described the design process as consisting of the framing of the design problem, the discovery mediated by the materials, and the subsequent reframing of the problem in the light of the discoveries made during designing. The contribution of this work is to identify just how the materials – in this case hardware – mediate the learning process and to identify specifically what kinds of things are learned through use of hardware to support thinking. Hardware has been identified as playing the following roles in mediating the learning process, as described in Table 4.1:

1. Hardware as a starting point.
2. Hardware as a kinaesthetic memory trigger.
3. Hardware as a thinking prop.
4. Hardware as a chameleon.
5. Hardware as a medium for integration.
6. Hardware as an embodiment of abstract concepts (functional and theoretical).
7. Hardware as an adversary.
8. Hardware as a prompt.
9. Hardware as a communication medium.

In observations of design activity, Harrison and Minneman (1996) found "that the processes of interaction with objects are an integral part of the communications, alter the dynamics in multi designer settings and form part of the pool of representations that are drawn on by designers" (role 1). This chapter describes roles 1–5. For more detailed descriptions and discussion of roles 6–9, see Brereton (1998).

Hardware starting points and kinaesthetic memory triggers

Hardware and prior experiences with hardware are the starting points from which students develop design proposals. As the previous section illustrated, students look for possibilities in existing hardware to meet design requirements. We might expect this result when hardware is readily available, as in the crane exercise. However, it is interesting to notice where students look for inspiration when there is no hardware at hand. In the scales exercise, students were asked to develop concepts for an internal mechanism for kitchen scales, as illustrated in Figure 4.2b, with only paper, pens, and a fully assembled kitchen scale which they were asked not to disassemble. The exercise revealed that in conceptual design, students draw on memory of experiences with hardware (internal representations) and are opportunistic in seeking out any kind of miscellaneous hardware (external concrete material representations) to think with. We can get some idea of students' internal representations by observing them in the conceptual design exercises. In recalling prior experiences with hardware, students mentioned winding clock springs and watching music boxes unravel. They recalled with varying success how moving coil galvanometers, pressure gages, wind up toys, and ball-point pen deploy-retract mechanisms work. It was notable that many groups, in saying that

a design could be "like a biro" or "like a wind-up toy," did not make any explicit reference to the abstract function or geometry, but simply referred to behaviours of similar devices. Often these comments were accompanied by gestures or simple sketches in the form of recorded gestures that indicated that manipulating hardware led to bodily learning.

Table 4.1. The roles of hardware in mediating design negotiations and the associated learning outcomes

The roles of hardware in mediating design negotiations	Design learning outcomes
Hardware as a starting point	Hardware is tangible. It exists. It serves as a starting point, is easily noticed, remembered, seen and touched. It offers a basis for comparison. (It is a concrete external durable representation.)
Hardware as a kinaesthetic memory trigger	Episodes of kinaesthetic experiences with physical objects serve as memory devices (internal representations).
Hardware as a thinking prop	Hardware objects have all sorts of properties that afford different actions. Hardware that is easily accessible and has a useful property is adopted as a gestural aid to support thinking.
Hardware as a chameleon	Hardware is always in a context of use. What the hardware reveals depends on the context of use. A variety of informal experiments in different contexts reveal different facts.
Hardware as a medium for integration	Integrating components in their functional context reveals: practical limits of use; characteristics of operation; methods of connection; causal relations; and physical quantities. This empirical knowledge extends the student's hardware repertoire.
Hardware as an embodiment of abstract concepts (functional and theoretical)	Observing and testing hardware reveals through the hardware behaviour: fundamental concepts; physical embodiments of abstract concepts; and unanticipated design issues.
Hardware as an adversary	Challenging theoretical model predictions against hardware behaviour reveals discrepancies and provides clues to modelling errors. This reveals theoretical assumptions and causal relations.
Hardware as a prompt	Device behaviour prompts student questions and suggests experiments. Through repetitive interaction with hardware, students bring order, distilling out key operational parameters and their relationships.
Hardware as a communication medium	Hardware is integral to learning communications, affecting the course of enquiry, idea generation, discovery and the dynamics of group interaction. Hardware is used to command attention, to demonstrate, and to persuade.