engineering design, and stress the need to understand and encourage the use of multi-modal means of representation.

The study by Margot Brereton in Chapter 4 is set in the studio where student engineering designers work on a number of design assignments. The study demonstrates that learning occurs through continually challenging abstract representations against material representations. The gaps between the two modes of representation inspire further design activity: representation in the two modes informs and advances the design solution, enhances the designers' understanding of design requirements, and brings to light implicit design assumptions. Hardware repertoires are extended, and fundamental engineering concepts are sorted out through a continual process of representation and rerepresentation in abstract terms and in material form. In particular, the role of material representation in supporting cognitive activity is instantiated through rich examples concerning design exercises such as the design of a crane or a kitchen scale. In these examples hardware is shown to assume a variety of roles in mediating the learning process, including those of starting point, thinking prop, medium of integration, embodiment of abstract concepts, and more. Brereton's in-depth analysis is grounded in a theory of the primacy of multi-modal representational modes in learning, and in particular negotiations between abstract and material representations. In our estimation this theory can and should be extended beyond the scope of the educational setting, into the realm of practice in general, where ill-structured problems habitually require relearning and reformulation of problems.

In Chapter 5, Petra Badke-Schaub and Eckart Frankenberger are concerned with the availability of information through communication among team members who are involved in the development of a new product. Information is transmitted through representations of various kinds: verbal, written, sketches, drawings, and electronic data. The present study concentrates on verbal information transfer in what the authors call "critical situations" (defined by task requirements) of the design process. Data was collected by observing design activity on a daily basis for a relatively long period, using three criteria: "individual prerequisites," "prerequisites of the group," and "external conditions." To those we must add the givens of "the task": in one case the redesign of a pneumatic fruit press, and in another case the developing and redesigning of several components of a particleboard production plant. The study found that the main venue for information transfer in teamwork (critical situations) was verbal exchanges. Designers testified that asking colleagues was their preferred way of acquiring specifically required information, and that informal conversations also provided very useful information. Further analysis showed that critical evaluations are mostly achieved through positive affirmations, but not exclusively so. "Positive affirmation" representations are particularly instrumental in enhancing a good group climate, which in turn contributes primarily to activity of the type "solution search."

The third chapter in Part II, Chapter 6 by Gilbert Logan and David Radcliffe, is dedicated to a unique engineering task in which a team works to adjust and refine engineering solutions to the personal needs of patients in a Rehabilitation Engineering Centre. A case in point is the seating clinic, where a patient born with congenital amputations of his arms and his right leg is seeking help in adapting his wheelchair to the operation of a laptop computer, using his degenerated left leg. By the nature of the task, team members

continually communicate with each other and with the patient. The authors analyze communication using three categories of representation: talk, action (such as gestures and mimicry), and the use of artefacts. The combination of the three factors in design activity is called "artefacting" and the act of using objects at hand to simulate design ideas is called "impromptu prototyping." Sessions of routine work in the clinic were videotaped and later parsed into "events". A fine-grained analysis of these events shows how interrelated the three types of representation (divided into subcategories) are; in fact, in more than half of the events, all three types were detected, hence an emphasis on impromptu prototyping. We believe that this analysis mirrors a large number of engineering design episodes in which goal-oriented behaviour takes advantage of all the available means to reach the best possible solutions, relying primarily on common sense and on affordances provided by contextual settings.

Beyond Disciplinary Perspectives

Every design discipline has developed its own traditions, norms, and conventions of representation, commensurate with its evolving culture(s), professional objectives, and the organization of the workplace and work methods. Architecture, for example, has been primarily concerned with space and its enclosure, with questions regarded as pertaining to "aesthetics", with cultural integrity and continuity over time, and hosts of other material, as well as non-material, mostly qualitative, issues. Engineering design is much more, if not exclusively so, about material qualities of objects. Function and performance precede consideration of any independent aesthetic nature, and design entities are not single, individually designed "one-off" products but often "revised models" of prior existing products, the properties of which are usually quantitatively evaluated. Representations in the two fields should, and do, reflect these differences. They are embedded in their respective cultures and respond primarily to the needs and expectations of members of their respective professional communities and their audiences. In no way do we wish either to overlook the differences or mitigate their significance. However, at a fundamental level, there also exist considerable commonalties in design thinking and therefore also in representational properties and in the way that designers in all disciplines go about generating and utilizing them. Commonalities are discernible when assertions proclaimed in the context of one discipline resonate in the context of another discipline as well. For example, when Brereton talks about negotiations between abstract and concrete representations in engineering design, we can easily map her descriptions on to architectural design. Likewise, the dichotomy between the role of representations as simulations and as objects in their own right that Porter brings up in the context of architecture is not foreign to engineering. Part III contains three chapters that address issues of universal significance to all design disciplines: the role of sketching in design thinking, the evolution of representational design skills, and, finally, a possible paradigm for the study of design representation.

Jonathan Fish in Chapter 7 is interested in the role of sketching in solving problems that require visual invention, as is typically the case in the various design domains. Sketching, he claims, amplifies the mind's ability to translate descriptive ideas to depictive images and vice versa. Such back-and-forth