered successful if participants agree on an ”informed compromise”, feel ”shared ownership” and understand the reasons underlying decisions. In cooperative modelling there is no model monopoly of persons or subgroups, as all members participate actively.

This description denotes an ideal and highlights differences to other forms of cooperation, which rely more on coordination, routine, division of labour, and less on conflict resolution and shared understanding. It focuses on development of shared understanding in highly interactive and argumentative design processes, whereas in engineering cooperative design is often described as coordinated division of design labour or as mere shared access to design data/objects. Cooperative modelling is related closely to participatory design, as PD wants user involvement to exceed reacting on given proposals and to actively participate in design. In PD, users and system designers build a shared practice of design, often using non-linguistic tools which allow hands-on exploration and evoke tacit knowledge (Ehn, 1993; Kyng, 1995). Use of mock-ups in PD methods resembles cooperative modelling with graspable interfaces.

Crutzen (2000) argues that information systems tend to support routine activity. The notion of interaction as held widely in computer science still relies on the information transfer model of causal impulse-reflex processes between sender and receiver and focuses on routine action. She describes another notion of interaction, situated in life-world, 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 and leading to new understanding and to the *activity of change*. Crutzens view calls for information systems to enhance the visibility of differences and to support us in reviewing and changing our beliefs, in creating new meaning and giving up routines. Taking her view into account, cooperative modelling relies on accepting irritations caused by different perspectives or the problem domain and on constructing new meaning. Without any irritations there will not result anything new because routine, custom or habit govern thinking.

2. Effects of Graspable Interfaces on Cooperation

Whereas there are many studies showing the important characteristics of paper as a medium due to its physicality, only few studies 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 on cooperation. Much interesting work is done in ethnographic studies and is influenced by distributed cognition, situated cognition or activity theory. Due to the space limitations given here, 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 success. Thus mediation or moderation may be necessary. This is a task of humans, who can react flexible, relying on embodied experience. Existing technical systems supposed to support group processes concentrate on brainstorming techniques, voting and rational argumentation structures. But the expertise of a moderator lies in deciding *when* these methods are appropriate. Often the most important part of a meeting is free discussion about arguments, ideas and their relation, building new understanding. Graspable interfaces do not interfere in this free discussion, but support it.

2.1. Description of effects

Concrete graspable models allow for playful, intuitive and experience-oriented ways of interaction (Bruns, 1993). This is especially important for heterogeneous groups and people without abstract access to the subject domain. This holds for learners as well as for workers, whose tacit knowledge is concrete and not abstract. We can discern two levels of intuitiveness. *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 (Muller, 1993; Ehn, 1993). Intuitive manipulation thus 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 of the domain. What exactly experience-orientation means, thus differs. In many domains where users have concrete experience in the real world, physical models help in expressing and eliciting tacit knowledge (Kyng 1995, Ehn 1993). 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. Thus active participation and contribution of knowledge by all participants is supported. Graspable interfaces can be *manipulated by several people in parallel*, thus not interfering with habituated interaction patterns, which serve as social synchronisation mechanisms. Social synchronisation/negotiation e.g. usually prevents people form 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.

Experiences in participatory design, especially with design games, show that graspable models or artefacts provide *focus* to discussions (Arias et al., 1997; Muller, 1993).

Abstract arguments must be concretised in face of the model, thus getting disputable. Discussion does not get stuck in abstract arguments and endless repetitions because the objects are a steady visible reminder of the problem. Many contradictions and problems get visible more easily and graspable artefacts cannot be talked away. This fosters consensus and pragmatic resolution of conflicts. Their visual, public availability facilitates the function of physical object as reminders and can heighten commitment.

Gutwin & Greenberg (1998) analyse central properties of physical workspaces (versus virtual ones) supporting *awareness* of partners and environment. Most of these can be taken to hold for graspable interfaces. In physical space and through the size of the visible workspace peripheral perception is eased, supporting coordination of actions.[1] People see announcing movements, the actions themselves, and the results of manipulation. *Deictic actions* augment oral communication, supplementing additional information or directing attention. Objects serve as shared, visible reference for communication and resolve ambiguities (Robertson, 1997). In physical space embodied actions are visible for communication partners and thus have *performative meaning* besides of manipulating objects (Robertson, 1997). Body movement can be used as familiar resource of interaction control. Sharing a space bodily also contributes to a feeling of *social nearness* and can raise willingness to cooperate.

Graspable models are *visible externalisations*. They can act as anchor, as graspable symbol to point onto and to show something with. Graspable models serve as externalisation for the acting person in two ways. Being used as markers, they help in following a line of thought and visualise things to oneself, supporting individual cognition (Norman, 1994). The person interacts with the representation, using the ”backtalk” of the situation as feedback. While a mental image cannot be separated from its interpretation, externalisations can cue new interpretation and offer the possibility of doubt and ambiguity (Kirsh, 1995). Graspable models also relieve the individual from some of the effort of verbalising, thus extending expression ability. At the same time the artefacts are visible to the listening/watching person, enhancing their understanding, often more easily understood than complicated verbal explanations.

Graspable models can thus be a medium of communication across the borders of (professional) languages and can be understood before a common vocabulary is found. Through shared experience of usage and showing things, meaning is associated with and ascribed to the artefacts, forming a new ”language-game” (Ehn, 1993; Arias et al., 1997;

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[1] Crutzen (2000) describes interaction as a process to which conscious commitment and involvement are central and scrutinises the CSCW definition of awareness as a vague indication of this. She points out that ”social awareness” is usually associated simply with the perceptibility of information. Thus we have to be careful, not to infer from the availability of information on social results. Perceptibility makes it easier to concentrate on crucial aspects of communication and can improve shared understanding, if sensitivity for the situation and for each other and the will to accept irritation exist.

Arias & Fischer, 2000). In Susan L. Stars terms graspable models can serve as ”boundary object” in developing a common language.

Up to now only effects due to the physical parts of graspable interfaces have been described. But they integrate 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 virtual representations associated. This offers additional transitions (or translations) in-between representations, where each kind of representation may serve different purposes or highlight different properties of the information. Augmentation can also ”add attributes” to the physical model, e.g. colour or behaviour. Users interact with both real and digitally represented aspects of the system. 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 (Arias & Fischer, 2000). Simulations allow for an 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 physical models (Arias et al. 1997), adding behaviour and attributes which can not be manipulated as easily in the physical world.

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 workspace. A closer look, searching for enabling/facilitating factors of these social effects, reveals that many result from common properties. These properties coincide with the key characteristics of graspable interfaces. This hypothesis seems a promising solution to explain which properties render graspable interfaces a valuable tool for cooperative modelling. Looking for enabling factors I found most often constant visibility, bodily shared space, haptic direct manipulation and parallel access. These factors obviously relate to the key characteristics of graspable interfaces from (Brauer, 1999). The following graphic shows a subset of this net-structure. At the top are the key characteristics, in the middle the enabling factors, concretising the characteristics, below some effects, connected with enabling factors.

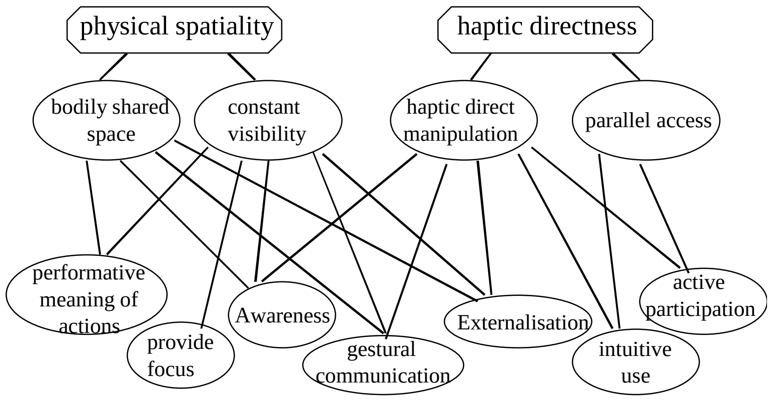

Figure 1. Relation of effects to enabling factors and key characteristics.

Performative meaning of actions is enabled through bodily shared space (of actors and objects). Embodied actions (Robertson 1997) 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 the physical world a result of shared space) is a prerequisite for performative actions and *gestural communication*. A broken off attempt to manipulate the workspace is noticed and attracts attention. The moderator looking on his/her watch gives a (cultural) sign to come to an end.

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, as described by (Gutwin & Greenberg, 1998) 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 final results (in most virtual workspaces the only thing visible). 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 (Norman, 1994). Constant visibility also supports individual cognition, as objects serve as external memory aid (Kirsh, 1995). For watchers and listeners constant visibility enhances understanding by grounding communication and visibility of performed actions and representations. Artefacts are reference of communication or medium of demonstration. Gestures and performative actions can be interpreted as representations (Crutzen, 2000).

Intuitive use is facilitated by haptic direct manipulation, lowering thresholds for active participation. When parallel manipulation of the workspace eases *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 will be sustained with evidence and empirical support for these relations. To achieve a deeper understanding of cooperative modelling processes, I started analysing video material of groups working with graspable interfaces.

2.3 Video analysis of a design session with a graspable medium

In a seminar on PD methods a group of six women used the design game PICTIVE (Muller, 1993). PICTIVE is a low-tech prototyping method for the participatory design of user interfaces, using paper scraps, pens, scissors and transparent foil. Thus it can be considered a graspable medium of physical material only (without digital elements). The group designed the user interface for the local transportation ticket machine. One person was assigned the role of technical expert, the others of users. These six people sat around a table whose centre was reserved as design space and was captured on video. Material was distributed surrounding the centre. The moderator had prepared some potential elements for the user interface (sheets of paper with prepared text). I transcribed about 40 minutes of the 50 minute session, including all visible gestures.

Types of activity and frequency distribution

In comparison with prior studies of face-to-face design sessions which used paper primarily for writing and drawing (Tang, 1991; Neilsen & Lee, 1994; Bekker, 1995), there are additional types of actions due to the possibility of manipulating the material (cp. Robertson, 1997). There are gestures and actions

- *on the rim* of the central design space,, e.g.: cutting, writing, scribbling, searching, sorting of scraps. These have rarely been mentioned yet.
- *referencing the design space* (mostly identical to interaction with sketches) These consist of: simulating interaction with the system (”kinetic, mimicking” gestures (Bekker, 1995), or ”enactment” (Tang, 1991; Robertson, 1997)), pointing onto something, indicating an area by circling or waving, and communicative gestures.
- *manipulating the design space* (rare when using paper as drawing surface). This is laying scraps of paper, removing scraps, fastening them with glue, rearranging or shifting positions (from seemingly unconscious, playful little moves, over tidying and straightening out, up to complete new arrangement).

I analysed frequencies and types of gestures. Very often on pointing or circling the hand persists, enforcing performative meaning. This persisting has not been counted.

Categorising gestures is a very subjective task, because categories depend on goals. As gesture function is not always evident or gestures serve several purposes, analysis was restricted to the three categories above. I counted as gesture every movement which could be interpreted as meaningful action and occurred in one flow of movement. Chains of gestures have been counted as several gestures, according to reference and meaning.

After ten minutes of low activity, frequency of gestures referring to objects rises rapidly. There are four phases with a ”burst” of gesturing. During quiet phases with on average one (seldom two) gestures in a ten second interval discussion usually centres on more general topics (user requirements, colour choice, text, dialogue flow). In phases rich of gestures frequency rises up to four to five gestures average per interval. In these phases the group usually rearranges interface elements. Often several people are active and other persons in parallel create new elements at the rim. Sometimes four persons are simultaneously active. While one person lays down scraps or shifts their position, the other persons point to other areas of the design space while talking.

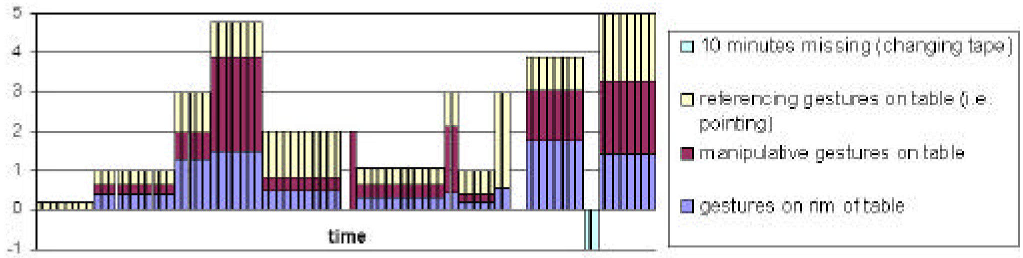

Figure 2. Frequency of gesture types over time
(1 bar = 30 seconds, 10 minutes of tape changing shown as negative value)

Parallel activity: interaction, synchronisation and orchestration

The horizontal workspace promotes parallel activity, because actors’ bodies remain on the periphery of the table while only arms and hands reach into the middle. Working on a blackboard would require more proximity. Researchers working on applications of interactive whiteboards (informally) report no problems although 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 peoples personal space when standing before a wall-blackboard. In contrast, in recent publications Arias & Fischer (2000) report of breakdowns in use of the EDC system, which has a touch-sensitive whiteboard as planning table, because the touch-screen realisation creates a turn-taking and modal interaction.

Fascinating are several scenes with highly ”orchestrated”, almost parallel manipulat-ive actions. One has to look closely, frame-by-frame, to observe that these are not par-allel, but alternating manipulations. These are examples of social synchronisation and negotiation of floor control. If the technology used in implementation of graspable interfaces prohibits parallel manipulation, this fast and effective manipulation is endangered, as there is no guarantee that the social synchronisation always works out. Knowing of this constraint runs danger of destroying peoples ease in handling the system and makes them concentrate on the constraint.

Seven scenes show truly parallel manipulation. Four times two persons interacted in rearranging paper scraps, manipulating highly interactive and synchronised. This seems to occur especially when there is some consensus (shared vision) about the design. Usually one person begins to rearrange scraps and a second person helps by dragging scraps away to create free space or removes unnecessary objects. Three times people independently but synchronously manipulated objects in different areas of the interface. There are also situations with interlacing interaction. While one person cuts off paper scraps and lays them into the design space, the other person takes these and positions them.

Figure 3. Parallel work: (left: parallel pointing and arranging scraps, right: parallel, interactive manipulation of rearranging).

Gesture and talk in interaction

In-between ”bursts” there are longer phases of discussion with many deictic gestures, referencing design space, and laying down material. During these phases ideas are formed, discussed, and interface elements created. When a shared vision is produced, there results a rush of activity of positioning and finishing the screen. Effects on discussion style differ. Sometimes people are so busy with preparing and positioning material that they 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”, ”Where is X?”, ”OK”). During heavy action we also find a kind of *fragmented talk*, i.e. several lines of talk in parallel with some people doing organisational talk, other people interjecting short ideas or telling anecdotal stories (i.e. on ticket automata in other cities). When discussion proceeds while the group is busy, people sometimes take the opportunity for longer statements of opinions or explaining problems. At the end 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 the type of work can only be speculated.

Interaction is very quick. When someone states an idea or requirement and there is no objection, others usually look around for material and start cutting and laying the scraps into the design space, while discussion proceeds (background activity). This reaction takes place often immediately, usually within 10 seconds, no more than 20 seconds, and sometimes even includes asking ”who does it?” Comparing this with other experiences in group work, this is extremely quick and effective.

Often decisions are pragmatic. E.g. orientation of the two sheets serving as ”screen” is decided implicitly and pragmatically by first use. At (4.00) Sharon simulates typing on a virtual keyboard in the lower half of the sheet (seen from her), then she points to the lower edge and says ”down here”. Three minutes later, when scraps are laid, the screen is oriented facing her without any further argument. The second screen receives the opposite orientation because Debbie (sitting opposite Sharon) makes the first manual suggestion, although not carrying it through. The group pragmatically accepts the first definition of orientation, although someone always will have problems reading text. But only once there is a question regarding what is written on a scrap, the other times this is inferred from conversation.

There are very different proportions of speech. Two persons talk markedly less, but contribute almost as many ideas, questions, and objections as the rest. These have been accepted alike ideas from talkative persons. Regarding non-verbal action, these quiet persons are active. They react on discussion by searching material or information, creating new interface elements, cutting, writing, laying down, all on their own accord. They thus participate and express their opinion non-verbally. In one example (at 10.30) we can see how her activity of preparing ”buttons” keeps Lynn thinking about the fare system and what is needed on the interface. This can be deduced form her question ”Is it the same fare for a bicycle regardless of being adult or student?”

Gestures, visible representation and talk augment each other. When the design space is yet void (2.00), gesture and talk produce a first vision how interface elements could be arranged. Debbie: ”I’d like to see a list somewhere” (waves hand in the middle). Sharon: ”We could make a box, where one says - keyboard” (makes a two-handed gesture of a square bracket, indicating area, size and form). Sharon also explains how a virtual keyboard works, simulating its usage and indicating size and area. Further on, these areas are referenced with this meaning. Thus talk and gesture in interaction help in evolving a common language. Verbal and non-verbal suggestions come in one flow, 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”).

Later on user interaction with the system is simulated (enactment) serving (here) either the summary of results or clarification. The first summary (9.40) uses a mixture of simulating usage and referencing ”buttons”, delivering a very concrete summary of design results. Then the summary seamlessly shifts into new questions. The other simulations (e.g. 16.20 and 31.00) serve as clarification of results (”Do we agree, that...”, ”Did I understand correctly, that...”), summarising and producing a vivid image. In simulations, 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, using several sheets as ”dialogue screens”, simulations were restricted to referencing gestures. In other domains one could imagine earlier manipulative gestures in simulation. Instantly seeing designs results leads to concrete questions (at 11.10 Ruth: ”But the seven-day ticket costs differently for adults and kids?”) caused by irritation about the mismatch of knowledge and design. Visibility and concreteness of design offer irritations, evoking questions and objections (16.50 Debbie, angry: ”When I already said I’m adult, I do not want to see these parts on pupils!”) and stimulate imagination of the use situation.

3 Conclusion

These empirical findings stress the importance of parallel manipulative activity. They show how gestures, talk and visible artefacts interact in producing meaning and shared understanding. Graspable media promote quick and pragmatic interaction and fast trials of ideas. Visibility and concreteness evoke irritation, questions and objections, enforcing focus and clarifying discussion. Searching, cutting and scribbling together fosters involvement, produces a dynamic atmosphere and a feeling of shared activity. Non-verbal activity keeps people involved, allows parallel action and thus supports active participation. The group developed a reasonable proposal within 50 minutes while discussing central questions regarding requirements and design, while having only ten minutes to get accustomed to the task. This can be seen as indication for the effectiveness of modelling with graspable material. These results can be transferred to graspable interfaces concerning their physical elements. The analysis thus supports my hypothesis of the relation between positive social effects and properties of graspable interfaces.

As next step I will look closer to the transcript to relate the findings with the collected positive social effects and the enabling factors of graspable models. How the social effects contribute to successful cooperative modelling has to be examined. I also want to look at different scenarios and application domains with more resemblance to graspable interfaces, integrating real and virtual system elements.

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