

Viewpoint

Improving the Usability and Safety of Digital Health Systems: The Role of Predictive Human-Computer Interaction Modeling

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Abstract

In this paper, we describe techniques for predictive modeling of human-computer interaction (HCI) and discuss how they could be used in the development and evaluation of user interfaces for digital health systems such as electronic health record systems. Predictive HCI modeling has the potential to improve the generalizability of usability evaluations of digital health interventions beyond specific contexts, especially when integrated with models of distributed cognition and higher-level sociotechnical frameworks. Evidence generated from building and testing HCI models of the user interface (UI) components for different types of digital health interventions could be valuable for informing evidence-based UI design guidelines to support the development of safer and more effective UIs for digital health interventions.

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KEYWORDS

digital health; human-centered design; usability; human-computer interaction; predictive modeling

Introduction

User interfaces for digital health systems such as electronic health records (EHRs) or clinical decision support systems should be designed so that clinicians can accomplish tasks efficiently without making errors that could compromise patient safety. Designers of digital health systems should be able to use the best research evidence currently available, drawn from systematic reviews and meta-analyses, to inform their designs. However, the evidence base for designing user interfaces (UIs) of digital health systems has been difficult to establish, as evaluations of UIs are often subjective and difficult to generalize to new clinical contexts [1]. Recent systematic reviews of usability issues with different types of digital health systems (such as computerized physician order entry [2] and electronic medical records [3]) highlight some common issues identified

across different studies but also describe the difficulties in generalizing guidance from context-specific evaluations. This evidence is of use to designers but does not offer specific design patterns or quantitatively demonstrate the trade-offs between efficiency and effectiveness that may be involved in different approaches to making designs more usable. Partly due to the weakness of the scientific evidence base, usability guidelines have therefore generally recommended adopting a human-centered design (HCD) approach and the use of expert heuristics to guide the design of interfaces rather than quantitatively validated design patterns.

In this paper, we examine how the use of human-computer interaction (HCI) predictive models can contribute to building a more robust and generalizable evidence base for UI designs for digital health interventions. This evidence base could then

be used to advance UI design guidelines and could be incorporated in the human-centered design process to accelerate innovation and improve clinical safety.

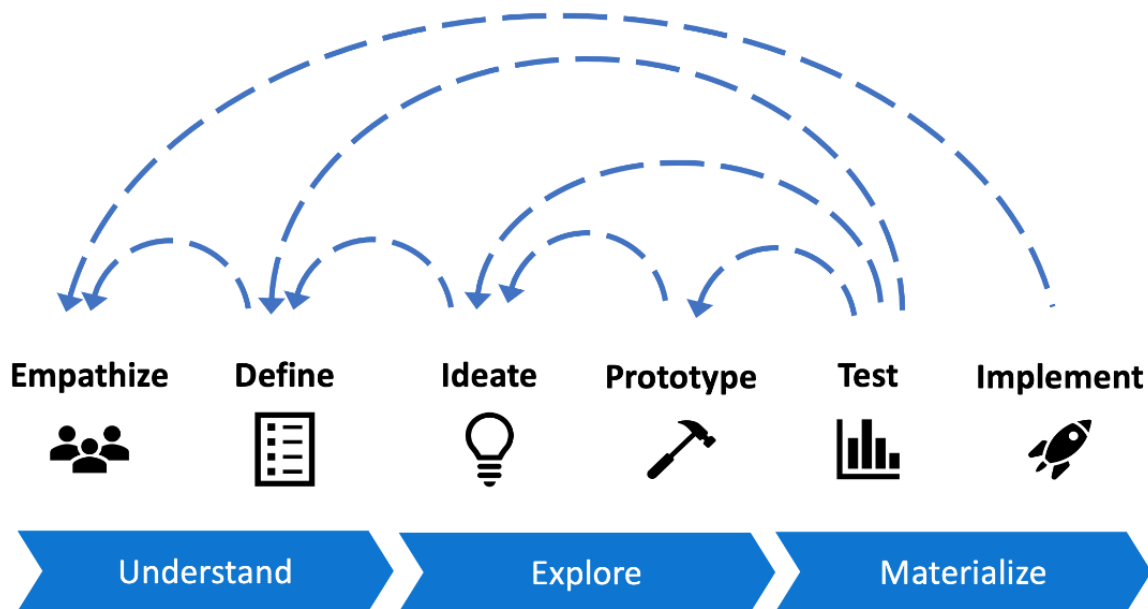
HCI modeling was used to develop the first computer mouse [4,5] and the modern window-based graphical UIs in wide use today [6]. As digital health systems become widely (albeit often reluctantly) adopted in health care, HCI modeling could have an important role in ensuring that the systems we use to care for patients are as safe and effective as other medical innovations such as drugs and diagnostics.

To discuss this approach, we provide a summary of the historical origins of predictive HCI modeling, show examples of how it can be used in modern digital health system design, and show how HCI modeling can be integrated into the human-centered design process.

The Digital Health Design Evidence Gap

The current best practice for designing UIs for digital health systems is to use a human-centered design (HCD) approach such as “design thinking” [7], in which designers and developers move through an iterative and flexible process of understanding, exploring, and materializing the end product (Figure 1). This process is often guided by design heuristics (“rules of thumb”) that include such guidance as keeping the UI simple and aesthetically pleasing and ensuring that help and documentation are readily available (see Textbox 1 for the 10 Nielsen heuristics) [8,9,10]. Iterative design thinking methods attempt to ensure that systems are aligned with users’ behaviors and needs and allow for improvements to be made throughout the course of the design process.

Figure 1. Human-centered design helps designers move from computer code to real-world use. Adapted from Gibbons [7].



Textbox 1. The 10 Nielsen usability heuristics.

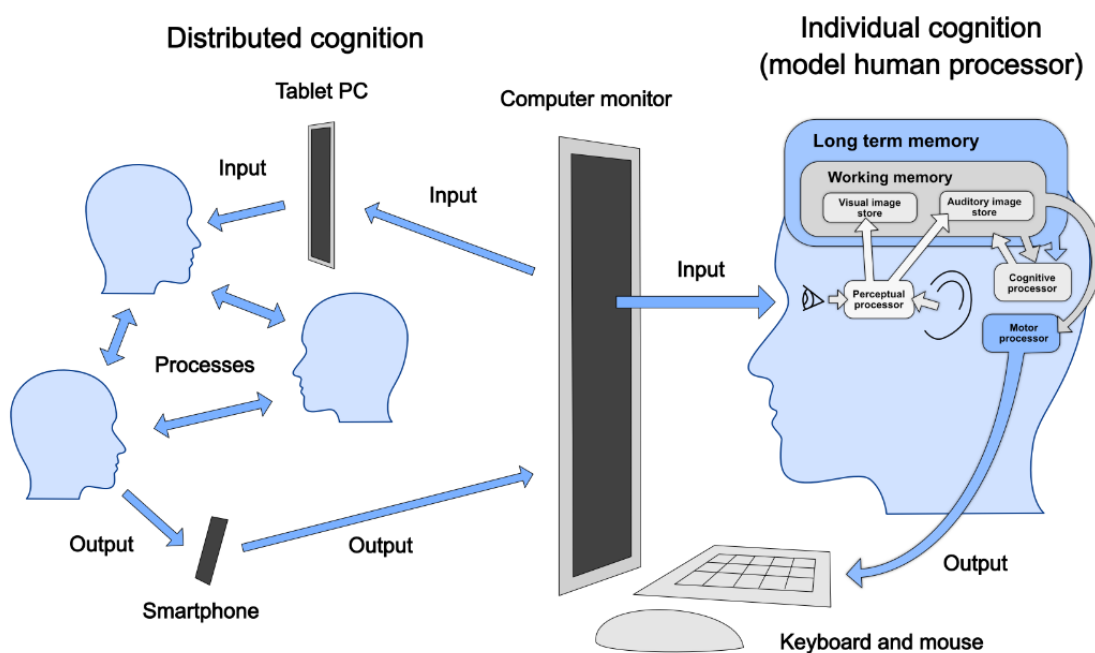
1. Visibility of system status
2. Match between system and the real world
3. User control and freedom
4. Consistency and standards
5. Error prevention
6. Recognition rather than recall
7. Flexibility and efficiency of use
8. Aesthetic and minimalist design
9. Help users recognize, diagnose, and recover from errors
10. Help and documentation

HCD has been developed to ensure that UIs work well for specific contexts but does not provide the kind of evidence normally expected for medical interventions. HCD should be part of the design process; however, additional methods are needed with a more scientific basis to be confident that digital health UI designs are suitable for use in high-risk settings such as hospitals.

Predictive Models of HCI

Predictive HCI models have the potential to explain how users interact with digital health interventions at the level of individual

Figure 2. The model human processor: a model of how long it takes to process information (from perception to action) and how we can use the limited “chunks” of information in working memory. Building on the idea of a model human processor is the concept of “distributed cognition,” with multiple humans and devices working together. Adapted from Card et al [11].



There are now several types of HCI predictive models that can be used depending on the context or type of tasks analyzed. For example, the Fitts law is used for mouse pointing [12], the Hick-Hyman law is used for reviewing a sorted list [13,14], and goals operators methods and selection rules (GOMS) [15] is a high-level model that is used to describe the cognitive processes and methods involved in using a computer to achieve specific goals. The keystroke-level model (KLM) is a more specific type of GOMS model that is used for compositions of tasks that fit how an experienced user interacts with the interface [11]. KLM has also recently been updated for touch interfaces [16]. Although individuals will vary in their performance speed, these models give a good indication of the relative effort required to accomplish a task. For example, Warren et al and others [17-19] have used such models for simulation-based evaluation of split-menu designs (placing commonly accessed options at the top of a list) for clinical information systems. These models are primarily aimed at reducing the time needed to complete tasks by eliminating unnecessary clicks and ensuring that UI elements are easy to navigate. In the health care domain, simplifying

human cognition. For more than 50 years, empirically derived predictive HCI models have been used for ensuring the safety and usability of information systems (physical and digital) for industrial and commercial applications ranging from avionics to power plant control systems. These models informed the designs of the first desktop computers, with innovations such as the computer mouse and windows-based graphical UIs. The “classic” HCI model was called the “model human processor,” in which the different components of human cognitive systems were modeled and combined with models of the interactions (inputs and outputs) between the human and the computer system (see Figure 2).

designs and increasing efficiency is also likely to reduce errors that can cause patient harm, such as choosing incorrect items from unnecessarily long menus or clicking through lengthy screens too quickly [20,21].

Limitations of HCI Modeling

Although the abovementioned models proved useful and effective in the design of early graphical UIs and input devices, the ways in which teams of people began to use computer systems in the 1990s prompted a move in HCI research communities away from the micro-level interactions to meso-level systems of “distributed cognition” [22] (Figure 2) and “situated action” [23]. These systems included the described cognitive models by attempting to place them within a social context, with human-human interaction playing a role in addition to machine-machine interaction (Figure 2 shows how distributed cognition can be integrated with micro-level HCI modeling). In the health care domain, Borycki and Kushniruk [20,24-26] led the development of an integrative cognitive-sociotechnical

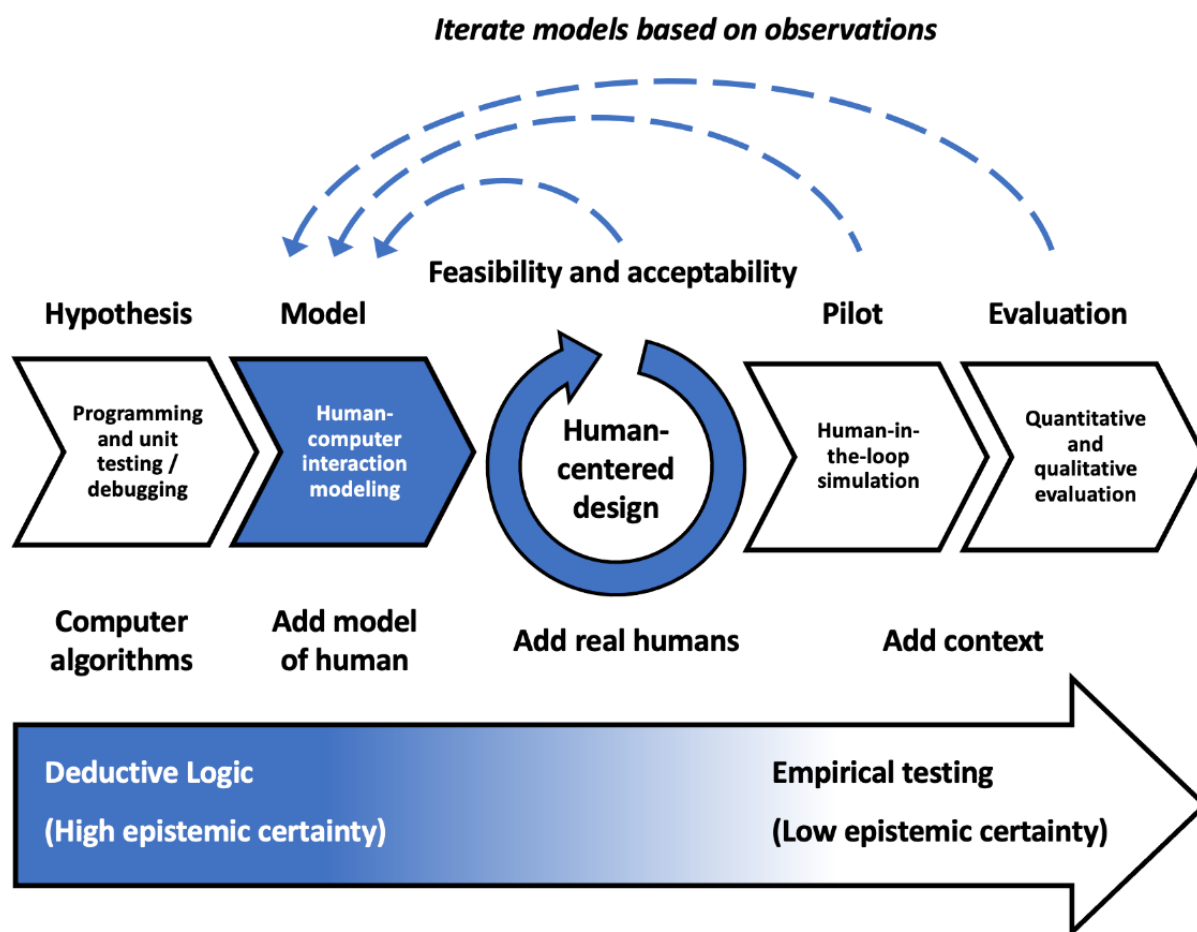
generate evidence that is generalizable beyond the specific contexts of the studies.

Integrating Predictive Modeling With HCD

Using predictive models to inform the HCD process could accelerate the design of digital health systems. By having a validated evidence base of UI designs to draw on, designers could eliminate a large number of potential designs that might meet basic usability heuristics or that could be appealing to early testers but that could be shown through predictive modeling to have poor usability. Figure 3 shows how HCI modeling could fit into the process of designing the UI for a digital health application. The design process moves from implementing the computer algorithms needed for the software to function (developed using deductive logic with a high level of epistemic certainty) to modeling how users would interact

with the UI of the system using HCI cognitive models. Once designs that show poor results with modeling are weeded out, the project will then enter a human-centered design phase in which the system is trialed with real users (for example, nurses and physicians who will use a digital health system on the wards) and repeatedly iterated until the software is sufficiently acceptable to pilot. At this stage, human-in-the-loop simulations can be conducted as the system is piloted. Finally, more formal quantitative and qualitative evaluations in clinical contexts can provide higher-level empirical evidence (albeit with lower epistemic certainty than with in-silico HCI modeling). At each stage, in keeping with the design thinking approach, the development team can move back to modeling and HCD to improve the design if needed. In addition to showing whether a particular application works, real-world evaluations based on HCI models will show which models work in the real world, building the evidence base for future design guidelines.

Figure 3. Predictive human-computer interaction modeling could augment the human-centered design process and help us understand how an application achieves real-world effectiveness.



Conclusion

UIs for digital health applications are currently designed using techniques developed for commercial software applications based on human-centered design processes and heuristics. Predictive HCI modeling of applications may help improve the design process and allow for more scientific progress toward safer and more effective digital health systems. We have

described in this paper how predictive HCI modeling has developed from individual cognitive modeling to distributed cognitive models and provided examples of how these models can be integrated into sociotechnical modeling approaches. Although predictive HCI modeling has fallen out of favor in recent years, as the demand for more evidence of the safety and effectiveness of digital health systems increases, it is worth re-evaluating whether HCI modeling can contribute to the science of evidence-based digital health system design. Future

research on the integration of predictive modeling with usability and human-in-the-loop simulations) is both needed and and software engineering approaches (such as usability testing warranted.

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Conflicts of Interest

None declared.

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Abbreviations

- DHI:** digital health intervention
- EHR:** electronic health record
- GOMS:** goals operators methods and selection rules
- HCD:** human-centered design
- HCI:** human-computer interaction
- KLM:** keystroke-level model
- UI:** user interface

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