Sketches, Drawings, Diagrams, Physical Models, Prototypes, and Gesture as Representational Forms

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ABSTRACT

What is the role of physicality when interacting with different representations? Representational forms differ in type of representation (e.g. sketch, diagram, 3D model) and in the way they are materialized. These variations influence the properties of a representation and suggest or enable different usages, interaction styles and variations in meaning, even if they represent the same object, idea or concept. Here we present a literature survey summarizing knowledge about the properties of representational forms such as sketches, drawings, diagrams, physical models, and also of gesture.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: Models and Principles, - *human factors*.

General Terms

Design, Human Factors, Theory.

Keywords

Representational form, sketches, diagrams, models, prototyping, gesture.

1. INTRODUCTION

Representations are made to represent something else. Therefore representations are never identical with the represented, always underspecified, designed with a specific purpose in mind, and usually connected with conventialised practices [31]. We have to discern in particular between sketches, drawings, diagrams, different kinds of prototypes, and graspable models and also gesture, which can be interpreted as a perishable type of representation.

In computing we are used primarily to sketches, engineering drawings, and diagrams. But in other disciplines a much wider range of representations is employed, often in parallel, not competing, but complementing each other. For example, within architectural practice relevant representational forms encompass conceptual models (being abstract and lightweight), plans, sketches, diagrams, and models of different sizes and materials [6]. In design, art, and architecture often a multitude of different media are created in parallel, looked at simultaneously, put next to each other, and connected with each other. This is because different techniques of representation and different media allow the exploration of different aspects of a design idea. Furthermore often they are suited for different phases of the design process. Representations direct the focus of discussions and thereby can take the role of an implicit vehicle of facilitation. This means that the choice of representation can influence the discussion focus – representations are not neutral, but need to be chosen carefully in accordance to aims.

Different representational forms of one and the same design, such as schematic construction drawings, sketches, and physical models, can be interpreted as variations or 'modulations' [10] which each have different characteristics and suggest or enable different ways of usages, interaction styles and variations in meaning.[1] Different media or modulations differ in the type of feedback they provide to interaction, and the ease of conducting certain actions on or with them. Furthermore the type of representation chosen interacts with its medium (being on paper, on-screen, physically embodied etc.). Thus, for example, even what in terms of the definition of 'a sketch' might be the same representation type, is modulated with the choice of a different medium of embodiment.

This paper starts an exploration of the differences between representational forms. This refers mostly to physical instantiations of these representations, leaving out of consideration e.g. digital sketches. In physical representational forms the representation is embodied in its medium [32], and thereby representation, storage medium, and display are always connected with each other. With digital representational forms, this connection is broken – the representation 'floats' on the display, which turns into a physical object in its own right. This influences both the affordances of interaction and the feedback received by the user. While there have been a range of studies comparing e.g. digital with physical sketches [2, 11], there seems to be much less discussion about the properties of the representations themselves and the differences of the way they are materialized, let alone a systematic comparison of representational forms. Here, I am summarizing results of a literature survey on this question, which was conducted as part of my PhD thesis [12].

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[1] Glock [10] borrows the term 'modulation' (or 'key': the metaphor of musical modulation of a melody) from Goffman, referring to the transformation of an object that attains a different understanding by being reframed.

2. TYPES OF REPRESENTATIONS

2.1 Visual Graphic Representations

2.1.1 *Sketches and Drawings*

Purcell and Gero [25] summarize design research knowledge on the function of drawings. They conclude that drawings and sketches usually embody abstract design ideas and allow for imprecision regarding material attributes of the designed object. This density, ambivalence and unstructuredness of drawings is important in early design phases. Studies have shown that words predominantly activate conceptual and abstract knowledge, while images activate perceptual knowledge, for example about materials, forms, and analogue cases. Purcell and Gero [25] suspect that the work in design teams is successful because the integration of sketching and discussion in teams automatically activates both types of knowledge.

Drawings and sketches enable us to put different representational levels next to each other, to mix them and connect them [7]. Textual annotations can be added, alternatives sketched in, highlighting and marks added, and details inserted. These different elements of a drawing are typically connected with lines, which for example graphically denote which part of a larger drawing is detailed in a corner. This next-to-each-other is a source of ambiguity, as the different levels do not need to be coherent and complete. Some lines may look more definite and others are clearly tentative and vague. To some extent these things can be done on engineering drawings, despite of formal rules for draughtsmen [11]. As long as the drawing is not analysed by software, it is up to the human reader to tweak apart informal and formal elements and to interpret their relation.

Ambiguity really seems to be one of the most important properties of sketches. Allowing for imprecision is essential to the process of idea generation, as studies into effects of the introduction of CAD in construction planning have shown. CAD systems force the designer to start from concrete, exactly specified details, building up larger elements from core elements. Sketching on the other hand can start from a holistic picture and slowly become more precise [2, 11]. CAD, because it is based on numeric data, requires exact data input. If one wants to be ambiguous while sketching digitally, one needs to make this explicit - but explicitly invoking a different mode might interrupt the process of sketching…

2.1.2 *Diagrams*

Diagrams are a specific type of drawing, since their interpretation and manipulation is heavily conventualized and formalized. They offer a rather small scope of action and little ambiguity, but similar to sketches, take their powers from human perceptual intelligence and situated seeing [13, 14, 28]. Just as sketches and drawings, diagrams are selective representations. The ability to see spatial representations not just sequentially, but simultaneously, allows for perceptual inferences, which would require a whole series of inferences if employing a language-based representation. This holds in particular for transitive, symmetrical or asymmetrical relations [33]. Yet negations or contradictions are notoriously difficult to represent in a diagram.

So-called ‘secondary notation’ [24] supports legibility of diagrams. This concerns for example the layout and spatial arrangement of elements, which in addition to the logical connections provide information by guiding the order or flow of reading and emphasizing structure. For example diagrams of circuits will often have the input on the top left and the logical flow will continue to the bottom right, analogue to normal text flow. With pneumatic circuits this is partly reversed, and usual practice has the elements receiving input (from a user pushing a button or an object triggering a sensor) on the bottom and the ‘output’ elements (pistons) in the top row (see Figure 1).

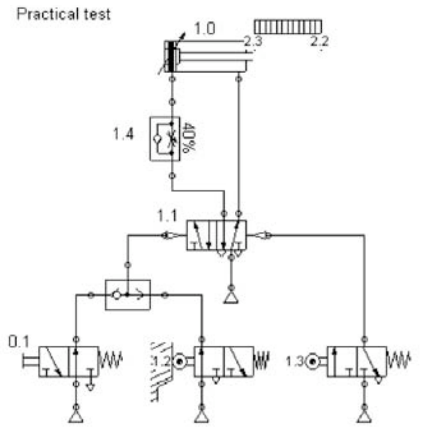

Figure 1. Diagram of a pneumatic circuit

Reading of diagrams needs to be learned and trained, and requires a lot of expertise due to its condensed and abstract nature. Direct perception (without explicit translation effort, employing perceptual inference) of spatial representations such as diagrams requires experience and confidence with the application area, the type of representation and reading conventions.

2.1.3 *Graphic representations on paper and on screen*

Moving graphic representations onto computers change the medium of display. This also changes the way we can interact with them and how we can perceive them. Besides of screen resolution, which may cause eyestrain, the size of the monitor is a key variable. Studies of draughtsmen in architecture who were shifting from drawing on paper to CAD emphasize the loss of overview and context [2]. The professionals complained about loosing context of where the current section they were working on is located on the overall plan and about loosing sense of scale. When working on the big printouts which used to be put onto slanted tables or hung onto walls, they could physically view the entire plan from a distance and zoom in bodily while keeping a peripheral overview. Even when rolling the plan up or folding it, it seemed easier to keep aware of which piece of the plan they were currently looking at.

2.2 Material Models

Material models come in a variety of types that differ in how accurately they represent the thing modeled, and how exact or open they are to interpretation. Models can look rather sketchy or ‘ready for production’. This is reflected in the literature on prototyping, which differentiates a wide range of different types of prototypes (mock-ups, functional or paper prototypes, low-fi and hi-fi …). Much of this literature originates from research about design practice in engineering from the past 10 years. Design research only rather recently started to discuss the role of physical prototypes – but we must remember that the acknowledgment of the role of sketching was comparatively recent [25]. For a long time sketching and diagrammatic thinking were thought to be ‘just a practical proficiency’ and not an essential part of the thinking process in design.

Different types of prototypes possess different degrees of openness or ambiguity [26]. ‘Impromptu prototypes’ (objects being at hand, that get employed ad-hoc) are spontaneously used as a helper for explaining or testing an idea, and are rather short-lived. They are “conduits for design conversation, not fixtures” and thus serve as a direction-guiding medium of

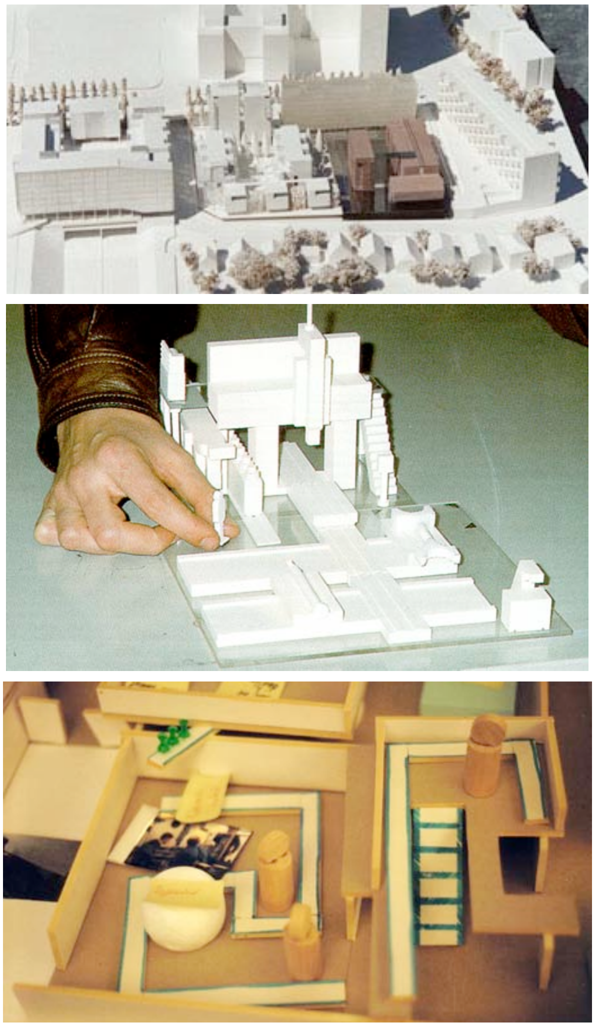

Figure 2. (top) Architectural model. (middle) Model used for production planning [29]. (bottom) Cardboard model used during participatory design sessions to envision new work practices in a plant.

conversation. In a similar way we tend to employ anything at hand for building “thinking props” when trying to understand and reconstruct processes and mechanical or logical principles. Seen out of context, these tinkered objects are meaningless for an outsider. “Embodiment prototypes” on the other hand already contain central aspects of the final structure. They are semi-permanent and to a large degree resolve ambiguity. They thus offer an (almost complete) plan for the production of the final product.

Creating models and prototypes forces us to differentiate, correct and control our ideas successively, for example in construction design in mechanical engineering [27]. In particular models embody abstract ideas, allowing for feedback from the model and thereby potentially uncovering errors in the designers’ mental models – ideas can be implemented and instantaneously tested [20]. While all kinds of external representations allow for feedback and dialogue with the representation (see Schön’s [30]’s discussion of sketching as a ‘conversation with the material’), material models provide feedback of a specific kind, implicitly invoking physical laws. Specific types of models (such as Fischertechnik ©) lend themselves to simulation or test of behavior (restricted to the elements of the construction set) [7]. Yet if these pose constraints that are irrelevant within the application domain, this can restrict the action space too much.

While CAD for other reasons (like supporting distributed design, digitizing designs, and thereby shortening the road to production) has taken over in many design areas, it has also resulted in increased effort in rapid prototyping technologies. These are expected to re-enable a direct assessment of designs (e.g. being able to assess a form by taking the object in one’s hand or walking around it) and enabling distributed design teams to talk about the same thing [9].

Architects throughout the design process often create a variety of models of different sizes and materials [6]. Usually several physical models are created, where one for example explores the effects of chosen materials, another depicts structural decisions, and the next model serves to experiment with sources of lighting. Specific attention is put on the materials used. The search for ‘the right material’ often takes a long time and, in doing so, inspires new ideas. In making use of various materials, models can be extremely rich and inspiring [6, 16].

2.2.1 Spatial or enactive knowledge

Another aspect of physical models is that they help to activate spatial and kinaesthetic knowledge, being ‘enactive’ representations [11]. For this reason, physical mock-ups, low-tech prototypes and design games with cardboard models are widely used in participatory design [3, 18, 21, 23, 29]. They can be employed in performative ideation and role play sessions, taking the role of props that ease staging ideas, or triggering ideas in bodystorming [16, 18, 34, 23]. Real artifacts or mock-ups that work as ‘things-to think with’ can also support reflective conversations [3. 23].

Models in particular allow us to discern spatial relationships – firstly they model spatial relations (without transforming modalities, because space is represented as space), and secondly we can move around the model, take different perspectives, turn the model around, move and manipulate it. Models thereby allow us a rather intuitive understanding of geometrical and spatial relations. For this reason physical models are still popular e.g. in archaeology, reconstructing how by-gone buildings might have looked like.

2.2.2 Ambiguity and the restriction of action space

Yet material models in some aspects restrict the space of action more than sketches (even if these models are sketchy and open-ended). They materially embody domain specific constraints through physical affordances, and symbolically through cultural and perceived affordances, suggesting particular actions [22]. Models enforce greater precision when positioning objects than a sketch would do. A brick can be put on one spot only, and one needs to decide for one – even if exemplary and rough – spatial relation, there is no way to just ‘allude’ to and sketch it.

Not being able to be ambiguous in terms of positioning makes it difficult to represent alternative solutions in parallel, but at the same time can provide more clarity (sketches often contain many ‘nonvalid’ and outdated objects). It can force people to make concrete suggestions – a valuable property for negotiations. Furthermore it is easier to rearrange objects when they can be grasped (often as a whole group) and moved, instead of needing to be redrawn (digital sketches in this regard do better than physical sketches, allowing for copy and paste manipulations).

With physical models one needs much more effort than with a sketch or a drawing to do anything similar to putting different representational levels next to each other, mix and connect them [7], e.g. having a detail view next to an overview. As sketching of evocative connecting lines is very difficult to achieve within a physical 3-D model, and detail views and alternatives are difficult to represent. Some work has been done

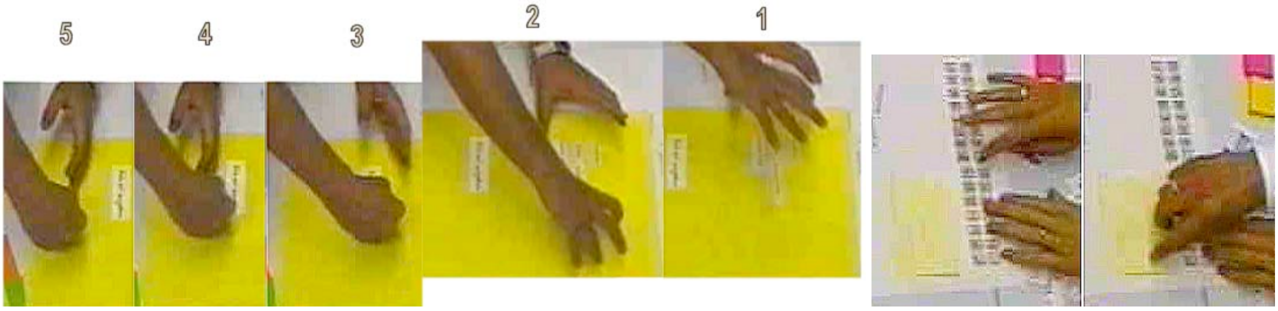

Figure 3. Gestural explanations of spatial relations and gestural mimicking (both taking reference to a visual representation)

on physical annotation of models. Annotations can be written on notes and laid into the model [23] or be represented with pins in the model, which are electronically tagged and connected with digital text or recordings [6].

Material objects, in restricting the action space, also help to focus on the remaining options. They present a basic vocabulary, which suggests starting points and topics for discussion. Taking a prototype into a meeting that went in circles, would shift the focus "from separate mental models (…) to the external material model that all can see, touch and manipulate" [1]. The model confronts with reality – it can't be discussed away and doesn't' disappear, even if temporarily forgotten about.

2.2.3 Spatial Configurability

Media with the property of spatial configurability [8, 15] ease reversal of simple actions and quick successive testing of variations. Most studies seem to point out that physical representations, in particular if they consist of a set of elements that can be moved about, provide advantages for rapid and intuitive interaction because of their configurability. With a paper prototype [21] the paper slips, and with a magnetic whiteboard [37] the magnetic slips for medical staff and patients in a ward can be moved around to quickly test alternative solution ideas or to simulate a process. Sketches or things written onto a fixed medium need to be redrawn, slashed through, and annotated with pointers.

Spatial configurability also is used to visually highlight things. Paper cards for not yet assigned work tasks are pinned slanted sideways to the edge of a project planning board [36]. Magnets on the ward planning board that represent soon finished surgeries are attached diagonally [37]. Here the standard structure, which is almost like a diagrammatic language, and the (allowed) deviations together result in an easy legible picture.

If we think of spatial configurability as a typical property of physical models, it becomes clear that a method like paper prototyping stands halfway between graphic representations and physical models. The manipulable elements carry graphic representations on them, and there is no real three-dimensionality. Most of the examples just mentioned in fact are only '2 ½ D' – they are more than two-dimensional because we can lift elements off the surface and place them over each other while still being able to access what's underneath, but they are nevertheless flat. The two lower pictures of physical models in figure 2, both from participatory planning in industrial domains, do exploit three-dimensionality, indicating height of objects, distance, and including human figurines (thereby providing a reference to bodily experience of the place discussed about).

2.3 Gesture

Gestures also can be interpreted as a possible representational form and externalisation – the gesture creates a transient and fading image for perception. Hutchins describes the effect of drawing lines with the finger on the navigation chart: "The memory of the trajectory of the fingers decays with time, but it seems to endure long enough that several of these can be superimposed on one another and on the perceptual experience of the chart" [13, pp. 156].

Gestures can imitate a series of events, mimic an object, demonstrate spatial or temporal relations, measure something, point to objects, and organize conversation. Tang [35] found that gestures made up about 35% of actions during a design session. Gestures in the design discussions of construction engineers often serve to represent a construction idea or to visualize the interplay of parts, acting as a 'substitute for a sketch' [10; cp. 19].

Bühler [4] already pointed out that motoric processes are an important element of imagination, even for adults. For children the manipulation of the play object creates the required inner impulses to continue with play and ease identification. Adults tend to need only the movement impulses or inner imaginations (like mental rotation), but if our imagination does not suffice, we often use our bodies to simulate the goal object.

Figure 3 (from [12]) shows two examples of gesture used in design discussions from paper prototyping the interface for a ticket vending machine. On the left (images read from right to left as numbered) the gesture indicates areas of the screen where specific content could be organized. The gestures in the right image-set mimic interaction with the interface (the user types on a virtual keyboard on a touch screen and sees the typed text in the small window above it). These video stills also demonstrate how gesture is often tied to the physical surrounding, using it as a frame of reference and integrating elements of the environment into the expression.

What results is a multi-modal, multi-layered expression (or representation). Hutchins and Palen [14, p.38-39] argue: "space, gesture, and speech are all combined in the construction of complex multilayered representations in which no single layer is complete or coherent by itself. (…) Does gesture support speech? Clearly it does, but no more so than speech supports gesture. [...We saw] the creation of a complex representational object that is composed through the superimposition of several kinds of structure in the visual and auditory sense modalities. Granting primacy to any one of the layers of the object destroys the whole."

Gesture even seems to share characteristics with language. It sometimes precedes linguistic naming, and often is imitated and shared by conversation partners, turning into a 'standard phrase'. Especially mimetic and descriptive gestures tend to be repeated, appropriated, and adapted by conversation partners [17], e.g. mimicking the form of a building can result in the gesture later-on being used as a stand-in for the building. Mimetic gestures often precede the linguistic term and may help to activate tacit knowledge, easing mental access for the correct word ('gestural foreshadowing'). Koschmann and LeBaron [17, p.271] therefore say that gestures are 'material signs' which embody the knowledge being articulated.

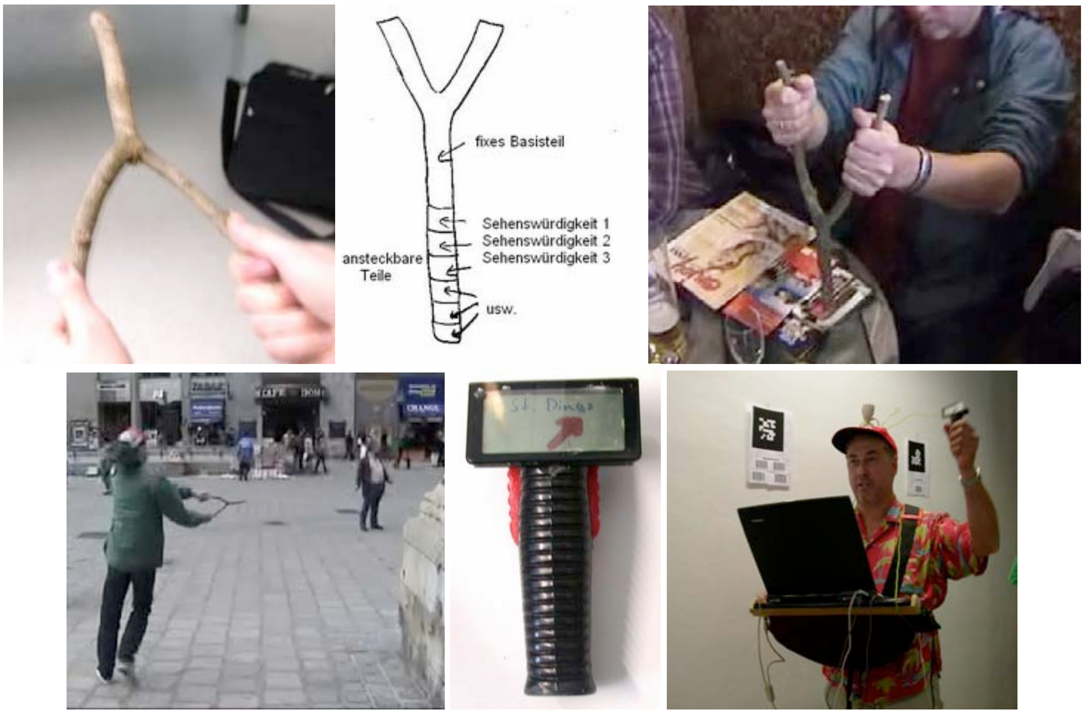

Figure 4. Evolution of a material model / prototype / mock-up in a student design exercise.

Students had the idea of a mobile tour guide that 'nudges' tourists to sites they are interested in, while allowing them to stroll through the city serendipitously. The initial guiding idea of functionality and form factor was inspired by a 'water divining rod' (top left). The envisioned functionality was sketched, extending the rod with plug-on parts (top middle). Then students used a rod when creating a video prototype, which also had them in-situ emulating use of the device (reading codes for interesting sights, and being nudged to a particular object of interest). This experience led to more insight into the usability and social appropriateness of the form factor, simplifying the form factor to a simple handheld device which would vibrate and hold a display at the top (bottom middle shows a mock-up). The functional prototype has no resemblance to the envisioned device, but provides a simulation of interacting with such a device, allowing initial insight into the user experience of the interaction process.

In comparison with sketches or fixed models gestures have the advantage of being able to represent movements and time-based processes. Spatial and time-based imagination, enactive and kinaesthetic knowledge do not need to be translated into a medium that is not time-based and spatial. The transience of gesture here turns into an advantage, and one can quickly represent a series of alternatives, without creating 'representational garbage'. Yet it is difficult to represent larger relationships with gestures. The sequential nature of gesture, its 'linearity' which it shares with spoken language, allows us to demonstrate and perceive only one part of a bigger relation at once. Persistent graphic objects, in contrast, "can be visually taken in simultaneously, at a glance (…) modalities of interaction that are fundamentally different from the sequential order of speech and action" [31, p. 271].

3. CONCLUSION

This paper has attempted to collect and summarize some of the current knowledge about the properties of different representational forms. The focus has been in particular on understanding the different properties of physical models or prototypes in comparison to graphical representations such as sketches. This discussion is far from complete, and far from satisfying, as I am aware.

A particularly intriguing issue in summarizing evidence from literature has been the degree of ambiguity that different media afford in comparison to the freedom of action they allow for. Other issues have been the kinds of interactions a particular representation allows for, as well as the types of knowledge it activates or allows to express (cp. Figure 4). With a physical model it is more difficult to make annotations than on a sketch. The gesture of showing by demonstration can orient itself much closer to a physical model, while it needs to divert from the sketch where the planar nature and invariance of the sketch does not support the demonstration.

Something that is fundamentally changed by transferring sketches to digital form is the medium, changing the ways we can interact with it. This is essentially true for all representations. Any representation that is affixed to a sheet of paper can be moved around, handed over physically, creating visible reminders. Gestural references to physically embodied representations are easy to decipher, because the spatial relation is clear – unlike the text that scrolls off the screen.

Interpreting gesture as a kind of representation may first seem surprising, but in discussing the materiality of representation we should also be aware of the physicality of the people that create or perceive representations – in performative activity the body turns into a representational medium. Gesture has long been neglected as something that merely adds to and accentuates speech. Thus emphasizing its unique qualities of being able to show temporal things and its interrelation with the external representations it might engage with and refer to, highlights aspects that we might be missing in other representational forms.

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