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On an Engineering Use of Engineering History

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This is a tale of how writing about the engineering past is benefiting the engineering present. Our story is not of the familiar kind, however, in which knowledge of the past failure or success of a particular device has influenced later, related designs. Instead, we deal here with a general methodology from the history of one engineering field and its fruitful application to present-day research and design in another, very different field.

The field of application—human–computer interaction—is the primary discipline supporting the design of computer-based artifacts that people use directly, such as websites, computer games, mobile phones, electronic notebooks, and other interactive programs and devices. Like many fields of engineering in their early years, it has been feeling its way as an area of activity. Because advances in information technology have been so rapid and new applications have emerged with such regularity, no overall research or design methodologies have become established—a situation rarely apparent to those who enter the field.

This was certainly true of one of the coauthors of this tale, William Newman, an engineer and computer scientist who went to work in the Xerox laboratory in Cambridge, England, in 1988. Confronted with design choices in his work on novel user interfaces, he sought help in journals and conference proceedings devoted to human–computer interaction, but rarely found it. It gradually dawned on him that there was no coherent view

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of the nature of *design requirements* in the field—that is, of the criteria or parameters by which the performance goals of a device are incorporated into the design procedure. There was no concept of performance requirements that could bind research together and link it up with design. Concerned to find such a concept, he looked for guidance in the engineering literature. Here, however, he was surprised to find that requirements were hardly mentioned in methodological terms or ever listed in a book's subject index. Instead, design criteria were introduced in discussing particular methods and solutions, but with no general treatment or explanation of their source.

Increasingly puzzled by his situation, Newman happened one day upon Walter Vincenti's *What Engineers Know and How They Know It*, with its historical case studies and analyses from aeronautical engineering, which he quickly devoured. This showed him the way mature engineering research is conducted and how it informs and conditions the design of products, a methodology that had little resemblance to his own or those of his colleagues. He read how engineering researchers develop quantitative analytical tools for predicting the outcomes of design, and how they focus on incremental improvements instead of deliberate departures. Most relevant to his needs, he saw how engineers in advancing fields arrive at design requirements and criteria.

To explore the methodological contrast with human–computer interaction, Newman made a literature-based study of the outcomes presented by researchers in his field. This showed that interaction researchers were producing a wealth of novel designs, but very few analytical criteria by which to specify or evaluate their performance; instead, they had to build a prototype in each case and have it tested in a special experiment. Newman was initially baffled by this peculiarity, but he found an explanation in Vincenti's chapter on the development of quantitative criteria against which to judge an airplane's "flying qualities"—that is, characteristics that enable the pilot to control the vehicle's flight path with satisfactory ease and precision. For longitudinal control, for example, engineers were able, by experiment and extensive flight experience with various suggested criteria over the twenty-five years from 1918 to 1943, to settle on *stick force per g*—the force exerted on the control stick by a pilot in a simple curved-path maneuver divided by the resulting centripetal acceleration measured as a multiple of the acceleration of gravity *g*. This became universally accepted as the critical parameter to which airplane manufacturers should—indeed, are required to—design, with different quantitative limits specified for different types of airplanes. Newman was especially struck by Vincenti's remark that "[a]eronautical engineers today express amazement that any maneuverability criterion besides stick force per *g* ever existed." He realized that this explained the lack of specific reference to requirements in engineering textbooks.

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In 1997, he therefore set up a program at Xerox aimed at identifying quantitative design requirements, or *critical parameters*, for interactive systems. His supposition about the current state of affairs was confirmed by studies, with his colleague Alex Taylor, of designers' reports on their work and by published accounts of design methods used by software providers. In the absence of quantitative performance targets, designers simply aimed qualitatively to provide sufficient functionality to support task performance by the user. A shift of human–computer interaction toward incremental research or toward developing analytical models seemed unlikely, since there were no quantitative criteria by which to assess design progress or predictive accuracy.

The Xerox research, which ended with the laboratory's closure in 2002, made considerable progress toward finding critical parameters, and more has since come at Microsoft Research. An example is a study, begun at Xerox, of primary-care doctors' use of computers for record searching and diagnosis in patient consultations. Videotapes of over sixty consultations and detailed interviews with four general practitioners yielded an unanticipated result: if the physician spent more than about ten seconds attending silently to the computer, the patient started to speak, distracting the physician and increasing the consultation time. The critical quantitative design parameter thus became the maximization of the number of tasks that can be completed in ten seconds. At Microsoft this line of research is being extended, revealing parameters governing the disruptive effects of using laptops instead of written notes in meetings, and suggesting design strategies for reducing these effects. Critical parameters for other interaction problems are also being studied.

Other interaction research groups are also exploring the use of quantitative design criteria, spurred on by interests in taking a more incremental approach and in basing this on identified critical parameters. At MIT's Media Lab, for example, R. J. K. Jacob and coworkers have tackled the problem of designing a tool to assist in conference planning and compared the performance of their tangible interaction design with more conventional solutions; at Virginia Tech, D. Scott McCrickard and associates have drawn on the Xerox work in taking a critical-parameter approach to modeling the evaluation of notification systems; while at the University of Southampton, Maria Karam and Monica Schraefel have taken a similar approach to the computer recognition of human gestures. In an examination of the software-research activities reported in conference and journal papers, Mary Shaw at Carnegie Mellon University concludes generally that "[o]ne indication that ideas are maturing is a shift from qualitative and empirical understanding to precise and quantitative models."

In all of this, the history of technology played a central, if serendipitous, role.