CRITIQUE AND RESPONSE: Response to Maddox Critique

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CRITIQUE AND RESPONSE

Response to Maddox Critique

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We sincerely thank both the editor and Michael Maddox for the opportunity to participate in this collegial debate centered on our article, "A Longitudinal Study of the Effects of Ecological Interface Design on Skill Acquisition" (this issue). As we hope to show, the human factors discipline can benefit greatly from such an open process. We and Maddox agree on many issues, which is comforting to us as researchers, given Maddox's practical experience in the nuclear industry. The remaining disagreements seem to arise from differences in terminology and in the perceived role of human factors in systems design.

We address the former issue first by defining several concepts that are part of the foundation of our work. An *abstraction hierarchy* (Rasmussen, 1979) is a multilevel representation of the structure of a work domain defined by a means-ends relation between levels. In process control, five levels of representation have been found to be of use: the purposes for which the plant was designed (functional purpose), the mass and energy topology of the plant (abstract function), the generic functions that implement that topology (generalized function), the plant components that realize those functions (physical function), and the spatial location and appearance of those components (physical form). A detailed description of an abstraction hierarchy for the DURESS II system that we used as a testbed in our research can be found in Bisantz & Vicente (1994). *Physical* information describes the state of material components in a plant (e.g., pumps, heaters, valves). *Functional* information describes the state of the functions or purposes that those components are intended to satisfy, rather than of the components themselves. The higher levels of the abstraction hierarchy contain functional information, whereas the lower levels contain physical information.

Note that the distinction between physical and functional information is not equivalent to the implementation distinction between data that can be sensed directly and that which must be analytically derived from sensed data. Physical information can usually be sensed directly (e.g., valve position), but functional information can either be sensed directly (e.g., flow rate) or derived (e.g., energy inventory).

An *ecological interface* is one which is designed according to the principles of the ecological interface design (EID) framework, summarized in our article (for more details, see Vicente & Rasmussen, 1992). The content of an ecological interface is defined by an abstraction hierarchy analysis of the plant and thus includes both physical and functional information.

The P+F interface in our study satisfies this criterion, whereas the P interface does not because it contains only physical information and the status of system purposes (the latter must also be included, otherwise the system cannot be controlled). Vicente & Rasmussen (1990) provided a detailed description of how the principles of EID were used prescriptively to design a slightly different version of the P+F interface for the original DURESS system.

These definitions invite a reinterpretation of two of Maddox's statements. First, he states that at least one other study examined operator performance with an ecological interface in the process control domain. Although the paper he cited does indeed use the adjective *ecological* to describe its displays, those displays do not satisfy the aforementioned definition. It is not surprising that there is confusion on this point; the human factors field has yet to reach the state of maturity in which all researchers consistently use the same set of well-defined terms, regardless of theoretical orientation.

Second, Maddox points out that the idea of presenting process information according to abstraction hierarchies is not a new one and that such interfaces were designed after the Three Mile Island accident. We agree with the first part of this claim; Rasmussen's (1979) abstraction hierarchy was first described in a seminal technical report published 17 years ago. However, we disagree with the second part, again perhaps because of a difference in terminology. There are different kinds of abstraction hierarchies, but the one we have defined has a relatively unique and valuable set of characteristics (Vicente & Rasmussen, 1992). The displays cited by Maddox do present information at multiple levels of abstraction, but because they were not based on an abstraction hierarchy analysis, they are not ecological interfaces.

For example, unlike the P+F interface evaluated in our study, the displays to which Maddox refers do not fully represent the plant at the level of abstract function. This is an important omission, given that state information about first principles (i.e., mass and energy conservation laws) is crucial for dealing with events that pose the greatest threat to safety (that is, events that are unfamiliar to operators and have not been anticipated by plant designers). These divergences between Maddox and us have important implications, but they are relatively specific. We turn now to a much broader issue.

Maddox's critique of our work can be broken down into several parts. First, he states that the "physical system" includes all of the primary sensors and the plant components. We do not adopt this convention. Instead, we distinguish between the instrumentation and control (I&C) system (including sensors) and the plant process itself. This distinction is standard in control engineering (see any introductory textbook, such as Kuo, 1987).

Second, Maddox implies that our study compared "two different underlying systems." This criticism follows from his definition of physical system, in that the P+F interface needs more sensors to drive it than does the P interface. At this point the aforementioned distinction between the I&C system and the process itself comes into play. The addition of sensors does not change the underlying dynamics of the process. Rather, the dynamic equations governing the behavior of DURESS II are exactly the same for the P and the P+F interfaces. We know this because one of us (Vicente) wrote the specifications for the simulation software. Therefore, we would not say that the "physical systems" are different in the two experimental groups for the reason that there is only a single, common process model driving the behavior of the two interfaces. This is not merely a disagreement over wording, as the next point makes clear.

Third, Maddox states that developing an ecological interface should not include adding any sensors. Although we disagree, we can understand how Maddox, being a former instrumentation engineer, would adopt such a position. Typically, human factors engineers in the nuclear industry begin their interface design efforts after the I&C system has been specified by control engineers. This is precisely where the problem lies. The role of sensors is to provide information about plant state. How does one decide what information is needed and therefore what sensors are required? A comprehensive answer to this question must include an understanding of the information that operators need to cope with the entire set of demands that they may face, particularly in unanticipated events.

Currently, however, the decision of what sensors to include is based almost solely on "traditional" engineering constraints, not on human factors engineering constraints. Thus it is not surprising to find that many nuclear power plant control rooms do not display crucial functional information because the sensors that are necessary to supply that information were not built into the I&C system. As a result, the human factors engineers are left with the unenviable job of designing an interface based on an incomplete information set. This simple fact has enormous implications, for no matter what other features the human factors engineers design (e.g., easy-to-use displays and controls), they will never be able to recover all of the information that operators need to deal with life-threatening, unanticipated events. If the proper sensors are not built in from the start, this information simply cannot be displayed in the interface. With this design process, the best that the human factors engineers can do is make the interface usable, as opposed to useful (see Rouse, 1990).

One of the defining features of the EID framework is that it rejects this traditional design process. Instead of limiting ourselves to issues of usability, reachability, and visibility, we also wish to have a say in the specification of interface content and, thus, design functionality. This is accomplished by developing an abstraction hierarchy representation of the plant, which can then be used to determine which sensors are needed to drive the interface (e.g., Reising & Sanderson, 1996). Consequently, EID is fundamentally broader in scope than other approaches to interface design that do not address the question of what the information content of the interface should be (e.g., Wickens & Carswell, 1995). This increase in scope has a price associated with it. Adopting EID as a design framework requires that human factors engineers contribute to decisions regarding which sensors should be in the I&C system, but this is far from the standard practice in the nuclear industry.

From our perspective, then, the most significant point of disagreement is not the one that Maddox identified. His question—"How do we know that the observed performance differences are attributable to the addition of abstract information to the interface and not to the addition of the physical sensors (and their information) in the system?"—is not really an issue because the abstract functional information cannot be displayed if the requisite physical sensors are not there. We believe that the more important issue is what counts as an interface. Maddox seems to view interface design as determining "the manner in which information is depicted," whereas EID also addresses the more fundamental issue of what information to select for depiction in the first place.

The broad issue at stake here is nothing less than the role of human factors in systems design. There is no doubt that human factors has not typically been in the pilot's seat in the systems design process of many companies. Instead, it has been at best a passenger and at worst, cargo. From a research perspective, however, the important question is not what that role is now or has been in the past but, rather, what that role should be in the future. If we are to create safer, more efficient, and more productive designs, human factors engineers must at least be copilots in the design process, having input into issues that have traditionally been viewed as solely under the purview of traditional engineering disciplines (e.g., control engineering). This point goes well beyond the confines of the process control domain and the interface design problem that were the focus of our article. It is relevant to all other domains in which designing for human use is an important consideration and to all other design problems associated with such domains.

If this sounds like a paradigm shift in the way in which products are designed, then we will have made our point clearly. Although paradigm shifts are usually idealistic, academic curiosities, the type of approach we advocate is already being adopted in industry. For example, Rouse (1990) has helped to implement a human-centered (as opposed to user-centered) approach to systems design, embodying the values we have described, in dozens of companies. In aviation, Honeywell is advocating that human factors engineers must have input into the design of the functionality of cockpit automation if truly human-centered designs are to result (Riley, 1996). The paradigm shift has already started.

Lest we be misunderstood, we will conclude by explicitly stating that we respect human factors engineers, like Maddox, who face challenging design problems on a daily basis. Moreover, we value their input much more than that of many academics because we view them as the end users, or customers, of our research results. The ultimate goal of our research, however, is to affect the design of sociotechnical systems so that they become safer, healthier, and more profitable than they are today. To achieve this goal requires that human factors be a pilot in the systems design process, not a passenger or cargo. In process control, we will know that we have achieved our goal when cognitive engineering ceases to be perceived as an oxymoron.

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In the Next Issue

The following is a list of articles tentatively scheduled for the December 1996 issue of *Human Factors*.

Special Section: Health Care
Special Section Editor: Marilyn Sue Bogner

Special Section Preface
Marilyn Sue Bogner

Medication Instruction Design: Younger and Older Adult Schemas for Taking Medication
Daniel G. Morrow, Von O. Leirer, Jill M. Andrassy, Elizabeth Decker Tanke, and Elizabeth A. L. Stine-Morrow

Adapting to New Technology in the Operating Room
Richard I. Cook and David D. Woods

Users As Designers: How People Cope with Poor HCI Design in Computer-Based Medical Devices
Jodi Heintz Obradovich and David D. Woods

Task Complexity in Emergency Medical Care and Its Implications for Team Coordination
Yan Xiao, William A. Hunter, Colin F. Mackenzie, Nicolas J. Jefferies, Richard Horst, and the LOTAS Group

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Visibility of Text and Icon Highway Signs under Dynamic Viewing Conditions
Gerald M. Long and Daniel F. Kearns

Aurally Aided Visual Search under Virtual and Free-Field Listening Conditions
David R. Perrott, John Cisneros, Richard L. McKinley, and William R. D'Angelo

Performance during Positive Pressure Breathing after Rapid Decompression Up to 72 000 Feet
Ann-Elise Lindeis, W. D. Fraser, and Barry Fowler

An Isometric Predictor for Maximal Acceptable Weight of Lift for Chinese Men
Yung-Hui Lee and Yi-Lang Chen

Keyboard Reaction Force and Finger Flexor Electromyograms during Computer Keyboard Work
Bernard J. Martin, Thomas J. Armstrong, James A. Foulke, Sivakumaran Natarajan, Edward Klinenberg, Elaine Serina, and David Rempel

Minimizing Fatigue during Repetitive Jobs: Optimal Work-Rest Schedules
David D. Wood, Donald L. Fisher, and Robert O. Andres

Effects of Adaptive Task Allocation on Monitoring of Automated Systems
Raja Parasuraman, Mustapha Mouloua, and Robert Molloy

Differentiation of Visibility and Alcohol as Contributors to Twilight Road Fatalities
D. Alfred Owens and Michael Sivak