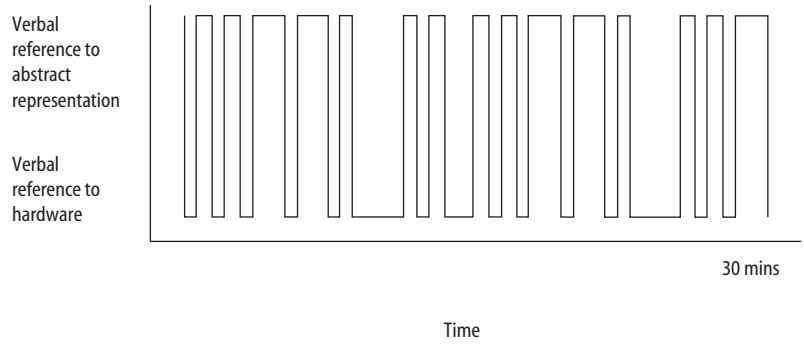

Figure 4.4 A plot of the crane design activity revealed that the discussion consists of interleaved references to abstract representations (design requirements or theoretical concepts) and hardware in the workspace.

(Figures 4.5a and b). Presumably, a design that would meet the requirements would need these properties, so these properties were used as a sort of shorthand way of referring to the requirements (support a 20lb load, 9in from the end of the platform). Once a prototype existed (Figures 4.5c and d), each design proposal sought to modify the hardware (shorten the diagonal strips, remove the brace) in order to change the properties (length, tendency to twist) that became apparent from the prototype behaviour. Design progressed through evaluating the hardware with respect to the requirements, making a proposal, implementing it in hardware, and then re-evaluating the hardware with respect to the requirements. This behaviour was typical in all groups that were studied designing cranes and in other kit design exercises.

The design process described above is negotiation in two respects. First, the designer argues the requirements (abstract representation) against the performance of the current hardware prototype (material representation) and tries to bridge the gap. Second, in group-work, the students negotiate one student's opinion against another and try to reach agreement among themselves about how to proceed. In the end, the hardware specification must satisfy the requirements, so there is a sense in which the requirements (abstract representation) and the hardware (material representation) must converge through the design activity; however, many divergent paths may be taken before final convergence is achieved.

Schön (1983) described the process of architecture students sketching as involving a reflective conversation with the materials of a design situation, the sketch talking back and revealing issues to the designer. The sketching process relies on the ability of the sketcher to interpret and modify the sketch, to see issues presented by the sketch. The evolving physical prototype is a yet more active and evocative participant than the sketch. It responds through physical behaviour. It may deform under loading, make noises, smell, wear, or jam. It is sensitive to attachment procedures. It is intolerant of poor assumptions or overlooked details that may not reveal themselves in a sketch. It reveals or suggests such oversights through its behaviour. The student gets feedback through seeing, feeling, smelling and hearing the prototype. As students become more acute observers, they learn to experiment and probe actively, watching, listening, touching, and smelling the prototype. They make

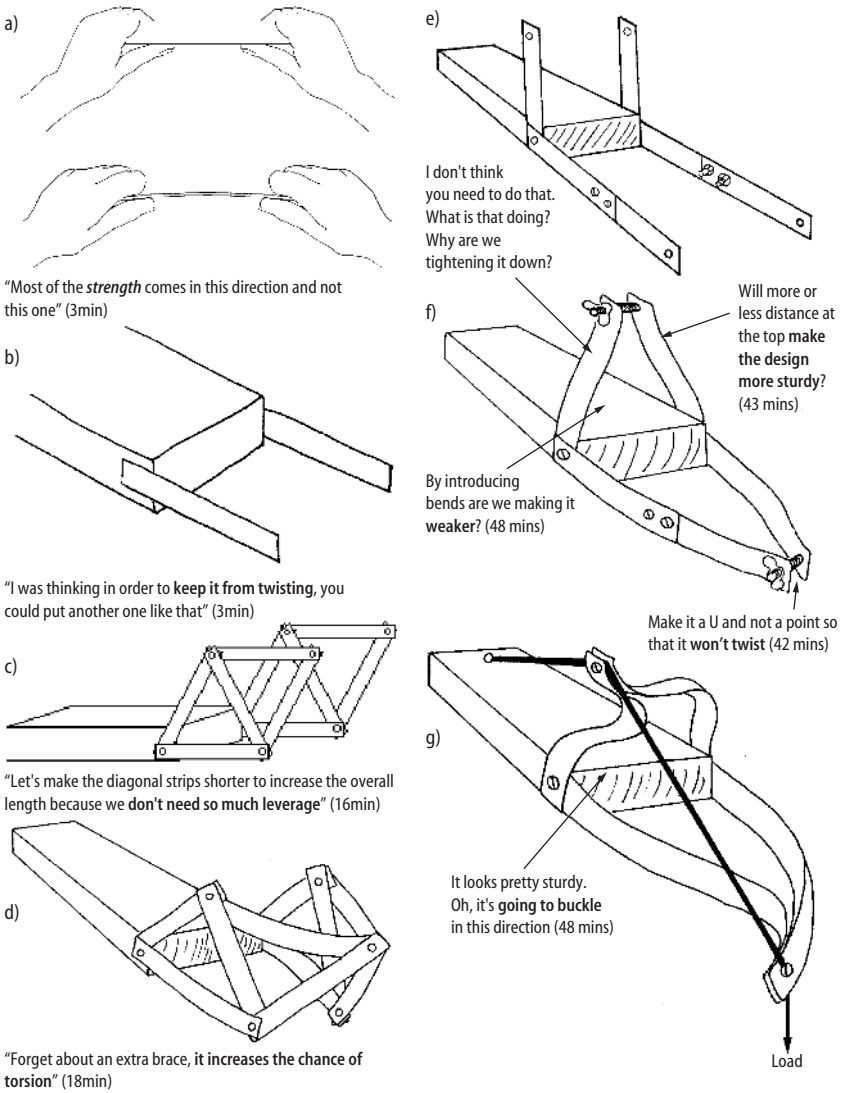

Figure 4.5 Students pit abstract requirements against hardware behaviour as they design the crane.

causal links between actions and behaviours. To learn from a hardware prototype, the designer must interpret the physical response and decide on the next move.

The Roles of Hardware in Learning

So far I have identified a learning process that is almost identical to Schön's (1994) notion of a reflective conversation with the materials. Schön (1990)