This is the accepted version of the paper, the final publication is available at Springer via
http://dx.doi.org/ 10.1007/s10798-015-9314-3

Designing *Interaction* – How interaction design students address interaction

Klas Karlgren[1], Robert Ramberg[2], Henrik Artman[3]

[1]Karolinska Institutet, Department of Learning, Informatics, Management and Ethics, 171 77 Stockholm, Sweden

[2]Stockholm University, Department of Computer and Systems Sciences, 164 07 Kista, Sweden

[3]KTH Royal Institute of Technology, School of Computer Science and Communication, 100 44 Stockholm, Sweden

Corresponding author: klas.karlgren@ki.se +46-70-718 10 02

Abstract

Interaction design is usually described as being concerned with interactions with and through artifacts but independent of a specific implementation. Design work has been characterized as a conversation between the designer and the situation and this conversation poses a particular challenge for interaction design as interactions can be elusive and difficult to describe. Moreover, current trends in interaction design introduce physical materials to a higher degree resulting in even more complex design situations. There is a lack of knowledge about how interaction designers, and especially students, address the very phenomenon of interaction. This study contributes by describing how interaction design students attempt to address aspects of interaction and by presenting an in-depth analysis in the context of an interactionary-type design exercise.

The quantitative and qualitative findings showed that (1) the design students brought up aspects of interactivity and dynamics through talk and gestures but (2) a comprehensive design idea about interaction did not guide the design work and they were to a little degree engaged in planning sequences of interactions or interaction on a longer time scale; (3) using physical materials disrupted interaction design, and, (4) there was a lack of continuity when addressing interaction compared to how proposals about artifacts were pursued.

As interaction is the core of interaction design, the findings are discussed in terms of how the immaterial design materials may "talk back" to designers. Practical strategies for how the observed phenomena could be constructively addressed within interaction design education are suggested.

Key words: Interaction design, design education, interaction, interactivity, sketching, interactionary

Introduction & Background

The technological agnosticism of interaction design

Interaction design is usually described as being concerned with facilitating interactions with artifacts or between humans through artifacts. The discipline of interaction design is distinguished by its interest in "behavior, function, and information" (Cooper 2004, p.22). Some characterizations of interaction design emphasize that interaction design not only should focus on interactions and behaviors but should do so as independently of a particular implementation as possible, e.g., (Benyon 2010). Dan Saffer similarly argues that interaction design is concerned with the behavior of products and services and how products and services work but that it should be "technologically agnostic" (Saffer 2007). Existing technologies evolve and new ones are constantly introduced motivating that interaction design shouldn't align itself to a particular technology or medium (ibid). It has also been pointed out that there is an ongoing process of "dematerialization" of products; CD's, coins and bills, books, music albums and photos are disappearing as independent products and are instead being accessed through other artifacts or networks (Van Campenhout et al. 2013). New ways of consuming music and books, enjoying photos and paying have followed. This departure of artifacts has changed the character of our interaction with devices that surround us and it has been pointed out that interaction may lose some of it physical richness and become more abstract in character which in turn has spurred a discussion about the challenges for designers (Van Campenhout et al. 2013).

Early on, Winograd identified interaction rather than “the machinery” or even its interface as the primary topic of what interaction designers need to be engaged in (Winograd 1997). He pointed at the increasing importance of “designing spaces for human communication and interaction” that would require designers “*to master the principles and complexities of interaction and interactive spaces*”. Understanding and analyzing human interaction and communication has however proven to be complex. Jordan and Henderson described the complexity of analyzing human interaction and the use of artifacts and technologies when proposing Interaction Analysis as an analytical approach suitable for such tasks. Some of the analytic foci they proposed concerned the temporal organization of activity (rhythm and periodicity, turn-taking etc) as well as how analysts structure events chronologically in e.g., beginnings, endings and how durations are segmented. They concluded by pointing out that a mutually agreed upon language for talking about their practice is lacking.

The lack of an established language has similarly been noted in the interaction design community itself. A language is needed to express design ideas and design qualities (Löwgren and Stolterman 2004) and interaction design lacks a developed language unique to interactive technologies and is still drawing on the language of previous creative modes in the way early stages of cinema was conceptualized in the languages of books and theater (Crampton Smith 2007). Gillian Crampton Smith suggested that one of the "dimensions" of a language of interaction design is *time* with which the user interacts with the interface (Crampton Smith 2007). Sounds, video, and animations are stretched over time and can be used to give feedback to users of an interface or to tell complex stories with limited means if designed well (ibid). Löwgren and Stolterman argue that digital artifacts are "temporal", and have emergent qualities which do not emerge until they are used over time (Löwgren and Stolterman 2004). They have suggested a number of "use qualities" for digital design materials, i.e., properties of a digital design which transcend the specific design itself and that emerge in the interaction with users over time (Löwgren 2002). Löwgren and Stolterman call this the dynamic gestalt of an artifact, e.g., a digital artifact can have a temporal flow with different feels to it (“calm, rapid, or stressful”) and to be able to conceptualize and talk about these qualities, several articulations have been proposed such as “fluency”, “flexibility”, “autonomy” etc. (Löwgren 2002; Löwgren and Stolterman 2004). Furthermore, Buxton has described how interaction designers can go about to sketch interaction and has made the argument that sketches of interaction must be distinct from other kinds of sketches, as they need to deal with time, phrasing, transitions, dynamics, feel and other unique attributes of interactive systems (Buxton 2007). However, as pointed out by Myers and colleagues, Buxton’s book says little about how to determine and achieve the behaviors (Myers et al. 2008). Yet in a survey study, Myers and colleagues found that most designers (86%) reported that it is more difficult to prototype the behavior than the appearance, and, 76% of the designers felt that the behavior was more difficult to communicate to the developer than the appearance (ibid.). Even so, few studies have focused on how the interactive behavior of an interface is created and communicated (ibid.). Kevin Silver described designing behaviors as dictating "the flow between actions and reactions", these

making up interactions (Silver 2007). Silver has therefore proposed a dimension to an interaction design language specifically focusing on behaviors—including actions and reactions, or, operations and presentation.

Another central task of interaction designers is to consider the possible sequences of interactions with and through technology that are enabled through artifacts being designed. An artifact imposes structure and order on how tasks can be conducted (cf. flexibility and autonomy in Löwgren's terms). Benyon argues similarly that interaction design is concerned with "with the structuring and sequencing of the interactions" (Benyon 2010, p. 54).

Context is central to any interaction and communication (Suchman 1987) and for interaction designers considering future situations this poses a challenge: from a designer's perspective taking into account the context of use of a proposed artifact means an inquiry into situations that do not yet exist, namely the future situations of use (Gedenryd 1998). Donald Schön has described design as a conversation between the designer and the situation; designers make things and the moves of designers shape situations and these eventually begin to "talk back" (Schön 1983) to the designers revealing new opportunities and challenges. Now and then designers produce unintended changes and by taking into account such unexpected consequences and the opportunities and challenges that they imply, designers may form new appreciations and understandings and make new design moves and thereby continue a reflective conversation with the situation. Although Schön's discussion was founded on examples from the field of architecture, the view of designers engaging in conversations with design situations has been widely influential also in interaction design (Dearden 2006; Löwgren and Stolterman 2004). Interaction designers are however confronted by particular challenges due to the elusiveness of digital design materials making it more difficult to capture the opportunities and challenges of back-talk. Ozenc and colleagues have noted that designers lack tools that support a reflecting conversation with the material of software (Ozenc et al. 2010). They suggest sketching with scenarios as an analogy to sketching physical products with a pencil on paper: "By sketching with scenarios, designers can explore how products might participate in a transaction over time, inventing features and controls as a reaction to the unfolding social situation" (ibid, p.1).

Similarly, a recent line of thinking in contemporary theory in educational psychology, applied cognitive science, and computer-supported collaborative learning tends to more than previously emphasize the role of the artifacts per se, and especially the interaction *through* these artifacts, in attempts to describe the dynamics of innovation (Paavola and Hakkarainen 2005). The 'turn towards objects' in these theories draws on the ideas about mediating artifacts (tools and signs) in cultural-historical activity theory (Engeström et al. 1999), knowledge-building of conceptual entities as presented by Carl Bereiter (Bereiter 2002), and the pragmatist Charles S. Peirce's philosophy on how human activity is mediated by sign-processes and practices. Also within interaction design (Robles and Wiberg 2010; Wiberg 2013; Sundström et al. 2011) have argued for what has been coined a "material turn" in interaction design acknowledging the material dimensions of the subject.

Interaction designers are required to address a number of issues or aspects related to interaction. If the focus of interaction design is on properties that do not emerge until actual use, and if sketches need to deal with time and dynamics, how then is interaction addressed in practice by interaction designers? And how do students learn to master such skills and competencies? Corinne Sas has called attention to the many challenges of teaching interaction design, e.g., the need to provide qualified feedback to students and how such feedback needs to be based on an understanding of how students organize their work which often is a problem for supervising teachers (Sas 2006). Different formats have been proposed to aid in overcoming these problems, for instance by adapting the format of interactionaries to expose design in progress (Ramberg et al. 2013).

Previous studies have shed some knowledge about how experienced practitioners may go about sketching interaction: Myers and colleagues found that most designers in their study used sketches and storyboards as part of their work and also agreed that sketches and storyboards are not sufficient for exploring interactive behaviors: the designers extensively used annotations such as labels, arrows, and narrative textual descriptions to describe the behaviors (Myers et al. 2008). Similarly, Barros and Velloso (2013) have in a study conducted with professional interaction designers developed a technique to improve sketching of interaction. The proposed technique aims to aid in representing interactions over time by use of *frames*, to organize different sketches and better represent interaction by use of *colors*, to represent

user actions and improve consistency in specific situations by use of *symbols*, and the use of *rules* to aid in applying the technique. Providing with detailed notations of how to sketch and represent aspects of interaction helped representing interaction. However, as noted by the authors, proficient use of the technique requires training (Barros and Velloso 2013).

Tholander and colleagues analyzed how interaction designers expressed interaction and dynamics through white board drawings and observed that whiteboard sketches did not carry meaning in themselves but *were made* meaningful through the talk accompanying the sketching activity as well as through the bodily movement and gestures of the designers oriented towards the drawings (Tholander et al. 2008).

The Research Problem, Aim and Research Questions

There is a lack of a well-established design language oriented towards the particular attributes of interactions. Moreover, how interaction designers in fact address interaction has not been investigated at depth. There is especially a lack of knowledge about how students of interaction design address, represent and reason about interaction during design work. Unawareness about such key issues may ultimately obstruct competence development of individual designers. There is also a risk that efforts put into teaching and supervision are misguided or invested sub-optimally – there is thus a need to further our understanding of how students approach and deal with interaction and interactive artifacts in order to plan supervision and teaching better.

The aim of this study was therefore to investigate how students of interaction design address interaction during design work carried out in extended interactionaries. We address the following research questions; i) How do students address interaction? ii) How do the students utilize physical materials? and iii) Which aspects of interaction are attended to and how?

Methods

Participants

Eight groups of self-selected interaction design students at a Swedish university were asked to work on a task of designing interactive artifacts. The student groups consisted of two to five students. In this article we have chosen to focus on two groups that to a larger extent than the other groups adhered to instructions given in the design brief. The student groups were first year students in interaction design having previously studied courses in computer science, human-computer interaction and prototyping before taking part in the study. Participating in the study was voluntary and was not part of their ordinary course work.

Interactionaries

An interactionary is a pseudo game show type format that allows teams to work on the same design problem on stage while assessed by a judge. The format was introduced by Scott Berkun as a way to "to expose the dynamic intangibles of design in progress, and allow an audience to listen in on four teams and observing how they work" (Berkun 2001). The design teams are scored by a group of judges on how well they do team work, handle a process, the final design and user-centeredness. A major constraint is that the teams are only allowed to work for a very short time (10 minutes) making the exercises fun and challenging.

In our work we adapted the concept of interactionary. We deliberately defined "wicked problems", i.e., unstructured problems that do not have one single solution. The students were presented with instructions containing a design brief on physical twittering with design constraints such as not being allowed to use conventional screens in the design proposals, thus aiming for physical interaction. The students were also presented with concepts and descriptions of core aspects relating to interaction (elaborated below). The design groups were allowed to work on their designs for a longer period of time than that of the original format, 25 minutes as compared to 10 minutes. They were asked to create design proposals including an artifact (i.e. a physical representation of the design proposal) and a use scenario with a special focus on interactive aspects of the artifact and its use. The students were further informed

they were to give a presentation of their final proposal to another group of students assigned the role of critiquing the design proposal (design reviewers).

The design groups were provided with various design resources (whiteboard, clay, paper, plastic paper, paper, scissors, Lego™, pencils etc.) to use in their design work. The room they worked in was spacious enough to allow the students to diverge and form subgroups to approach different tasks, as they seemed fit. The room was also equipped with a large whiteboard where they could sketch or present flow charts or other notations.

Framework for analysis

The design sessions were video recorded from two different angles and the video data was analyzed using interaction analysis (Jordan and Henderson 1995). Interaction analysis builds on ethnomethodology (Garfinkel 1967) and conversation analysis (Sacks et al. 1974). Viewing and transcribing of video recordings has been conducted both individually and in collaboration to try to neutralize any preconceived notions of the authors.

In the empirical study we have especially addressed five core aspects relating to interaction. By "addressing interaction" we refer to any means by which the students/designers bring up interaction that contributes to the interaction design work. We intentionally leave it an open question whether this is done through the use of spoken language, sketches, gestures, movement, drawing, and models.

The selection of the concepts was based on discussions with interaction designers and by reviewing interaction design literature. Another source has been the literature on how human communication and interaction is analyzed (Jordan and Henderson 1995; Linell and Gustavsson 1987). The five aspects were chosen because they were considered as important or recurring when considering interaction during interaction analysis or design. We do not claim that the set of aspects fully captures all possible aspects related to interaction. The aspects are not mutually exclusive but point out characteristics of any interactive computer system. Below is a summary and synthesis of aspects of interaction considered in relation to the literature presented in the background section (Table 1). Each aspect is then exemplified in more detail.

Table 1. Aspects of interaction and sources

Aspect of interaction	Sources
Dynamics	Buxton 2010, Löwgren & Stolterman 2004
Temporality	Buxton 2010, Crampton Smith 2007, Löwgren & Stolterman 2004
Interactivity	Löwgren & Stolterman 2004, Silver 2007
Sequentiality	Benyon 2010, Löwgren 2002
Context of use	Gedenryd 1998, Ozenc et al 2010, Suchman 1987

1. The dynamics aspect refers to indications of current and changing modes and states and how the system adapts to situations, tasks, people etc.
2. Temporality refers to time and can concern the extension over time, duration, immediacy, delays, pauses, segmentation, pace, rhythm and periodicity.
3. Interactivity refers to how users and artifacts initiate and respond to actions including openings, turn-taking and closures.
4. Sequentiality refers to how interactions are ordered and structured; how courses of events are planned and how much freedom, control, guidance, support etc are built into activities with the system.
5. Context of use refers to placing the planned activities or system in specific social and physical contexts which exemplify the artifact in use.

We account for two groups of students that represent two different examples of how a design task can be approached. By focusing on the use of different materials in representing and re-representing design ideas, taken together with an analysis of how frequently aspects of interaction were addressed, we could observe how the student groups organized their work throughout the design process. Three raters

independently rated the ways in which students addressed the five aspects of interaction. Ratings were based on an assessment protocol defining the characteristics of each aspect (see above). During the video analysis, each rater noted the occurrence of each aspect of interaction during ten second intervals. After individual, independent ratings the raters discussed and aligned their ratings. Final inter-rater reliability coefficients were 91% (group1 referred to as the Bird group below) and 96% (group2; Glove group).

Findings

Summary of the Bird group's design work

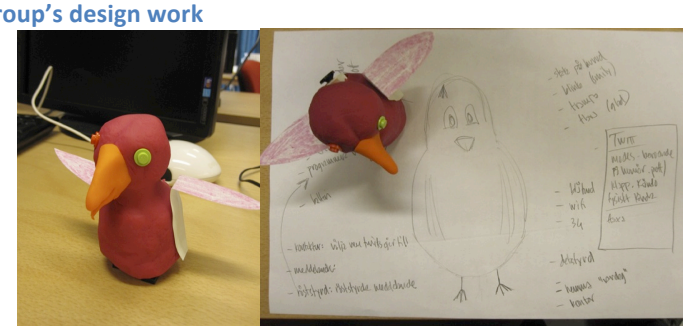

Fig. 1 A clay representation of a Bird to the left, the clay representation and sketch of bird to the right

The Bird group, consisting of two persons started out from the notion of twittering and associated to tweeting of birds and therefore early on decided to create an interactive bird. Language and gestures were used to illustrate aspects of interaction such as receiving and playing messages. This group used paper and pen to sketch the bird and when they began drawing the topic of their discussion moved to discuss the bird's appearance, e.g., its color. Focus was then on static features of the proposal and they did not attempt to illustrate changes or movements visually. Behaviors were mentioned (the bird stomps its feet and flaps its wings) but these behaviors were only mentioned verbally and not indicated in the drawing. After almost ten minutes they moved on to working with clay (Fig. 1). At this point they talked much less and notably stopped talking about interaction and instead focused on the physical materials. Only one physical clay model was constructed and the model was not used to develop ideas about interactions.

Summary of the Glove group's design work

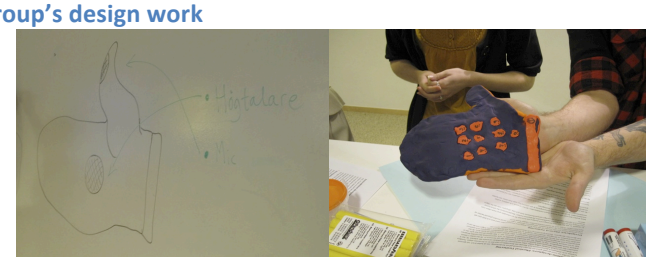

Fig. 2 Sketch of a glove on whiteboard to the left and clay representation of a glove to the right

The Glove group consisted in five members and the group early on considered several different design ideas. The work began when one of the members presented a use scenario to the other members. The scenario was however largely ignored and the group continued to discuss various designs and which features and functionalities to include. They chose one idea to move on with which was an idea of an interactive glove. The glove was a tool which could be used to communicate with others as it allowed sending and receiving messages to others with similar gloves.

In general they talked about and used gestures to illustrate interaction. Some whiteboard sketches were also created and they used clay to build a model of the glove (Fig. 2). As they began drawing and engaging in physical design this group also stopped addressing aspects of interaction and instead focused on sizes, colors and materials of the glove.

How often were different aspects of interaction brought up?

Interactivity was the aspect of interaction that was most frequently addressed by both groups, see Fig. 3 and 4. The Bird group addressed interactivity to a notably higher degree. One of the groups (the Glove group) addressed dynamics and context of use more than the other group, but neither group engaged in issues of temporality or sequentiality to a notable extent. Each aspect is discussed below.

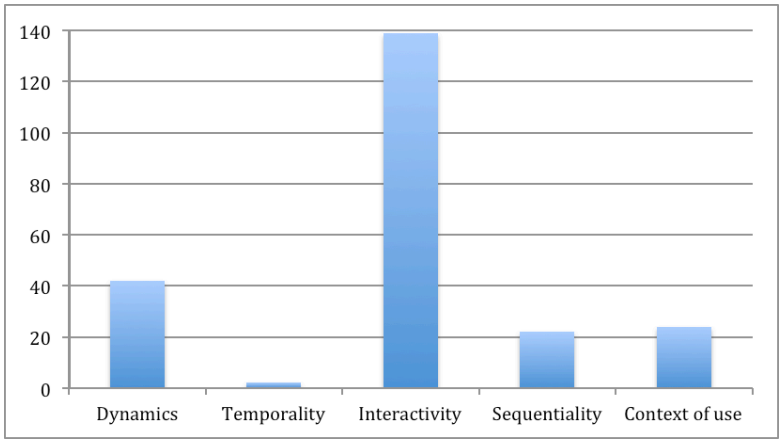

Fig. 3 Total number of occurrences of the five interaction aspects in the Bird group

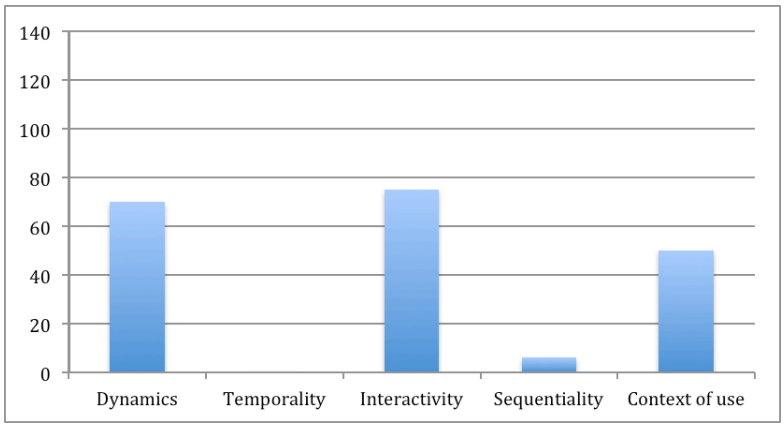

Fig. 4 Total number of occurrences of the five interaction aspects in the Glove group

Dynamics

The *Bird group* considered ideas about how the artifact could reflect other users' messages and moods and also their identities. The different ways that the bird was planned to move were meant to represent different expressions, e.g., the bird would let its owner know about a party by flapping its wings. Another idea relating to dynamics was that the bird would indicate whether it was active or not by being "awake" or "asleep" (eyes open/shut). This group considered the possibilities of reflecting users' moods: in certain contexts (e.g., an office) it may not be desirable to convey emotions such as anger by having the bird tweet in a disturbing manner. They therefore suggested a 'Silent mode' for the artifact to modify how moods were represented to others (instead of tweeting aloud, the bird would flap its wings or use its beak to silently convey emotions). As described, the bird group thus listed a few ways in which dynamic aspects were used to convey messages and modes and these were largely based on, and perhaps constrained by, the characteristics of birds in general.

The *Glove group* explored issues concerning dynamics to a higher degree. They focused on how the glove registered the state of the user (e.g., mood, temperature, pulse, perspiration) in order to convey information about such states to others wearing the same type of glove. Dynamic aspects were thus brought up in relation to how the glove reflected such moods by changing the state and behaviors of the other gloves by, e.g., affecting the temperature, humidity, and colors, or by contractions and vibration. The artifact was ascribed some levels of autonomy as it could change modes or convey information depending on users' states without users actively initiating each such message. Both groups were thus inspired by

characteristics of a physical object (birds, gloves) informing their design work. The Glove group however seemed to be less constrained by the features of the artifact inspiring them; the group not only considered features of regular gloves but also dynamic aspects of other objects such as mobile phones. Furthermore, the manner in which the glove reflected states and moods became more *symbolic* towards the end of the session. For instance, rather than just directly conveying physical features such as heat or humidity, colors were suggested to symbolize specific moods (e.g., red for angry). And instead of letting the gloves of others mirror a specific physical gesture - such as a thumbs-up gesture - the designers chose instead to use colors, which symbolically represented expressions.

Temporality

Time and temporal aspects were hardly addressed explicitly at all. In one single case when the Bird group students checked the instructions they commented on how long a certain interaction takes: ”this goes very quickly, happens quickly... what happens when we receive a tweet?” [accompanied by a quick gesture with her hand towards him]. Temporality was largely a non-issue for the designers or possibly, aspects of temporality were perhaps taken for granted: interaction was simply and unproblematically assumed to be fast or immediate.

The *order* of interactions was now and then addressed (one thing taking place before another) and time thereby could be viewed as implicitly being a part of the issue discussed. Order was not related to time units and we have therefore chosen to view order as being more an issue of sequentiality, see below.

Interactivity

In contrast to the other aspects, the two groups addressed interactivity both explicitly and frequently. Interactivity was discussed verbally and was also often heavily gesture-based: gestures were used to illustrate how to press buttons, turn one’s hand or flap wings while interacting with a device. The Bird group addressed interactivity almost twice as much, see Fig. 3 and 4. The Bird group was focused on how users were able to interact with and program the Bird device as well as organizing contact information to be used when sending messages. Their discussions were often detailed about the specifics of interacting with the Bird and not so directed towards contexts of use.

The Glove group addressed a number of issues and ideas relating to interactivity such as receiving spoken messages, sending gestures, interacting over distances, receiving a hand clasp, input of speech, gloves connecting to other gloves, translation of the sender’s speech or gestures into other modalities, controlling the device through gestures, etc. The Glove group, related ideas about interactivity to specific contexts of use such as being on the bus or doing window-shopping.

Sequentiality

Sequentiality, i.e., issues relating to the order and structure of interactions and freedom and control of user behavior, was hardly addressed at all. As mentioned above, the order of interactions was sometimes mentioned; e.g., designers discussed the relation between an event and how users of the artifact could come to know about the event using the artifact (e.g., ”How can you get to know what has happened over there?” (Glove group)). But these sequences of interactions were not designed in any explicit way. The design students were generous in adding functionality to their design proposals. This could be viewed as a form of "feature creep", i.e., adding extra features beyond the basic function of a product resulting in over-complication of the design (Jacob et al. 2008). Consideration was not given to possible drawbacks of and conflicts between the added functionalities and how this affected the sequentiality of interaction. The students did not discuss whether users would have to do something in a particular order or sequence. Like temporality, aspects of sequentiality may therefore have been taken for granted.

Context of use

Context of use was essentially based on narratives, short stories or scenarios: (”go to Dan’s party...”, ”look at a jumper in the window and send a message to a friend...”).

Context of use was not discussed much in the Bird group until one of the designers turned to the instructions and read that they should relate to one. In the Glove group, discussions about the context of use had a more central role earlier on than in the Bird group.

The Glove group occasionally presented examples referring to specific contexts of use, such as when talking about a portable device that could be carried around when walking around in the streets, in the

city. They discussed whether it should be worn at all times - even at the supermarket - or if the glove was only to be used when communicating. They gave concrete examples such as being at a specific spot in the city (at the Odenplan square) and doing window-shopping. Although contexts of use were brought up in terms of scenarios and gave some directions for the prototype, e.g., portability of the device, it was not related to analyses of interactions.

Lack of continuity when addressing interaction

The design of interactivity was usually not connected to any overall idea of what the designers were trying to achieve. Rather a number of ideas and examples of different ways of how to interact with or receive messages were brought up. But these were not explicitly motivated by any overall design rationale. The aspects of interaction were in both groups addressed in an unsystematic way and not from the perspective of an overall idea about which kind of interaction was being planned.

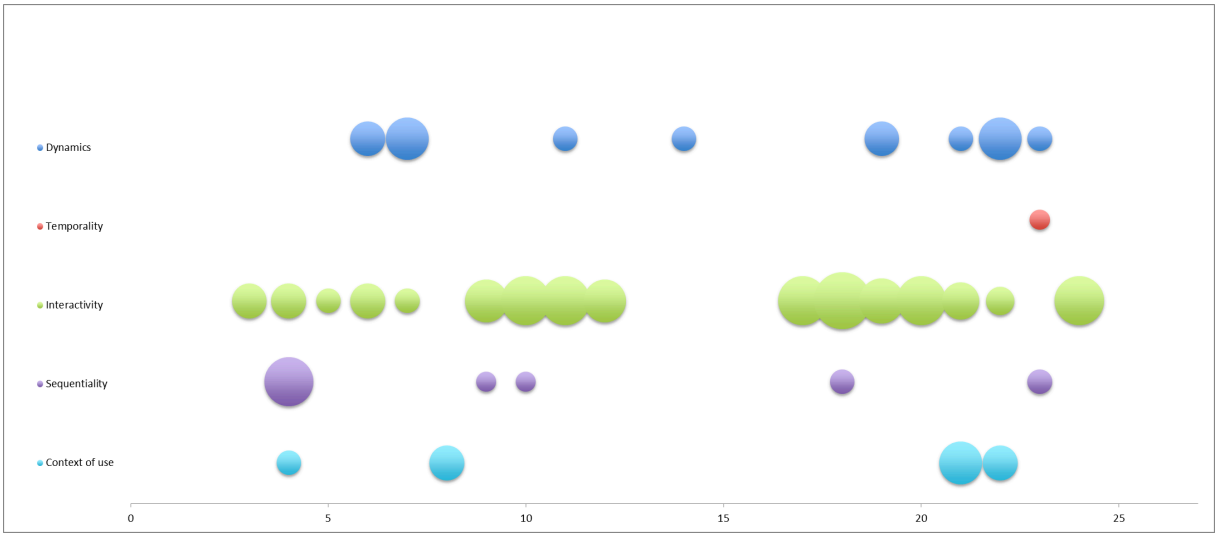

Fig. 5 A bubble diagram showing the degree to which the different aspects of interaction were addressed over time in the Bird-group. Bigger bubbles indicate that an aspect was addressed more frequently; the sizes of the bubbles indicate number of occurrences per minute.

In Fig. 5 we can see that interactivity in the Bird group to a larger extent is addressed more continuously during the design work of the students as compared to for instance context of use. Context of use was not addressed to a particularly large extent, meaning that the aspects of interaction were not contextualized to any notable extent. We can furthermore observe how other aspects than interactivity were handled quite sporadically.

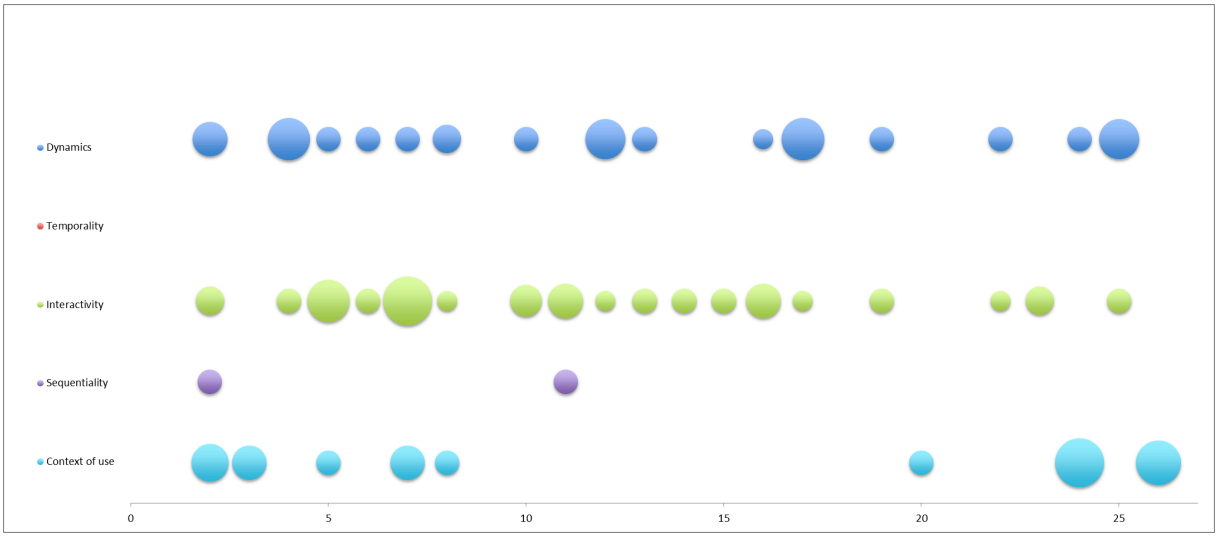

Fig. 6 A bubble diagram showing the degree to which different aspects of interaction were addressed over time in the Glove-group. The sizes of the bubbles indicate number of occurrences per minute.

Similar patterns can be observed in the Glove-group (Fig. 6). Here context of use was handled more frequently. This group to a larger extent investigated interactivity by contextualizing use scenarios. Further, the two aspects of dynamics and interactivity are handled reciprocally throughout the design work. This was not as prominent in the Bird group. An example of how the designers handled the aspects of dynamics and interactivity was when at one point it was suggested that the glove should be able to vibrate. One of the designers then questioned the need for it (”Why?”). She was given a brief answer that the vibration could convey the feelings of other users (”if he is angry then da-da-da-da-da-da...”). The rationale was however not discussed or elaborated on any further and the vibration idea was instead documented on the whiteboard as a design decision.

Designing with physical materials disrupted interaction design

The graphs below show during which phases different aspects of interaction were addressed during the entire session (see Fig. 7 and 8). The most striking observation is however that the designers stopped addressing interaction once they arrived at the tangible design phase, i.e., when they began constructing physical representations of their design ideas. This does not mean that working with the physical material did not inspire individual design students but rather that their continued collaborative investigation of aspects of interaction stopped.

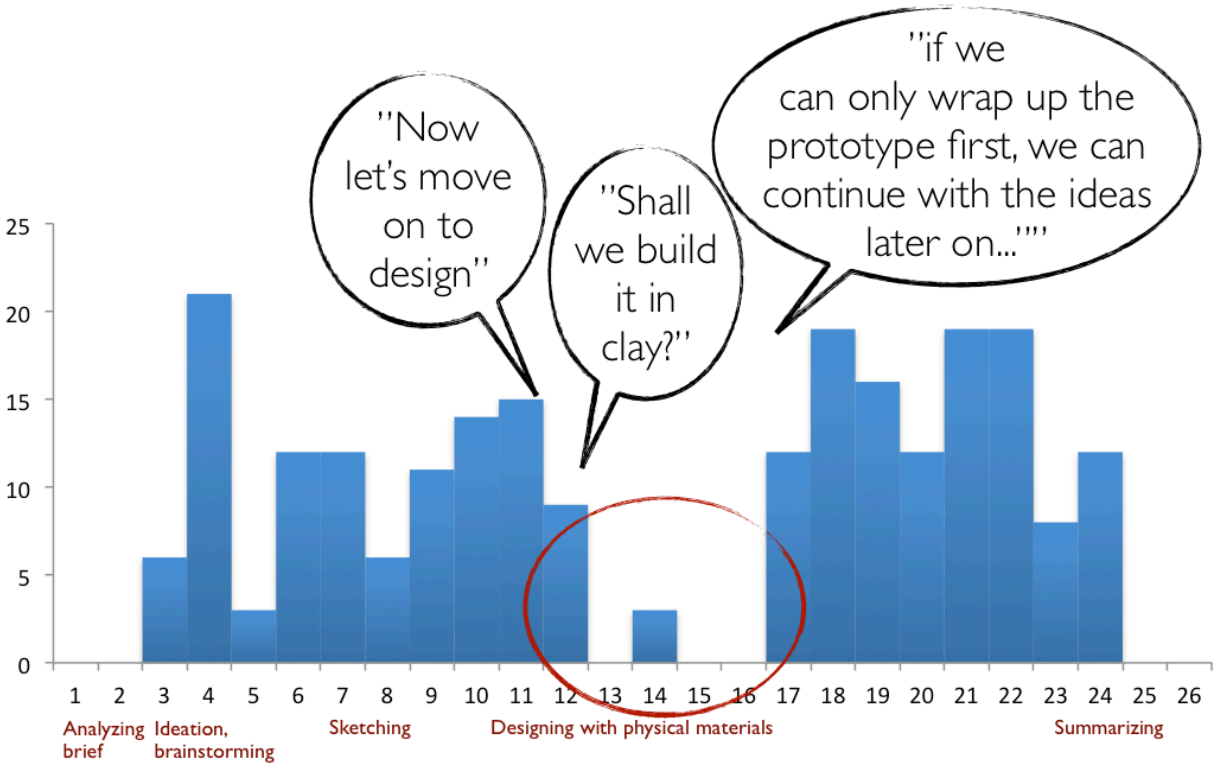

Fig. 7 How often interaction aspects were addressed over time by the Bird group

The graph presents how often interaction aspects were addressed by the Bird group over time and related to different design activities that the designers engaged in. As can be seen, when the designers began designing with physical materials (clay and paper), they addressed aspects to a dramatically lesser degree. The comments in the graph seem to reveal something about the design students' view of the task. Just before beginning to use clay one of the designers exclaims "Now let's move on to design". The comment appears to indicate that he did not view what they had been doing up to that point as design work. One interpretation is that he viewed the work up to that point as preparatory work for the physical design that was to follow and that the physical design was the actual, real design work. The other designer then asks the question "Shall we build it in clay?". The formulation of the question ("build *it* in clay") suggests that only a single physical design was to be constructed. This was also what happened; alternative clay models were not built. After working on the clay design for quite some while, she interestingly utters ”if we can only wrap up the prototype first, we can continue with the ideas later on...”. As mentioned, the designers do not focus on aspects of interaction during their work with the physical materials and this comment

appears to reflect this observation: it is as if she has noted that they need to go on working with the ideas about interaction and that their work with the clay was not advancing the work on ideas about interaction.

Fig. 8 How often interaction aspects were addressed over time by the Glove group

Similarly, the Glove group reached a point when they decided to construct a physical model and represent their design ideas. One of the group's members said "Can anyone begin making the glove?", see Fig. 8. Like the Bird group, this group also decided to use clay as a design material but they continued to use the whiteboard in parallel to represent ideas. Also in this group, work on interaction decreased once they began working with the physical materials; see the circled area in Figure 8. While two design students were occupied with the physical material (clay), the other two were focusing on the whiteboard representation and were commenting on it explaining the aspects of interaction brought up during minutes 19 and 20.

The physical models were used to document or represent ideas about interaction that had been previously brought up. After the physical representations had been constructed, it could have been expected that when no longer being occupied with the details of constructing physical models they would return to the ideas about interaction. This, however, did not happen: the designers did not use the physical objects to further investigate aspects of interaction. They did not use the objects to illustrate interactivity, or to exemplify dialogue, or enact sequences of events, or try out alternative paths of events etc. The physical models were not manipulated in such a way to visualize what happens first and what happens afterwards. They were not used to show how the physical models could modify their appearance to convey messages, modes or to symbolize states etc. Nor were the models moved around to display their behavior. The primary use of the physical models was instead simply to document and represent previously suggested ideas.

How interaction was addressed

Interaction was addressed and represented in various different ways. Now and then, the students brought up topics related to interaction and this was mostly done by talking about interaction. Occasionally interactivity was described in a narrative way in the form of user scenarios. Especially questions from the reviewers and sometimes co-designers promoted the generation of ideas about how interaction was a part of the design – often it appeared as the character of the interaction was determined at that point, on the spur.

Fig. 9 Design students using gestures to illustrate how buttons are tapped under a wing (Bird group). And designers in the Glove group suggesting that users can interact by pressing keys on the back of the glove illustrated by make tapping gestures on the backs of their hands; note that the clay model on the table is not used when exploring these interactions.

Occasionally gestures were used to illustrate interaction, see Fig. 9. For instance, a designer in the glove group proposed that the artifact should have the shape of a hand. They explored ways how the artifact could convey messages in the form of gestures by shaping of the hand into a thumbs-up gesture and the same gesture was to be mirrored by other users' devices. The design students in the Glove group used gestures to suggest how users could interact by tapping on keys on the back of the hand. When having agreed on a proposal they continued by "documenting" this design decision first by adding buttons to their clay model and then by also drawing a keyboard on the whiteboard sketch.

Students typically did not include interaction in sketches on paper nor on the whiteboard. E.g., states and modes were not illustrated visually by drawing versions of the artifact. Storyboards were not created and arrows were not used to illustrate sequentiality or interaction. Instead static images of artifacts were drawn and aspects of for instance sequentiality and interactivity were instead expressed using spoken language and in some cases gestures, see Figure 9. For instance, at one point one of the designers drew a sketch of the glove on the whiteboard and suggested that the glove should have a microphone. This suggestion was not made in relation to the sketch on the whiteboard but by pretending to wear one on his hand. Having agreed upon the idea he continued to draw and added a microphone to the whiteboard sketch. I.e. spoken language is used and accompanied by gestures but attention is not directed towards the whiteboard sketch, which rather appeared to have the role of documentation of agreed-upon proposals.

When sketching using physical materials, focus was largely on appearance and physical features rather than on interactivity. Physical representations were static and typically only one model was created. Phases, modes, courses of events etc. were not indicated using the physical model. Interaction (e.g., flapping of the bird's wings) was mentioned verbally but such ideas were not represented in the physical models.

According to our observations the whiteboard/physical models were thus not central to the design of interaction. There was no immediate "talk back" during physical design work and the models were not used for generating design ideas. Instead the students turned away from the whiteboard and clay models and instead used language and gestures to generate new ideas. These new ideas were then documented in the whiteboard sketches and the clay models. These models or drawings could have been used to further the design ideas by using or modifying them or by creating several different ones to illustrate interactivity.

Table 2 Table illustrating recurrent modes of expression and how these relate to aspects of interaction

Mode of expression	Aspects of interaction				
	Dynamics	Sequentiality	Interactivity	Temporality	Context of use
Gestures			✔		✔
Physical model					
Enactments		✔			✔
Sketching on paper or whiteboard					
Spoken language	✔		✔	(✔)	✔

Table 3 Table illustrating recurrent modes of expression and to what degree these contribute to the design work

Mode of expression	Contribution to design work			
	Documentation	Form	Function	Interaction
Gestures	Low degree	Low degree	Some degree	High degree
Physical model	High degree	High degree	Some degree	Low degree
Enactments	Low degree	Low degree	Some degree	Some degree
Sketching on paper or whiteboard	High degree	Some degree	High degree	Low degree
Spoken language	Low degree	Low degree	High degree	High degree

Tables 2 and 3 illustrate recurrent patterns rather than single observations. There were, e.g., occasions in which the mode of spoken language was used to address the aspect of sequentiality but these were exceptional. Table 2 illustrates how the use of gestures primarily related to aspects of interactivity and context of use. Further, gestures do not lend themselves to documenting the design work as shown in Table 3. However, gestures contributed to a higher degree to illustrate functions and interactions. Notable is also that sketching and physical modeling were mainly used for documenting ideas and illustrating form rather than contributing to specifying interaction. Spoken language, enactments and gestures often coincide in time but each precise slightly different aspects of interaction.

Additional aspects observed in review sessions

The design work in the interactionaries was followed by short sessions during which the designers presented their design proposals to fellow students who were asked to act as critical reviewers. During these presentations the fellow students not surprisingly posed questions about issues that were not highlighted in the designers' presentations of their design work. They would e.g., ask questions about issues related to time which as mentioned above was hardly addressed at all during the design sessions. When confronted by such questions, it seemed like the designers produced ideas on the fly. In the Glove group the reviewers asked how long it takes to send a message.

> *Reviewer: How long does it take to send a message... does it go fairly fast?*
>
> *Designer: You have something to say and then your friend receives it...*

We can here observe how the designers seem to take aspects of temporality, or more specifically time for granted. You send a message and it is immediately and without any problems received by the recipient. Much of the designers' handling of questions and critique consisted in adding of additional features and functionalities and on several occasions the design groups gave the impression of having agreed on solutions earlier in their design work.

Also observed was that presenting an elaborated use scenario invited the reviewers to ask questions about aspects of interaction, whereas presenting a less elaborated use scenario the reviewers raised questions about the context of use to try to position and understand the design proposal.

Discussion

The discipline of interaction design strives for being agnostic towards implementation, i.e., having a focus on interactions and behaviors but being independent of a specific implementation or technology. At the same time new opportunities and challenges are opening up for the discipline as the traditional focus on interactions with and through more or less stationary computers is extended to mobile, wearable, cloud-based, omnipresent technologies. The possibility to use novel physical materials and interweave digital technologies into these creates exciting possibilities for interaction designers. And as discussed in the Background, theory has recently advanced in cognitive and educational science as well as computer supported collaborative learning research and other fields to reflect the increased attention being given to the role of objects and artifacts in thinking, learning and creative activities. A challenge for the field is to investigate the role of artifacts and to develop technologies and arrange practices to support interaction design work. Understanding and analyzing interactions is a complex task as is clear from the work of interaction analysts (Jordan and Henderson 1995). Myers and colleagues (Myers et al. 2008) have reported that designers consider behavior difficult to prototype and it has been pointed out before that

interaction design lacks an established language (Crampton Smith 2007; Karlgren and Ramberg 2012). And as the conversation with interaction designers' design materials is extended to physical materials the challenge of developing this language for engaging in meaningful conversations about interaction is even higher. The five aspects of interaction proposed and focused on in this article can therefore be looked upon as a contribution to the continued work of establishing such a language and to conceptualizing the core issues addressed within the field of interaction design.

While the discipline of interaction design is characterized as being a conversation with the immaterial material of software (Ozenc et al. 2010), the design students that we have studied do not engage in a conversation with interaction to a great extent but tend to get stuck on material particulars and the appearance of physical representations that they construct. The students in this study did attend to interactivity; e.g., inputting and receiving messages and turn-taking in dialogues between users and an artifact. But comprehensive ideas about interaction guiding the design work were not considered and only to a small degree or not at all were more complex patterns or sequences of interaction over time brought up. When interactivity was brought up it was in the form of rather fragmentary and isolated ideas and not related to an overall design vision.

Some aspects of interaction, such as temporality and sequentiality, were not addressed explicitly and an interpretation is that these may have been taken for granted. Of course, interactions with and through artifacts will be extended in time regardless of the intended design ideas but the question is whether final implementations are in line with the intended design ideas if these aspects are not explicitly brought up during design work? Similarly, design decisions have to be taken about which kinds of sequences of interactions are suggested or permitted by the artifact if the realized design proposals are to correspond to the planned design ideas.

The physical representations, and the ideas about specific artifacts underlying the representations, appear to distract attention from the task of considering and developing different kinds of interaction as was shown in our study. Particular help may therefore be needed in order to draw attention to the interaction itself. Below we discuss the results but also point at possible paths that can be considered in interaction design education in order to encourage conversation with the immaterial design material of interaction. These are strategies or suggestions for how to intervene in order to affect the design students' approach that could be used after interactionaries or other exercises. These are not to be considered as the final solutions – other strategies certainly exist – but nevertheless as approaches that we have found supportive.

Planning Interactions

As observed in the analyses of the design work, the design students did not in a high degree engage in discussing a comprehensive idea about interaction or in planning sequences of interactions. Instead much focus was rather on an artifact and its characteristics and on adding functionalities to it. An idea about a specific artifact was typically the starting point of the design to which interactions now and then were added. The opposite was not observed; that the design students proposed possible interactions and *then* considered which types of artifacts might support the interactions. To avoid this one-sided focus on various artifacts and characteristics of these measures could be taken.

Firstly, if the designers focus on a single artifact and its details, the artifact could be replaced by other objects and as an exercise the designers could thus plan the interaction with a completely different type of physical object/material which can thereby lead the discussion towards interaction instead (e.g., if focus is on a bird, suggest replacing it with something else, a brick, fluid or insect etc). Or turn focus to interaction altogether by suspending talk about specific artifacts at all. Van Campenhout and colleagues similarly have shown how encouraging students of industrial design to design movement before asking them to design products led to solutions which otherwise would remain unexplored (Van Campenhout et al. 2012).

Secondly, labeling ideas about interaction can be encouraged. The designers typically quickly gave a name to their envisioned artifact (“bird”, “glove”), however they did not label ideas about interaction as such. Silver (Silver 2007) suggests a language specifying behaviors. Thus, *labeling* of ideas about interaction by giving these names in the way artifacts are labeled could be encouraged. Giving ideas about interaction labels, may support the conceptualization for the individuals and the team. This could also support more in depth analyses of aspects of interaction and its accompanying relevant modes of expression such as the use of gestures, enactments and spoken language (see tables 2 and 3) as well as provide a better chance of

holding on to ideas longer during the sessions. Moreover, besides labeling overall design ideas, encouraging the expression of features pertaining to interaction in words is helpful for making them more salient. E.g., aspects of temporality could be discussed not only in terms of speed and extension in time but also in terms of delays, pausing, rhythm, pace, promptness, feedback, immediacy, concurrency, increasing/decreasing intensity etc to foreground the temporal feel of the interactions.

Thirdly, encouraging the development of several *parallel, alternative* ideas about interaction may loosen the focus on a specific physical artifact (e.g., creating a system for distributing news vs. communicating messages to friends vs. conveying moods to others etc). An identified problem of student-designers is that they tend to get stuck on one idea and do not investigate alternative ideas (Cross 2004). Just as entertaining several alternative ideas and their advantages and disadvantages about the physical artifacts may be fruitful and eye opening the same goes for ideas about interactions (Hartmann 2009; Sundholm et al. 2004).

Sketching interaction

A striking observation was that the design students stopped addressing aspects of interaction once they began using physical materials and they did not continue exploring interaction with the physical representations that they constructed. When exploring the physical representations, they tended instead to add functionalities. Using tools such as paper and pen and whiteboards and physical materials such as paper and clay were used to document ideas previously discussed. Moreover, they represented static aspects of the design proposals (the appearance of a glove, keyboard and microphone) rather than interactive aspects. It could be expected that providing materials such as clay, Lego etc. would be helpful for students to express ideas with, but it is obvious that using these materials adds new challenges and may distract attention from the task of designing *interaction*. As illustrated in table 2 using physical materials in sketching did not aid the interaction design students to further investigate aspects of interaction. Further, the use of physical models and whiteboard sketches contributed to the design work in terms of documentation, form and function. Design students may tend to use tools and physical materials only for documentation and sketching static aspects rather than interaction.

A practical suggestion could be to contextualize the artifact (i.e., using enactments, scenarios, etc. with the artifact) and thus move focus to *interaction with* the physical artifacts. As Ozenc and colleagues (Ozenc et al. 2010) propose, designers can sketch by creating scenarios to explore how products might participate in a transaction over time. Learning to use a sketching notation when using pen and paper or a whiteboard could help in articulating and representing aspects of interaction (Barros and Velloso 2013). By encouraging the use of graphical means such as arrows, storyboards etc. to visualize a course of events may be one way to avoid over-working static details on physical models and whiteboard sketches.

Development of several and alternative physical artifacts may also avoid exaggerated focus on the details and appearance of a specific physical representation. The construction of more than one physical model may be motived by being able to represent alternative design ideas (in order to move focus from details of one physical model) but also for being able to physically illustrate changes, phases, transitions that may take place between different models.

Putting design ideas into context by enactments may further add to the exploration of interaction and specifics of the artifacts and thus conduct inquiry into the future situation of use (Gedenryd 1998; Arvola and Artman 2006).

On the time constraints of interactionaries

Interactionaries impose extreme time constraints on design teams working on stage on a design task. The strict time limitations force participants to make quick decisions and an intention is to expose design in progress and to allow an audience to observe how the designers work. In an educational setting there may be value in kick-starting students' design work and avoiding lengthy and potentially fruitless discussions about what to do. The format forces students to produce something and to argue for its values which may have pedagogical merits. Further, the design process can easily be discussed and reflected on in a follow-up debriefing or seminar.

While the time constraints of the original interactionaries were even stricter, the time limitations in this study raise questions as to how they affect the design work of the participants compared to what could

have happened in longer design projects. The limitations force designers to focus on ideas in a selective way but designers are obviously not allowed time to reflect extensively on design decisions. The participants cannot explore many alternative design ideas and they cannot linger on and investigate specific design aspects in depth. Nor do they have the time to revert to design concepts previously rejected. Prototyping cannot be advanced but has to be suggestive and explorative and needs to adapt to appropriate tools suitable for the purpose. Furthermore, while the format is intended to be fun and entertaining, there is a risk that participants have difficulties in adapting to the constraints and feel stressed rather than focused on the task. In addition, the extreme time constraints risk leading to that participants fall back on well-known solutions and technologies rather than engaging in the development of innovative ideas.

While interactionaries can uncover the design process of interaction designers, we acknowledge that the extreme format may affect the design work of the participants. What concerns experience of stress, we did not observe negative stress or inability on behalf of the students to act but rather that they actually demonstrated focus and a great deal of satisfaction with producing results. We did however observe groups that deviated from the instructions given in the design brief as well as groups that were not particularly innovative in their idea generation. And while the format cannot be expected to mirror exactly and fully what a longer design project would have looked like, interactionaries can give indications about which aspects students emphasize and find important and, conversely, which aspects are not brought up and risk being overlooked. As mentioned, some aspects of interaction were not addressed and this may have been due to that these aspects were taken for granted. While aspects such as temporality and sequentiality were clearly not prioritized by the students, this study cannot rule out that these aspects would have eventually been addressed systematically at a later point had the time constraints been less severe.

Concluding Remarks

There is thus, a tension between (1) technological agnosticism of interaction design, (2) the ongoing dematerialization of products on the one hand, and, on the other, (3) viewing design as a conversation with design situations and design materials as well as (4) the material turn or turn towards objects in interaction design thinking and other theory. If interaction is viewed as the main focus of interaction design, design education in the field needs to support students in extending reflective conversations from physical materials to the interactions in particular. There is a need for training to develop an understanding of how interactions "talk back" and our observations imply that design education needs to facilitate students in:

1. Directing the *process* of interaction design work towards interaction specifically by, e.g., considering overall ideas about interaction and entertaining several parallel ideas about interaction rather than one-sidedly starting from ideas about an artifact.

2. Practicing their *skills* in sketching interaction using a sketching notation, pen and paper, whiteboards, and other physical materials rather than using these means merely for documentation or for developing appearance.

3. Developing skills in analyzing, *conceptualizing* and labeling interaction, specifically.

Acknowledgements

This research was supported by the Swedish Research Council (Reg. No. 2009-5660).

References

Arvola, M., & Artman, H. (2006). Enactments in Interaction Design: How Designers Make Sketches Behave. *Artifact - Journal of virtual design, 10*.

Barros, G., & Velloso, L. (2013). How the communication between designers was affected by ActionSketch, a technique to improve sketches in interaction design. *Revista Brasileira de Design da Informação/ Brazilian Journal of Information Design, 10*(1), 1-17.
Benyon, D. (2010). *Designing Interactive Systems - A comprehensive guide to HCI and interaction design*: Pearson.
Bereiter, C. (2002). *Education and Mind in the Knowledge Age*. Mahwah, NJ: Lawrence Erlbaum.
Berkun, S. (2001). Interactionary 2000. http://scottberkun.com/essays/interactionary-and-design-sports/interactionary-2000/. Accessed June 2nd 2013.
Buxton, B. (2007). *Sketching User Experience. Getting the Design Right and the Right Design*: Morgan Kaufmann Publishers.
Cooper, A. (2004). *The Inmates are Running the Asylum - Why High-Tech Products Drive Us Crazy and How to Restore the Sanity*: Sams Publishing.
Crampton Smith, G. (2007). Foreword: What Is Interaction Design? In B. Moggridge (Ed.), *Designing Interactions* (pp. vi-xix): The MIT Press.
Cross, N. (2004). Expertise in design: an overview. *Design Studies, 25*(5), 427-441.
Dearden, A. M. (2006). Designing as a conversation with digital materials. *Design Studies, 27*(3), 399-421.
Engeström, Y., Miettinen, R., & Punamäki, R.-L. (Eds.). (1999). *Perspectives on Activity Theory*: Cambridge University Press.
Garfinkel, H. (1967). *Studies in Ethnomethodology*. NJ: Prentice-Hall.
Gedenryd, H. (1998). *How Designers Work: Making Sense of Authentic Cognitive Activity*. Lund University, Lund, Sweden.
Hartmann, B. (2009). *Gaining Design Insight through Interaction Prototyping Tools*. PhD thesis, Stanford University, Stanford.
Jacob, R. J. K., Girouard, A., Hirshfield, L. M., Horn, M. S., Shaer, O., Solovey, E. T., et al. (2008). *Reality-based interaction: a framework for post-WIMP interfaces.* Paper presented at the CHI '08 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Florence, Italy, April 05 - 10
Jordan, B., & Henderson, A. (1995). Interaction Analysis: Foundations and Practice. *The Journal of the Learning Sciences, 4*(1), 39-103.
Karlgren, K., & Ramberg, R. (2012). The Use of Design Patterns in Overcoming Misunderstandings in Collaborative Interaction Design. *CoDesign - International Journal of CoCreation in Design and the Arts - Special Issue on Quality of Collaboration in Design, 8*(4), 16.
Linell, P., & Gustavsson, L. (1987). Initiativ och respons - Om dialogens dynamik, dominans och koherens. In P. Linell, & L. Gustavsson (Eds.), *Studies in Communication* (Vol. 15). Linköping: Department of Communication Studies, Linköping University.
Löwgren, J. (2002). The use qualities of digital designs. http://webzone.k3.mah.se/k3jolo/Material/uqDDv1.pdf.
Löwgren, J., & Stolterman, E. (2004). *Thoughtful Interaction Design - A Design Perspective on Information Technology*: The MIT Press.
Myers, B., Park, S. Y., Nakano, Y., Mueller, G., & Ko, A. (2008). *How Designers Design and Program Interactive Behaviors.* Paper presented at the IEEE Symposium on Visual Language and Human-Centric Computing, Herrsching am Ammersee, Germany, Sept 15-19
Ozenc, F. K., Kim, M., Zimmermann, J., Oney, S., & Myers, B. (2010). *How to Support Designers in Getting Hold of the Immaterial Material of Software.* Paper presented at the CHI, Atlanta, Georgia, April 10-15
Paavola, S., & Hakkarainen, K. (2005). The Knowledge Creation Metaphor – An Emergent Epistemological Approach to Learning. *Science and Education, 14*(6), 535-557.
Ramberg, R., Artman, H., & Karlgren, K. (2013). Designing Learning Opportunities in Interaction Design: Interactionaries as a means to study and teach student design processes. *Designs for Learning, 6*(1-2), 30-57, doi:http://doi.org/10.2478/dfl-2014-0015.
Robles, E., & Wiberg, M. (2010). *Texturing the "Material Turn" in Interaction Design.* Paper presented at the TEI'10, Cambridge, Massachusetts, USA, Jan 24-27
Sacks, H., Schegloff, E. A., & Jefferson, G. (1974). Simplest Systematics for the Organization of Turn-Taking for Conversation. *Language, 50*(4, Part 1), 696-735.
Saffer, D. (2007). *Designing for Interaction: Creating Smart Applications And Clever Devices*: New Riders Publishing.
Sas, C. (2006). *Learning Approaches for Teaching Interaction Design.* Paper presented at the HCI Educators Workshop, Limerick, Ireland., 23-24 March 2006
Schön, D. (1983). *The Reflective Practitioner. How Professionals Think in Action*. London: Basic Books.
Silver, K. (2007). What Puts the Design in Interaction Design. http://www.uxmatters.com/mt/archives/2007/07/what-puts-the-design-in-interaction-design.php

Suchman, L. A. (1987). *Plans and Situated Actions – The problem of human machine communication*: Cambridge University Press.

Sundholm, H., Artman, H., & Ramberg, R. (2004). Backdoor Creativity: Collaborative Creativity in Technology Supported Teams. In F. Darses, R. Dieng, C. Simone, & M. Zacklad (Eds.), *Cooperative systems design: Scenario-based design of collaborative systems*. Amsterdam: IOS press.

Sundström, P., Taylor, A. S., & O'Hara, K. (2011). *Sketching in software and hardware Bluetooth as a design material.* Paper presented at the 13th International Conference on Human Computer Interaction with Mobile Devices and Services, Stockholm, Sweden, Aug 30-Sep 2

Tholander, J., Karlgren, K., Ramberg, R., & Sökjer, P. (2008). *Where All the Interaction Is - Sketching in Interaction Design as an Embodied Practice.* Paper presented at the Designing Interactive Systems (DIS2008), Cape Town, South Africa, Feb 25-27

Van Campenhout, L., Frens, J., Overbeeke, K., Standaert, A., & Peremans, H. (2013). Physical Interaction in a Dematerialized World. *International Journal of Design, 7*(1), 1-18.

Van Campenhout, L., Hummels, C., Frens, J., Standaert, A., & Peremans, H. (2012). *Hard Cash in a Dematerialized World.* Paper presented at the The 14th International Conference on Engineering and Product Design Education (E&PDE2012), Artesis University College, Antwerp, Belgium, Sept 6-7

Wiberg, M. (2013). Methodology for materiality: interaction design research through a material lens. *Personal and Ubiquitous Computing, 18*(3), 625-636.

Winograd, T. (1997). The Design of Interaction. In P. J. Denning, & R. M. Metcalfe (Eds.), *Beyond Calculation: The Next Fifty Years of Computers* (pp. 149-161). New York: Copernicus.