

Abstract

A series of short engineering exercises and design projects was created to help students learn to apply abstract knowledge to physical experiences with hardware. The exercises involved designing machines from kits of materials and dissecting and analyzing familiar household products. During these activities students brought their knowledge of engineering fundamentals to bear. They worked in teams. Videotape analysis was used to identify and characterize learning mechanisms observable during activity. In particular, the ways in which hardware contributed to learning fundamental concepts was examined.

Structural and qualitative analyses of videotaped activities were undertaken. Structural analysis involved counting the references to theory and hardware and the extent of interleaving of references in activity. A comparison of three table-top exercises undertaken by one group revealed that two exercises promoted much more discussion linking fundamental concepts and hardware than the third, (40% - 60% of minutes versus 13% of minutes). A comparison of three groups undertaking one table-top exercise revealed that two groups linked fundamentals and hardware in discussion much more than the third (42% - 61% of minutes versus 18% of minutes). These two groups identified and explained twice as many fundamental concepts as the third. The analysis showed that the interleaving of references to theory and hardware in activity is observable and quantifiable.

Qualitative analysis was used to investigate the dialog linking concepts and hardware. Students were found to advance their designs and their understanding of engineering fundamentals through a negotiation process in which they pitted abstract concepts against hardware behavior. Through this process students sorted out theoretical assumptions and causal relations. In addition they discovered design assumptions, functional connections and physical embodiments of abstract concepts in hardware, developing a repertoire of familiar hardware components and machines. Hardware was found to be integral to learning, affecting the course of inquiry and the dynamics of group interaction. Several case studies are presented to illustrate the processes at work.

The research illustrates the importance of working across the boundary between abstractions and experiences with hardware in order to learn engineering and physical sciences. The research findings are:

- (a) the negotiation process by which students discover fundamental concepts in hardware (and three central causes of negotiation breakdown);
- (b) a characterization of the ways that material systems contribute to learning activities, (the seven roles of hardware in learning);
- (c) the characteristics of activities that support discovering fundamental concepts in hardware (plus several engineering exercises);
- (d) a research methodology to examine how students learn in practice.