3B – Human-Computer Interaction

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Clinical Informatics Board Review Course

Clinical Informatics Subspecialty Delineation of Practice (CIS DoP)

Domain 1: Fundamental Knowledge and Skills (no Tasks are associated with this Domain which is focused on fundamental knowledge and skills)

Clinical Informatics

K001. The discipline of informatics (e.g., definitions, history, careers, professional organizations)
K002. Fundamental informatics concepts, models, and theories
K003. Core clinical informatics literature (e.g., foundational literature, principle journals, critical analysis of literature, use of evidence to inform practice)
K004. Descriptive and inferential statistics
K005. Health Information Technology (HIT) principles and science
K006. Computer programming fundamentals and computational thinking
K007. Basic systems and network architectures
K008. Basic database structure, data retrieval and analytics techniques and tools
K009. Development and use of interoperability/exchange standards (e.g., Fast Health Interoperability Resources [FHIR], Digital Imaging and Communications in Medicine [DICOM])
K010. Development and use of transaction standards (e.g., American National Standards Institute X12)
K011. Development and use of messaging standards (e.g., Health Level Seven [HL7] v2)
K012. Development and use of ancillary data standards (e.g., imaging and Laboratory Information System[LIS])
K013. Development and use of data model standards
K014. Vocabularies, terminologies, and nomenclatures (e.g., Logical Observation Identifiers Names and Codes [LOINC], Systematized Nomenclature of Medicine --Clinical Terms [SNOMED-CT], RxNorm, International Classification Of Diseases[ICD], Current Procedural Terminology [CPT])
K015. Data taxonomies and ontologies
K016. Security, privacy, and confidentiality requirements and practices
K017. Legal and regulatory issues related to clinical data and information sharing
K018. Technical and non-technical approaches and barriers to interoperability
K019. Ethics and professionalism

The Health System

K020. Primary domains of health, organizational structures, cultures, and processes (e.g., health care delivery, public health, personal health, population health, education of health professionals, clinical research)
K021. Determinants of individual and population health
K022. Forces shaping health care delivery and considerations regarding health care access
K023. Health economics and financing
K024. Policy and regulatory frameworks related to the healthcare system
K025. The flow of data, information, and knowledge within the health system

Domain 2: Improving Care Delivery and Outcomes

K026. Decision science (e.g., Bayes theorem, decision analysis, probability theory, utility and preference assessment, test characteristics)
K027. Clinical decision support standards and processes for development, implementation, evaluation, and maintenance
K028. Five Rights of clinical decision support (i.e., information, person, intervention formats, channel, and point/time in workflow)
K029. Legal, regulatory, and ethical issues regarding clinical decision support
K030. Methods of workflow analysis
K031. Principles of workflow re-engineering
K032. Quality improvement principles and practices (e.g., Six Sigma, Lean, Plan-Do-Study-Act [PDSA] cycle, root cause analysis)
K033. User-centered design principles (e.g., iterative design process)
K034. Usability testing
K035. Definitions of measures (e.g., quality performance, regulatory, pay for performance, public health surveillance)
K036. Measure development and evaluation processes and criteria
K037. Key performance indicators (KPIs)
K038. Claims analytics and benchmarks
K039. Predictive analytic techniques, indications, and limitations
K040. Clinical and financial benchmarking sources (e.g., Gartner, Healthcare Information and Management Systems Society [HIMSS] Analytics, Centers for Medicare and Medicaid Services [CMS], Leapfrog)
K041. Quality standards and measures promulgated by quality organizations (e.g., National Quality Forum [NQF], Centers for Medicare and Medicaid Services [CMS], National Committee for Quality Assurance [NCQA])
K042. Facility accreditation quality and safety standards (e.g., The Joint Commission, Clinical Laboratory Improvement Amendments [CLIA])
K043. Clinical quality standards (e.g., Physician Quality Reporting System [PQRS], Agency for Healthcare Research and Quality [AHRQ], National Surgical Quality Improvement Program [NSQIP], Quality Reporting Document Architecture [QRDA], Health Quality Measure Format [HQMF], Council on Quality and Leadership [CQL], Fast Health Interoperability Resources [FHIR] Clinical Reasoning)
K044. Reporting requirements
K045. Methods to measure and report organizational performance
K046. Adoption metrics (e.g., Electronic Medical Records Adoption Model [EMRAM], Adoption Model for Analytics Maturity [AMAM])
K047. Social determinants of health
K048. Use of patient-generated data
K049. Prediction models
K050. Risk stratification and adjustment
K051. Concepts and tools for care coordination
K052. Care delivery and payment models

Domain 3: Enterprise Information Systems

K053. Health information technology landscape (e.g., innovation strategies, emerging technologies)
K054. Institutional governance of clinical information systems
K055. Information system maintenance requirements
K056. Information needs analysis and information system selection
K057. Information system implementation procedures
K058. Information system evaluation techniques and methods
K059. Information system and integration testing techniques and methodologies
K060. Enterprise architecture (databases, storage, application, interface engine)
K061. Methods of communication between various software components
K062. Network communications infrastructure and protocols between information systems (e.g., Transmission Control Protocol/Internet Protocol [TCP/IP], switches, routers)
K063. Types of settings (e.g., labs, ambulatory, radiology, home) where various systems are used
K064. Clinical system functional requirements
K065. Models and theories of human-computer (machine) interaction (HCI)
K066. HCI evaluation, usability engineering and testing, study design and methods
K067. HCI design standards and design principles
K068. Functionalities of clinical information systems (e.g., Electronic Health Records [EHR], Laboratory Information System [LIS], Picture Archiving and Communication System [PACS], Radiology Information System [RIS] vendor-neutral archive, pharmacy, revenue cycle)
K069. Consumer-facing health informatics applications (e.g., patient portals, mobile health apps and devices, disease management, patient education, behavior modification)
K070. User types and roles, institutional policy and access control
K071. Clinical communication channels and best practices for use (e.g., secure messaging, closed loop communication)
K072. Security threat assessment methods and mitigation strategies
K073. Security standards and safeguards
K074. Clinical impact of scheduled and unscheduled system downtimes
K075. Information system failure modes and downtime mitigation strategies (e.g., replicated data centers, log shipping)
K076. Approaches to knowledge repositories and their implementation and maintenance
K077. Data storage options and their implications
K078. Clinical registries
K079. Health information exchanges
K080. Patient matching strategies
K081. Master patient index
K082. Data reconciliation
K083. Regulated medical devices (e.g., pumps, telemetry monitors) that may be integrated into information systems
K084. Non-regulated medical devices (e.g., consumer devices)
K085. Telehealth workflows and resources (e.g., software, hardware, staff)

Domain 4: Data Governance and Data Analytics

K086. Stewardship of data
K087. Regulations, organizations, and best practice related to data access and sharing agreements, data use, privacy, security, and portability
K088. Metadata and data dictionaries
K089. Data life cycle
K090. Transactional and reporting/research databases
K091. Techniques for the storage of disparate data types
K092. Techniques to extract, transform, and load data
K093. Data associated with workflow processes and clinical context
K094. Data management and validation techniques
K095. Standards related to storage and retrieval from specialized and emerging data sources
K096. Types and uses of specialized and emerging data sources (e.g., imaging, bioinformatics, internet of things (IoT), patient-generated, social determinants)
K097. Issues related to integrating emerging data sources into business and clinical decision making
K098. Information architecture
K099. Query tools and techniques
K100. Flat files, relational and non-relational/NoSQL database structures, distributed file systems
K101. Definitions and appropriate use of descriptive, diagnostic, predictive, and prescriptive analytics
K102. Analytic tools and techniques (e.g., Boolean, Bayesian, statistical/mathematical modeling)
K103. Advanced modeling and algorithms
K104. Artificial intelligence
K105. Machine learning (e.g., neural networks, support vector machines, Bayesian network)
K106. Data visualization (e.g., graphical, geospatial, 3D modeling, dashboards, heat maps)
K107. Natural language processing
K108. Precision medicine (customized treatment plans based on patient-specific data)
K109. Knowledge management and archiving science
K110. Methods for knowledge persistence and sharing
K111. Methods and standards for data sharing across systems (e.g., health information exchanges, public health reporting)

Domain 5: Leadership and Professionalism

K112. Environmental scanning and assessment methods and techniques
K113. Consensus building, collaboration, and conflict management
K114. Business plan development for informatics projects and activities (e.g., return on investment, business case analysis, pro forma projections)
K115. Basic revenue cycle
K116. Basic managerial/cost accounting principles and concepts
K117. Capital and operating budgeting
K118. Strategy formulation and evaluation
K119. Approaches to establishing Health Information Technology (HIT) mission and objectives
K120. Communication strategies, including one-on-one, presentation to groups, and asynchronous communication
K121. Effective communication programs to support and sustain systems implementation
K122. Writing effectively for various audiences and goals
K123. Negotiation strategies, methods, and techniques
K124. Conflict management strategies, methods, and techniques
K125. Change management principles, models, and methods
K126. Assessment of organizational culture and behavior change theories
K127. Theory and methods for promoting the adoption and effective use of clinical information systems
K128. Motivational strategies, methods, and techniques
K129. Basic principles and practices of project management
K130. Project management tools and techniques
K131. Leadership principles, models, and methods
K132. Intergenerational communication techniques
K133. Coaching, mentoring, championing and cheerleading methods
K134. Adult learning theories, methods, and techniques
K135. Teaching modalities for individuals and groups
K136. Methods to assess the effectiveness of training and competency development
K137. Principles, models, and methods for building and managing effective interdisciplinary teams
K138. Team productivity and effectiveness (e.g., articulating team goals, defining rules of operation, clarifying individual roles, team management, identifying and addressing challenges)
K139. Group management processes (e.g., nominal group, consensus mapping, Delphi method)

Knowledge Statements from the DoP

K033. User-centered design principles (e.g., iterative design process)
K034. Usability testing
K065. Models and theories of human-computer (machine) interaction (HCI)
K066. HCI evaluation, usability engineering and testing, study design and methods
K067. HCI design standards and design principles

K106. Data visualization (e.g., graphical, geospatial, 3D modeling, dashboards, heat maps)

3B: Human Computer Interaction

HCI Definition

Applicability to healthcare

Errors attributable to HCI issues and EHR Usability

Models of HCI – predictive and descriptive

Usability Evaluation – testing, inspection, inquiry

Discount Usability Engineering

Design Standards

Data Visualization

NIST recommendations for 3-step testing of EHR Usability

Human Computer Interaction

Definition of the Discipline

- Study of people and computers
- Discipline combines computer science, behavioral science, psychology, design, human factors analysis, and more

Applicability to Healthcare

- Increasing awareness that HCI limitations responsible for medical errors
- Cognitive overload, “alert fatigue”
- One of the “grand challenges” facing Clinical Decision Support

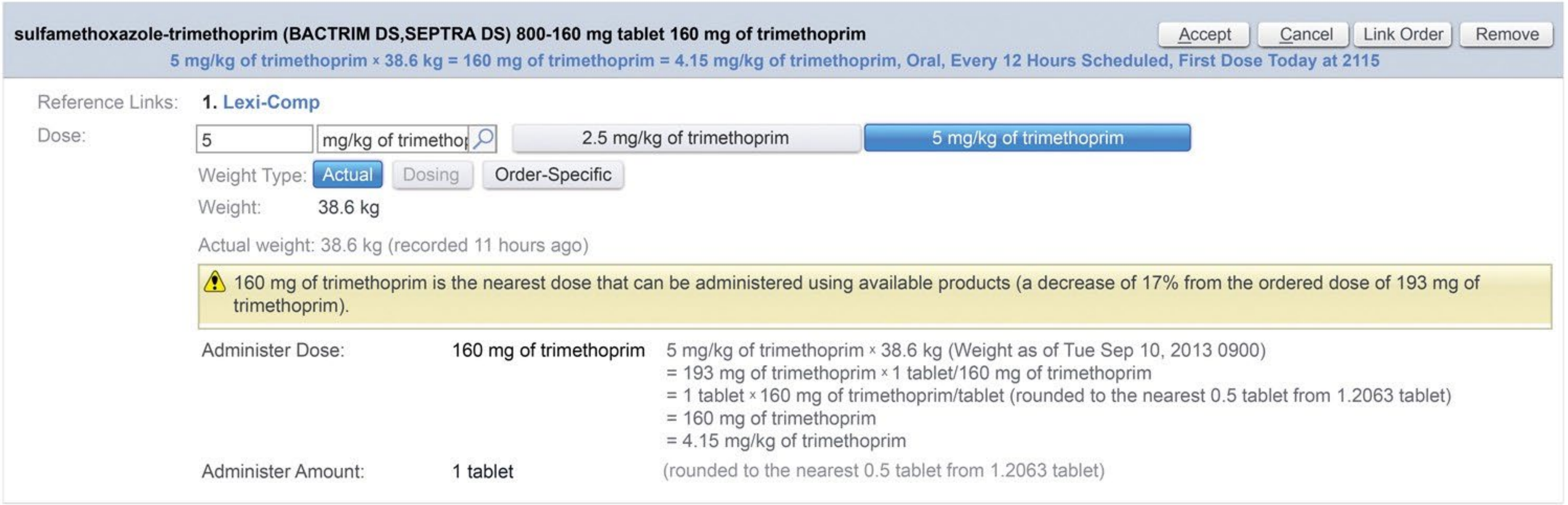

THE OVERDOSE

Harm in a Wired Hospital

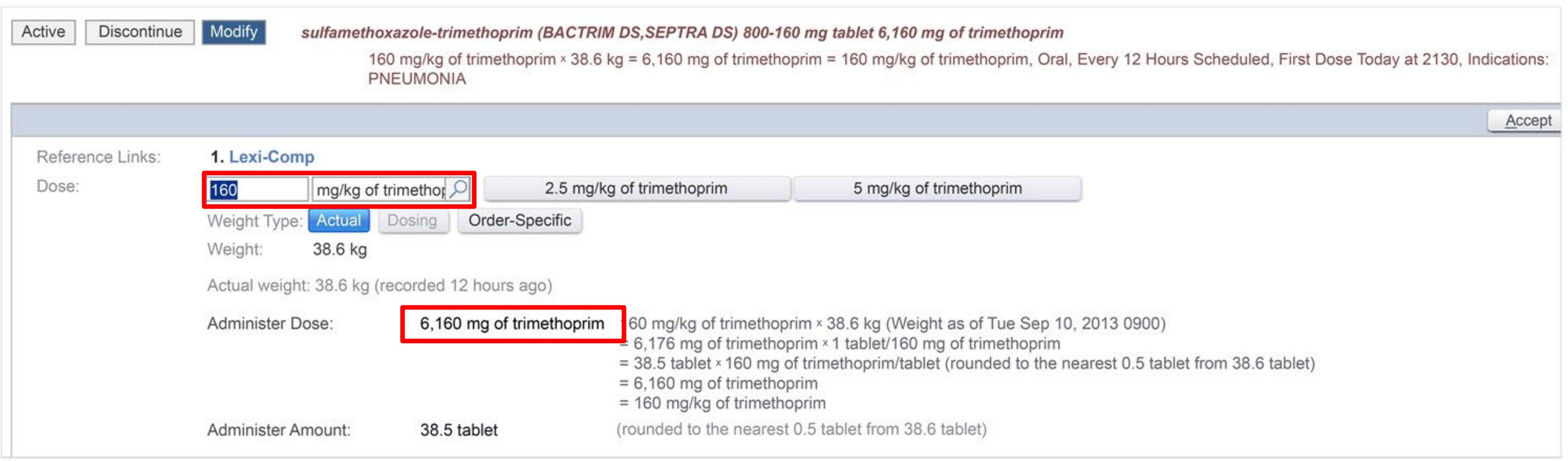
How Medical Tech Gave a Patient a Massive Overdose

Pablo Garcia went to the hospital feeling fine. Then the hospital made him very sick.

LINK: https://www.wired.com/2015/03/how-technology-led-a-hospital-to-give-a-patient-38-times-his-dosage/



LINK: https://www.wired.com/2015/03/how-technology-led-a-hospital-to-give-a-patient-38-times-his-dosage/



LINK: https://www.wired.com/2015/03/how-technology-led-a-hospital-to-give-a-patient-38-times-his-dosage/

sulfamethoxazole-trimethoprim (BACTRIM DS,SEPTRA DS) 800-160 mg tablet 6,160 mg of trimethoprim

New

Modified from: sulfamethoxazole-trimethoprim (BACTRIM DS,SEPTRA DS) 800-160 mg tablet 160 mg of trimethoprim

Edit Clinical Information

Order dose:	**160 mg/kg of trimethoprim**	Route:	**Oral**	Frequency:	**Every 12 Hours Scheduled**
Admin dose:	6,160 mg of trimethoprim (38.5 tablet)			For:	Until discontinued
Weight:	Actual (38.6 kg)			# of doses:	
				1st dose:	Today 2130
				Last dose:	

160 mg/kg of trimethoprim x 38.6 kg (Weight as of Tue Sep 10, 2013 0900)
= 6,176 mg of trimethoprim x 1 tablet/160 mg of trimethoprim
= 38.5 tablet x 160 mg of trimethoprim/tablet (rounded to the nearest 0.5 tablet from 38.6 tablet)
= 6,160 mg of trimethoprim
= 160 mg/kg of trimethoprim

Scheduled times (adjusted):

9/10/2013	2130
9/11/2013	0900, 2100

Indications: PNEUMONIA

Order questions: Edit

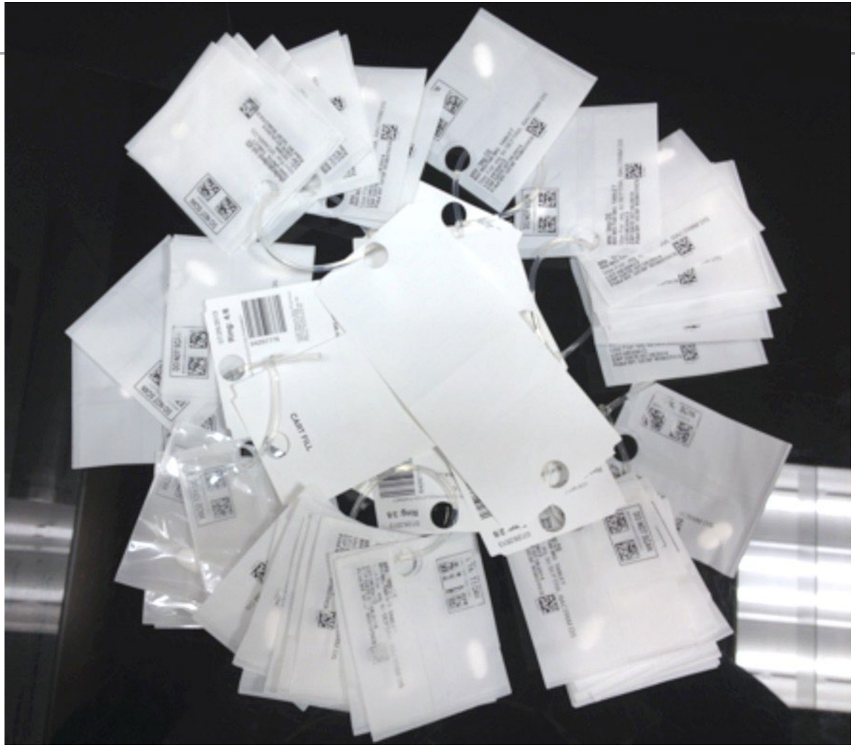
Suspected Pathogen: (no response given)

Admin instructions: Edit

(none)

Products to dispense (Add)	Order dose	Admin dose	Dispense	Package
SULFAMETHOXAZOLE 800 MG-TRIMETHOPRIM 160 MG TABLET	160 mg/kg of trimethoprim	6,160 mg of trimethoprim	39 tablet	100 EA BLIST PACK

LINK: https://www.wired.com/2015/03/how-technology-led-a-hospital-to-give-a-patient-38-times-his-dosage/



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HCI is Very Relevant to Informatics

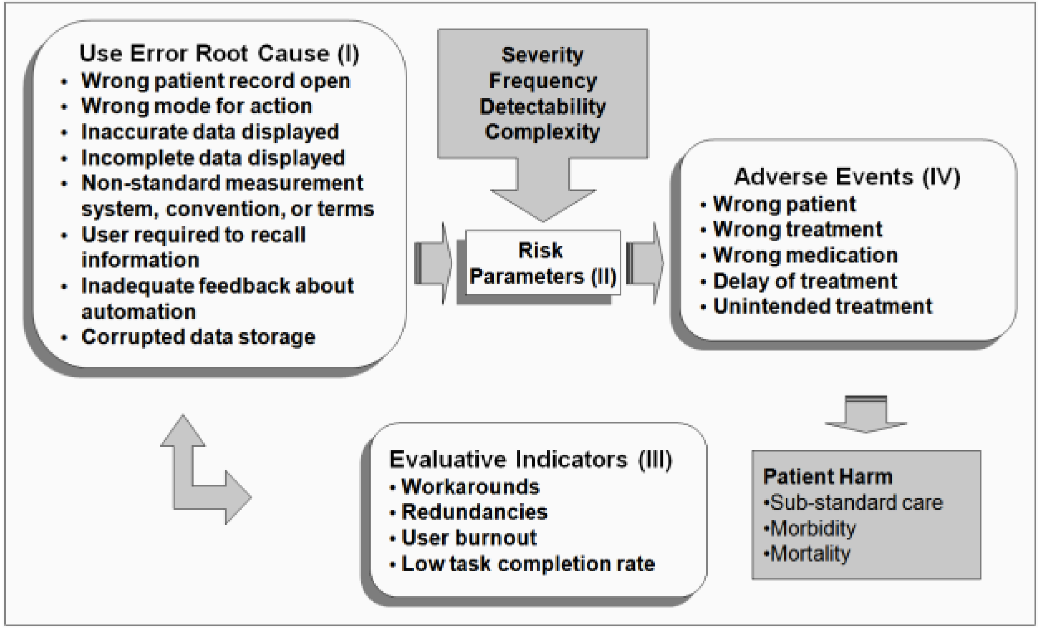


Figure 3. A model for analysis and understanding of use-related risks of EHR systems.

(image credit Lowry SZ, Quinn MT, et al. Technical Evaluation, Testing, and Validation of the Usability of Electronic Health Records. NISTIR 7804. National Institute of Standards and Technology, US Department of Commerce. February, 2012.)

Types of HCI / Usability-related Errors

- **Wrong Patient** – user has 2 charts open, enters orders on the wrong one
- **Wrong Mode for Action** – user tries to enter 100mg (direct dose) but accidentally enters 100mg/kg (weight-based dose)
- **Inaccurate Data Display** – lab value is truncated in a report, causing user to come to incorrect conclusion
- **Incomplete Data Display** – summary view of vital signs only shows last value per shift, user overlooks the max value within that shift
- **Non-standard measurement, convention, or term** – weight-based medications calculated using metric units, but order entry screen shows weight in English units
- **Reliance on user recall** – vaccine administration documentation screen requires a lot number. Lot number is visible on previous screen, but not on this one. Users mis-type info or type in nonsense data as a result
- **Inadequate feedback** –User attempts to order med requiring 0.1cc precision and submits incorrect dose because system silently rounds dose to nearest 0.5cc, calculation not transparent to user
- **Corrupted Data Storage –** user enters orders in discharge workflow then clicks “next”, but orders are not submitted because user did not click “sign” before proceeding to next step.

Predictive Models of HCI

Goals, Operators, Methods, Selection (GOMS)

- **Goal:** successful end-state of a task. Ex: “update my mailing address”
- **Operator:** action performed on machine. Ex: keystrokes, mouse clicks to achieve **Goal**
- **Method:** series of **Operators** chained together. Ex: “Click on the OK button by moving the mouse to the button, clicking the mouse, releasing the mouse, moving hand back to keyboard”
- **Selection:** a decision made by user when a task has parallel **Methods**. Ex: User could press ENTER key instead of clicking on “OK” button, but may not be aware that flow exists.

GOMS can be used to **benchmark/compare** efficiency of interfaces and **estimate cost savings** associated with increased user performance.

Source: https://www.usabilitybok.org/goms

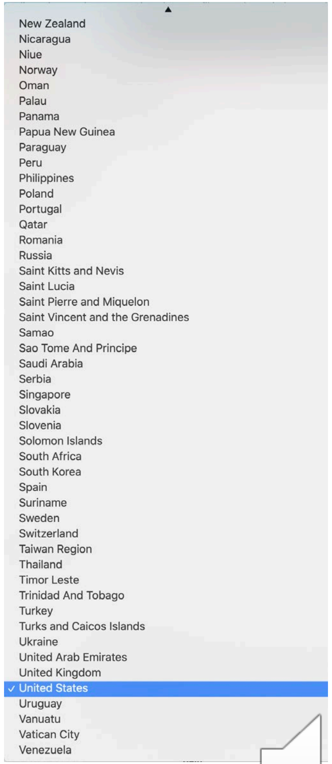
Predictive Models of HCI

Hick-Hyman Law

- User response time (RT) is a function of number of possible responses (n)
- Predicts user response to hierarchical menus, response to finding correct option among an unfamiliar list (like a non-QWERTY keyboard)
- **Law predicts: RT = b*$\log_2$(n)**

Keystroke-Level Model (KLM)

- Is a one of the GOMS models, looks only at keystroke **Operator**, not goals, methods, or selection.
- Time to task completion is the sum of the time spent key-stroking, pointing, homing, drawing, mental operator (thinking), system response operator (waiting).
- Used to anticipate which functions are most amenable to shortcuts and "hotkeys"



Predictive Models of HCI

Fitt's Law

- Time it takes to track to an object with a cursor is a function of distance traveled (D) and width of the target (W).
- Moving a cursor a large distance to hit a narrow target has a high Index of Difficulty (ID)

$$ID = log_2\left(\frac{2D}{W}\right)$$

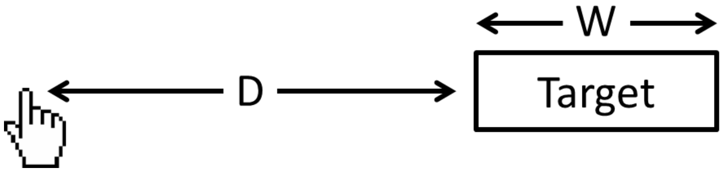


Image credit: https://en.wikipedia.org/wiki/Fitts%27s_law

Descriptive Models of HCI

Buxton's Three-State Model of Graphical Input

- Exhaustive description of the states and transitions involved in using a mouse.
- Three states: out of range, tracking, and dragging. To transition from "out of range" to "tracking" you lift or put down the mouse. To transition from "tracking" to "dragging", you depress or release the button.

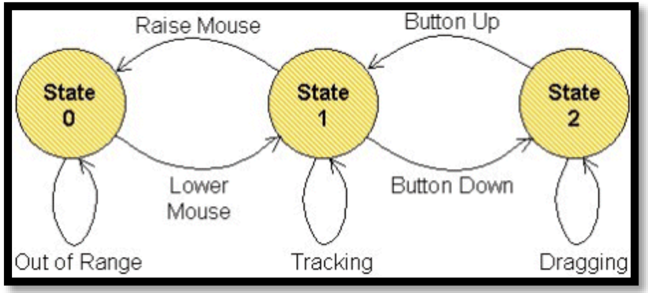


Image credit: Buxton, 1990

Descriptive Models of HCI

Guiard's Model of Bimanual Skill

- Hands are not used equally. Each hand, because of single hand dominance, has distinct roles
- The model describes – for example - why left-handed users are ill-served by modern 101-key keyboards
- Some keys are unilateral and only available on the left side, like CTRL, ESC, TAB, FN; putting those who use the mouse on the left side at a disadvantage
- Similarly, most "acknowledge" buttons on modal dialogues are on the bottom right – more mouse travel and possible error for lefties

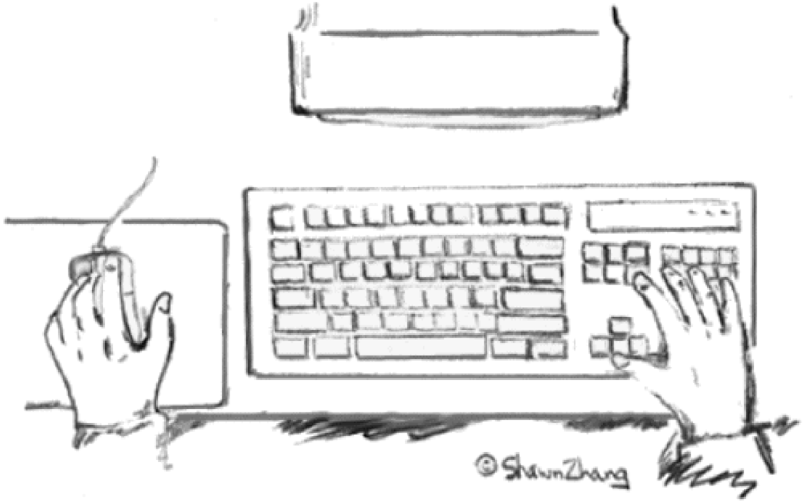


Image Credit: MacKenzie, I. S. (2003). Motor behaviour models for human-computer interaction. In J. M. Carroll (Ed.) *HCI models, theories, and frameworks: Toward a multidisciplinary science*, pp. 27-54. San Francisco: Morgan Kaufmann.

Usability Evaluation

Three major categories of evaluation

1. **Testing**
   - Coaching
   - Thinking-aloud
   - Eye-tracking / Click tracking
   - Performance
2. **Inspection**
   - Cognitive walkthrough
   - Heuristic evaluation
3. **Inquiry**
   - Field Observation
   - Focus groups / Interviews
   - Surveys
   - Usage Logs

Usability Testing

Coaching method – user asked to perform a task, allowed to ask any questions they want to an expert coach. Coach keeps track of questions – useful in determining training and documentation needs.

Thinking-aloud – user attempts to complete a task and speaks aloud each step he/she is doing, along with articulating difficulties, confusion, realizations.

Usability Testing

Eye-tracking / Click-tracking – electronic or manual measurement of use, can generate “heat map” of an interface

Performance measurement – Ideally, 5 - 8 users attempt to complete a specified set of tasks. Evaluator measures performance such as:

- Task completion time and rate
- Recovery rate (user makes a misstep but recovers)
- Failure rate (user unable to complete task)
- Frequently and never used features
- For tasks with multiple ways of accomplishing the same thing, measuring which way users choose to do it

Usability Inspection

Cognitive walkthrough – using low-fidelity paper models or wireframes

- Will the users try to achieve the right effect? Ex: system requires a weight before entering medication order. Will the user know to enter the weight?
- Will the user notice that the correct action is available? Ex: Button to submit/sign order is in an inconspicuous location. Will user see it?
- Will the user associate the correct action with the effect to be achieved? Ex: are the labels intuitive and easy to follow?
- If the correct action is performed, will the user see that progress is being made toward solution of the task? Ex: does system give feedback that a step in task was completed.

Image Credit: https://uxplanet.org/9-best-wireframe-tools-for-mac-ui-ux-designers-have-to-know-1 7645

Usability Inspection

Heuristic Evaluation – design principle or "rule of thumb" used to critique interface.

- Example heuristic for web design: Jakob Nielsen's Heuristic List

https://www.nngroup.com/articles/ten-usability-heuristics/

For an exercise in frustration and a lesson in how to violate **all** of the Nielsen heuristics at once, check out this site, and see how long it takes you to fill out the form:

https://userinyerface.com/

Nielsen’s 10 Usability Heuristics

Principles of User Interface Design

1. The system status should be visible.
2. There should be a match between the terminology and concepts used by the system and those in common use in the “real world”.
3. The system should give users control and freedom, with a clear way to undo, redo, or exit a task.
4. The system should be consistent and use standards where possible.
5. Built-in error prevention is better than a clever error message.
6. A user’s recognition of icons and pathways is stronger than their recall. By showing options that facilitate user action, one can avoid forcing users to memorize sequences of menus or keystrokes.
7. The system should support novice and expert users, with shortcuts and “accelerators”.
8. Dialogues should be sparingly written; design should be minimalist.
9. The system should help users to recognize, diagnose, and recover from errors.
10. The system should provide succinct and context-sensitive help and documentation.

Usability Inquiry

Field observation

Focus groups / Interviews

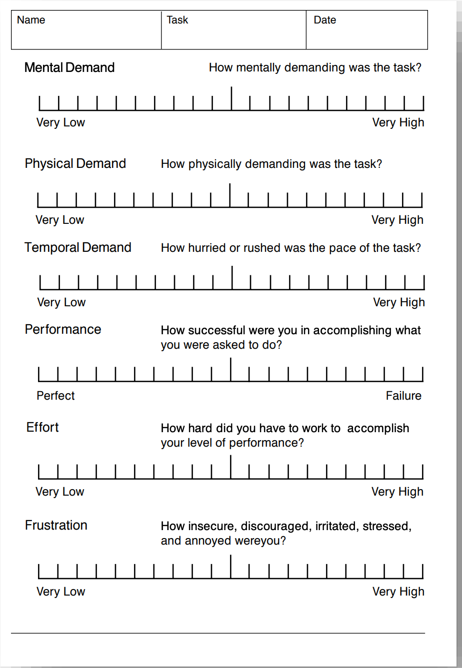
Surveys

Review of usage logs

NASA Task Load Index (TLX)

NASA-TLX assesses workload in 6 domains, each on a 7-point scale

- Mental Demand
- Physical Demand
- Temporal Demand
- Performance
- Effort
- Frustration Level



Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

Source: https://humansystems.arc.nasa.gov/groups/TLX/

Discount Usability Engineering

Method of HCI Evaluation that does not require large number of personnel or budget, described by Jakob Nielsen.

Minimum 5 testers perform a modified version of **testing** and **inspection**

- modified **think-aloud**, focus on qualitative aspects of interface
- **heuristic evaluation**
- low-fidelity **prototypes** to test one process at a time, rapid iterations

Wireframes / Low Fidelity Prototyping

Technique to design and gather feedback about an interface without actually having to code it

As in SDLC, identifying errors early is less costly

Can be paper-based, designed as “wireframe” designs, or can even mimic full applications using drag-and-drop software (e.g., Balsamiq, Proto.io, atomic.io)

But there are advantages to keeping it “lo-fi”

Low-Fi vs. Hi-Fi

Low-fidelity prototypes

- Cheap (can be made on paper)
- Theoretically quicker
- Quickly visualize alternative design solutions
- Some evidence that users feel more comfortable suggesting changes when prototypes feel less "final"

High-fidelity prototypes

- Can look almost as good as finished user interface, complete with interactivity
- Allows more accurate testing of things like task completion

Examples of Low-Fidelity Prototypes

https://www.usability.gov/how-to-and-tools/methods/prototyping.html

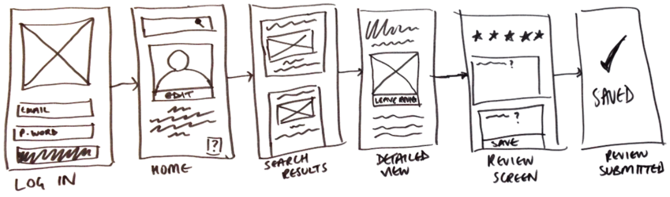
Wireframes

One form of prototype used to suggest basic structure of a user interface and relationship between pages

Clarifies function and features; focus on user, not programming

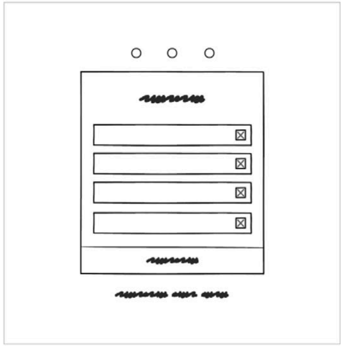
Serves as blueprint for design – precedes any design work, with attention to layout and usability

Can be easily created in design, presentation, or word processing software packages



Mid-Fidelity Wireframe

High-Fidelity Wireframe



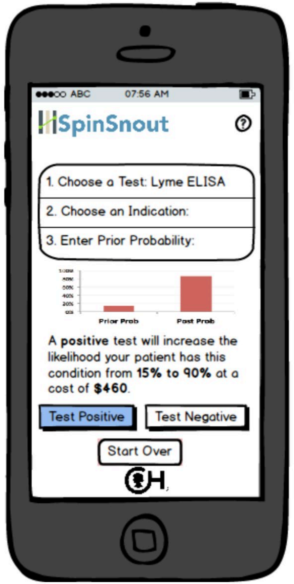
Source: https://careerfoundry.com/en/blog/ux-design/what-is-a-wireframe-guide/

Digital Tools for Low-Fidelity Prototyping

Often intentionally look “hand drawn”, again to emphasize the design is not final and to encourage feedback

Some tools have built in rendering options to switch between wireframe, “sketch” mode, and “hi fi” mode

Often allow interactivity (in example on the right, clicking the blue button takes user to next virtual screen of the application)



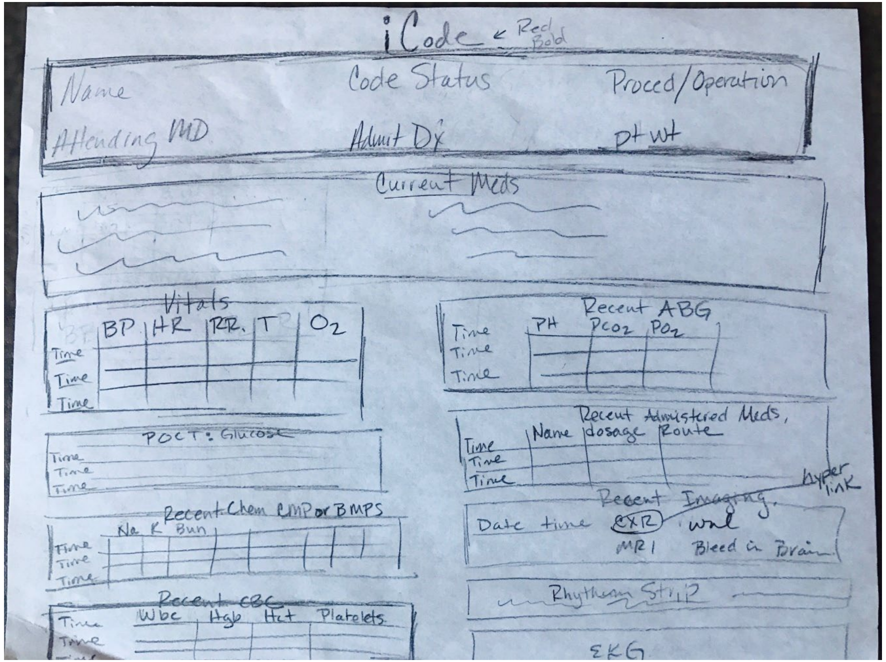
Low-fi prototype of a mobile web application
Used with permission by Bimal Desai

Prototyping With Commercial EHRs

In a sense, UX is less flexible, but still less costly to “mock up” a prototype than to build a working version

Lee Milligan, MD, SVP and CIO at Asante Healthcare shared a 3-step process for creating an information-rich report to be used during code events, built in a commercial EHR

Lo-Fi / Paper Prototype



Courtesy Lee D. Milligan, MD. Used with permission.

Higher Fidelity Prototype

iCodeBlue

Start Time: 1621

Code Status: **Full Code**

Name: John Q. Patient
Attending Physician: Jon Gell, MD
Admit Diagnosis: DVT

Patient Weight: 70 Kg.
Procedures/Operations:
none

Medications

1. Digoxin 0.125 mg q day
2. Metoprolol 25 mg bid
3. Albuterol MDI 2 puff qid
4. Lithium 900 mg q day
5. Synthroid 125 mcg q day
6. Lasix 40 mg q day
7. Potassium 20 meq q day
8. Percocet 10/325 q 6 hr
9. Coumadin 5 mg q day
10. Prednisone 10 mg q day

Vital Signs

Time	BP	Pulse	RR	Temp	Pulse Ox
1615	60/23	32	8		88
1530	84/42	44	12		90
1445	94/50	52	14		92
1415	112/62	60	16		95

Recently Administered Meds

Time	Drug Name	Dosage	Route
1600	Dilaudid	2 mg	IV
1530	Ativan	1 mg	IV
1500	Tylenol	650 mg	PO
1500	KCl	20 mEq	PO

POCT Testing

Time	Bedside Glucose
1605	71
1500	89
1400	101
1300	138

Key Metabolic Panel

Date	Time	Na+	K+	HCO3	BUN	Cr
15-Jan	1600	129	5.9	22	42	1.7
14-Jan	2300	133	5.3	23	36	1.5
14-Jan	1400	135	5.1	24	32	1.4
14-Jan	200	136	4.7	25	26	1.2

CBC Key Data

Date	Time	WBC	Hgb	Hct	Plt.
15-Jan	1400	26.5	6.2	18	56
14-Jan	2300	21.2	7.8	21.5	86
14-Jan	1500	18.3	8.4	24.8	96
14-Jan	200	14.4	9.9	29.8	110

Key ABG Data Points

Date	Time	pH	pCO2	pO2
15-Jan	1410	7.11	72	64
14-Jan	2340	7.27	62	74
14-Jan	1220	7.35	56	78
14-Jan	710	7.42	46	88

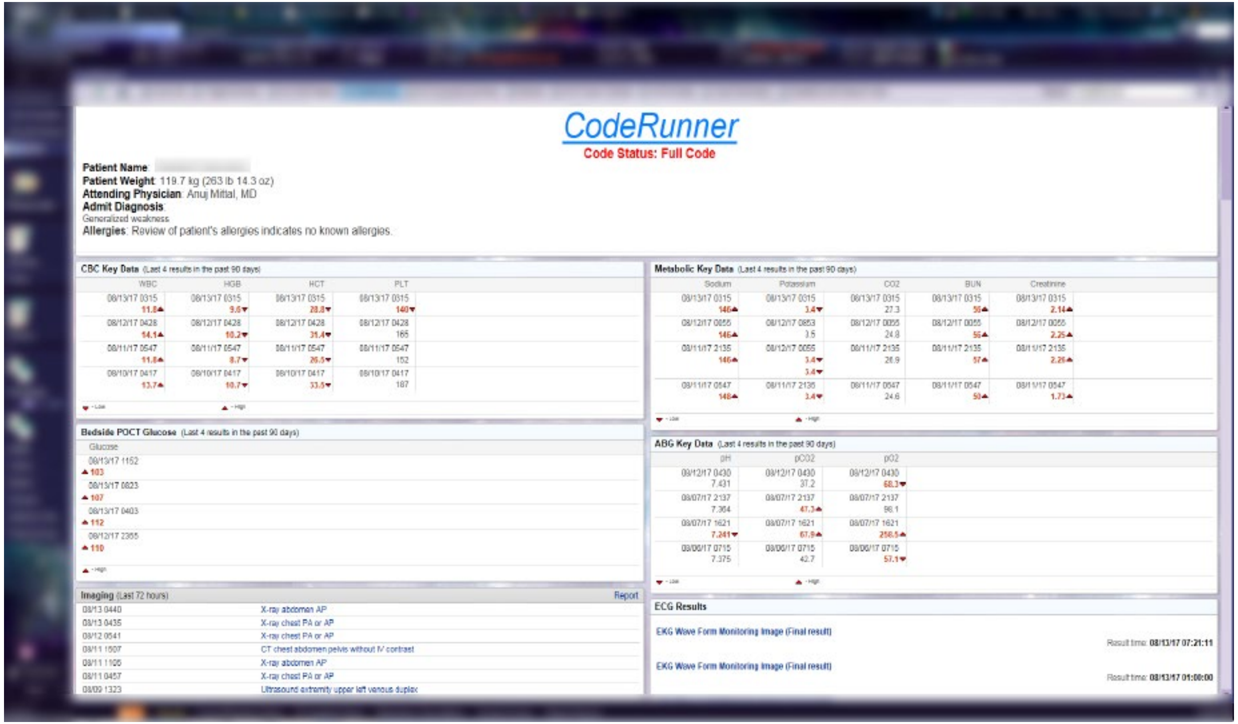
Recent Imaging

Date	Time	Imaging Type
15-Jan	1240	*X-Ray Chest*
15-Jan	700	*X-Ray Chest*
15-Jan	640	*CT Head*
14-Jan	2300	*CT Abdomen*

Recent Rhythm Strip

Courtesy Lee D. Milligan, MD. Used with permission.

Finished Product



Courtesy Lee D. Milligan, MD. Used with permission.

Importance of Design Standards

Widely accepted standards for interface design and HCI do not exist in healthcare, but are an active area of innovation and research.

- Horsky J, Phansalkar S, Desai A, Bell D, Middleton B. Design of decision support interventions for medication prescribing. *Int. J. Med. Inf*. 2013 Jun;82(6):492–503. [Abstract]
- Horsky J, Schiff GD, Johnston D, Mercincavage L, Bell D, Middleton B. Interface design principles for usable decision support: a targeted review of best practices for clinical prescribing interventions. *J. Biomed. Inform*. 2012 Dec;45(6):1202–16. [Abstract]
- Middleton B, Bloomrosen M, Dente MA, Hashmat B, Koppel R, Overhage JM, et al. Enhancing patient safety and quality of care by improving the usability of electronic health record systems: recommendations from AMIA. *J Am Med Inform Assoc*. 2013 Jun;20(e1):e2-8. [Article]

Challenge with commercial EHRs that much of design / usability is set by vendor.

NIST 2012 Recommendations

Standard for testing, validation of EHR usability. Three-step approach that includes many of the evaluation techniques described above.

Step 1 – EHR application analysis

- Who are users?
- What is their work environment? (lighting, noise, hardware)
- What do they do?
- What does the interface look like?
- What mistakes might they make?
- What evaluation has been done to mitigate mistake and improve usability?

Step 2 – EHR User Interface Expert Review

- Two-person **heuristic** review
- Clinical subject matter expert review for potential errors

Step 3 - User Interface Validation Test

- Performance measurement (**task completion** and associated metrics)
- Post-testing interview

Cognitive Informatics

Emerging field within health informatics

Study of human processing mechanisms: how and why people make decisions

National Center for Cognitive Informatics & Decision Making in Healthcare

- Located at UT Health Science Center at Houston, 9 partners
- Site of a Strategic Health IT Advanced Research Project (SHARPC)
- Led by Dr. Jiajie Zhang

Five Projects under SHARPC

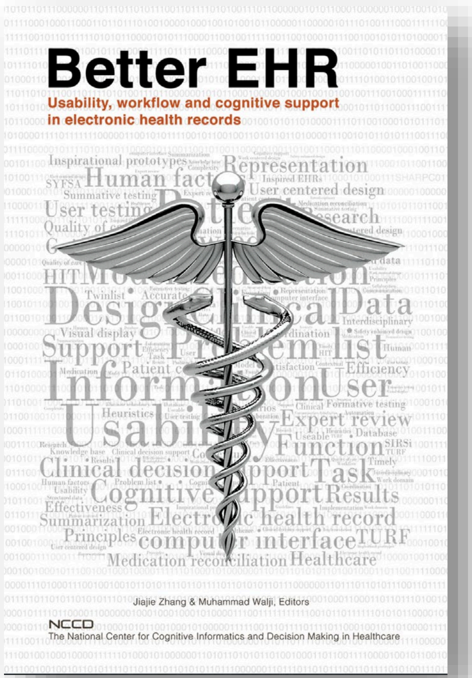
1. Project 1: Work-centered Design of Care Process Improvements in HIT
   A. EHR Usability
   B. EHR Workflow
2. Project 2
   A. Cognitive Foundations for Decision Making: Implications for Decision Support
   B. Modeling of Setting-Specific Factors to Enhance CDS Adaptation
3. Project 3: Automated Model-based Clinical Summarization of Key Patient Data
4. Cognitive Information Design and Visualization: Enhancing Accessibility and Understanding of Patient Data

Better EHR

Free PDF or iBook from NCCD

Describes TURF EHR Usability Framework

- Task, User, Representation, Function
- Main dimensions of usability
- Useful: supports the work domain
- Usable: easy to learn, use, adapt
- Satisfying: good subjective experience



https://sbmi.uth.edu/nccd/better-ehr/

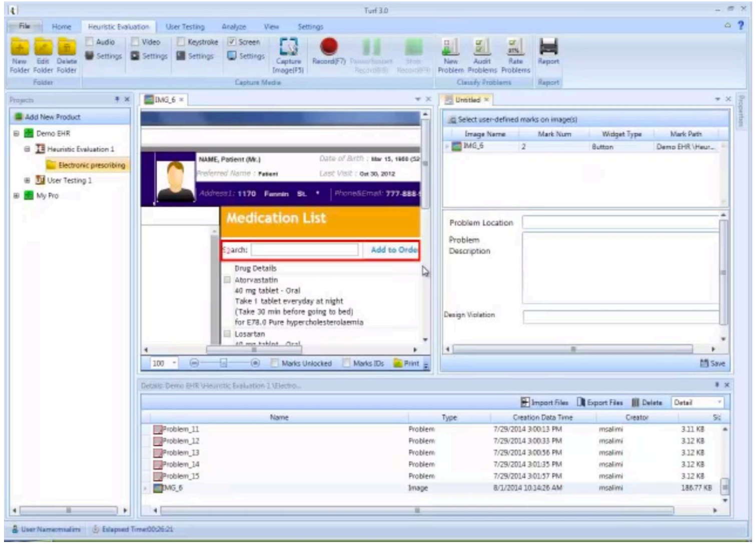
TURF Usability Software

Software for user testing

Users create products for heuristic evaluation

- Capture screenshots of EHR, upload into TURF software
- Markup image to capture design violation, using problem descriptions

Also capture usability surveys

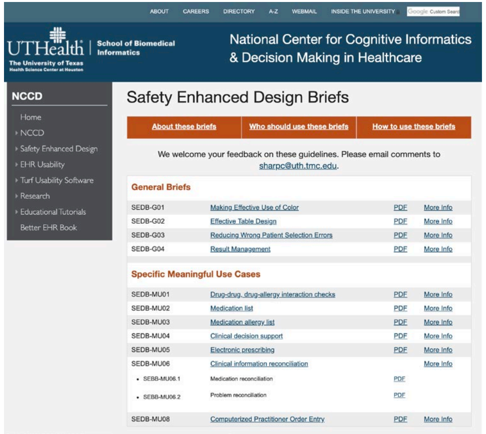


Safety Enhanced Design Briefs

Design guidelines for a variety of EHR use cases

- Effective use of color
- Table design
- Reducing wrong patient selection errors
- Result management
- Drug-drug and drug-allergy checking
- Medication and Allergy lists
- CDS
- ePrescribing
- Medication and Problem Reconciliation
- CPOE

- Each is a high impact, actionable, evidence-based recommendation for enhancing safety
- Each is a downloadable, illustrated PDF file



Source: https://sbmi.uth.edu/nccd/SED/Briefs/

Example Design Brief: Using Color

Safety Enhanced Design Brief
Making Effective Use of Color

Carefully used colors can dramatically improve the efficiency and safety of health information systems by drawing attention to important items and making it easier to perceive differences and trends.

Incorrectly used colors can make a display hard to use, hard to interpret and misleading.

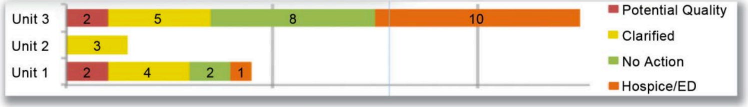
• Endocrine Events

BP:	H 178/80 mmHg	(03/02/10)	H 169/84 mmHg	(12/30/09)
Wt:	85.300 kg/188 lbs	(12/30/09)	85.400 kg/181 lbs	(12/29/09)
BMI:	0	(02/08/10)	0	(02/01/10)
Smoking Hx:	Non Smoker/History of Smoking	(03/02/10)	Non Smoker	(12/14/09)
HGB:	14.3 g/dL	(03/02/10)	16.0 g/dL	(12/21/09)
K+:	hemolyzed mmol/L	(03/02/10)	3.8 mmol/L	(12/21/09)
Cr:	0.84 mg/dL	(03/02/10)	0.86 mg/dL	(12/21/09)
MicroAlb/Cr:	18.3 mcg/mg Creat	(10/05/09)	H 52.8 mcg/mg Creat	(11/14/08)
GFR (AA):	112.22 mL/min	(03/02/10)	109.21 mL/min	(12/21/09)
GFR (non AA):	92.59 mL/min	(03/02/10)	90.11 mL/min	(12/21/09)
Glu:	105 mg/dL	(03/02/10)	H 123 mg/dL	(12/21/09)
HbA1c:	5.7%	(10/05/09)	5.8%	(03/18/09)
Total Chol:	H 205 mg/dL	(10/05/09)	193 mg/dL	(09/30/09)
HDL:	L 26 mg/dL	(10/05/09)	L 31 mg/dL	(09/30/09)
Chol/HDL:	7.9	(10/05/09)	6.2	(09/30/09)

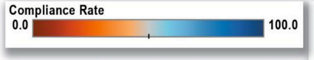
1. **To maximize the communication benefits of color, design**
   -Use gray scale, then add color sparingly

Colors emphasize only title and high (orange) / low (blue) values

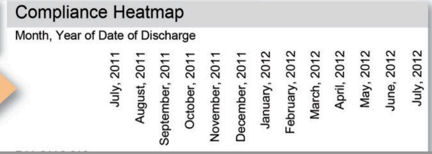
2. **To group items into different categories**
   -Use no more than 7 colors (4 recommended)



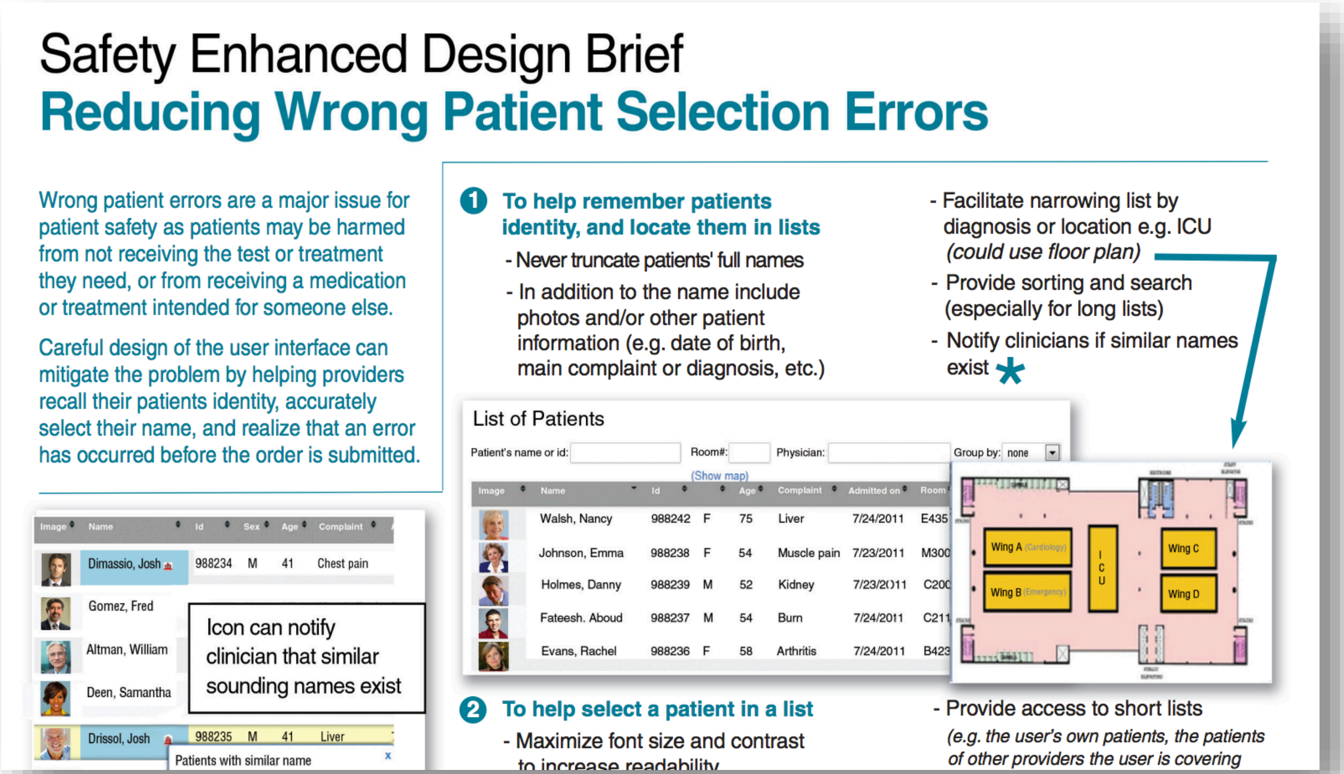
3. **To show sequential ranges of quantitative values**
   -Use 1 color (for sequential) and 2 colors (for diverging) values
   - Vary color intensity from pale (low values) to darker (extreme values)



2-color heatmap of varying intensity visualizes sequential ranges



Example: Reducing Wrong Patient Errors



Safety Enhanced Design Brief

Reducing Wrong Patient Selection Errors

Wrong patient errors are a major issue for patient safety as patients may be harmed from not receiving the test or treatment they need, or from receiving a medication or treatment intended for someone else.

Careful design of the user interface can mitigate the problem by helping providers recall their patients identity, accurately select their name, and realize that an error has occurred before the order is submitted.

Image	Name	Id	Sex	Age	Complaint
	Dimassio, Josh	988234	M	41	Chest pain
	Gomez, Fred				
	Altman, William				
	Deen, Samantha				
	Drissol, Josh	988235	M	41	Liver

Icon can notify clinician that similar sounding names exist

Patients with similar name

1 To help remember patients identity, and locate them in lists

- Never truncate patients' full names
- In addition to the name include photos and/or other patient information (e.g. date of birth, main complaint or diagnosis, etc.)

- Facilitate narrowing list by diagnosis or location e.g. ICU *(could use floor plan)*
- Provide sorting and search (especially for long lists)
- Notify clinicians if similar names exist *

List of Patients

Patient's name or id: Room#: Physician: Group by: none

(Show map)

Image	Name	Id		Age	Complaint	Admitted on	Room
	Walsh, Nancy	988242	F	75	Liver	7/24/2011	E435
	Johnson, Emma	988238	F	54	Muscle pain	7/23/2011	M300
	Holmes, Danny	988239	M	52	Kidney	7/23/2011	C200
	Fateesh. Aboud	988237	M	54	Burn	7/24/2011	C211
	Evans, Rachel	988236	F	58	Arthritis	7/24/2011	B423

2 To help select a patient in a list

- Maximize font size and contrast to increase readability

- Provide access to short lists *(e.g. the user's own patients, the patients of other providers the user is covering*

Example: CDS

Safety Enhanced Design Brief
Clinical Decision Support

Clinical decision support (CDS) systems bring relevant information to the clinician at the point of decision making.

Implementing CDS systems presents many challenges such as:

- Complex system constraints
- Complex nature of information to be displayed
- Challenging human-computer interaction design
- Organizational and change management to ensure system adoption

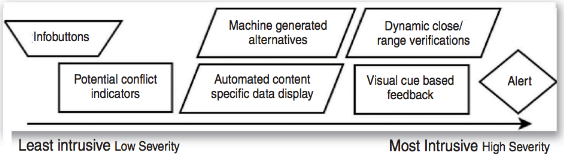
CDS is one of the most complex sub-systems available in EHR systems. This document reviews guidelines to *design useful and usable CDS interventions.*

1 To create useful, consistent and reliable communication of support material to the user

- Ensure your CDS system is capable of identifying preventable errors and informing the user of potential clinical hazards
- Adapt CDS interventions to the clinical workflow and not the opposite
- Create a system that supports human decision making rather than corrects it (e.g. give feed back on entered data as opposed to changing it automatically)
- Clearly differentiate alerts and interventions according to their type
- Show decision support elements near corresponding data entry fields or buttons
- Classify decision support elements (e.g. rules and alerts) by severity levels
- Incorporate insurance coverage information into the CDS scope
- Match the intrusiveness of the CDS intervention to the severity level of the problem

2 To prevent alert fatigue, provide support beyond alerting

- Use indicators to signal potential conflicts before triggering an alert
- Provide reduced lists of options based on context (e.g. a short list of clinically appropriate painkillers is presented when pain is entered as the chief complaint)
- Consider including automated machine-generated information views and automatic context-specific data display functions



Inspired EHRs

Co-funded by California HealthCare Foundation and SHARPC

Aspirational and provocative: imagines what an evidence-based EHR interface might look like and outlines the case for better design

Interfaces outlined in the book were not formally tested, but were reviewed by experts

Free online book and PDF download at http://inspiredehrs.org/

Font, Color, Saturation, Line Weight, & Formatting Matter

Figure 2.1 **Before: An Awful Medication List**

Current medications: (selected)
Prescriptions
Ordered
- albuterol HFA prn (90 mcg/spray) (ProAir HFA) oral spray; 90 mcg/spray, 2 puffs, oral, every 4 hours as needed, 21.6 mg/1 unit
- beclomethasone HFA (QVAR 40 HFA) oral spray; 40 mcg/spray, 2 puffs, oral, twice a day, 9.6 mg/1 unit
- carvedilol 25 mg oral tablet; 25 mg 1 tablet, oral, 2 times a day, 180 tablets
- chlorthalidone 25 mg oral tablet; 20 mg, 1 tablet, oral, daily, 90 tablets
- citalopram 20 mg oral tablet; 20 mg, 1 tablet, oral, daily, 90 tablets
- gabapentin 600 mg oral tablet; 600 mg, 1 tablet, oral, 2 times a day, 180 tablets
- insulin glargine (Lantus) 40 units subcut at bedtime, 10 ml
- losartan 100 mg oral tablet; 100 mg, 1 tablet, oral, daily, 90 tablets
- metformin 1000 mg oral tablet; 1000 mg, 1 tablet, oral, 2 times a day, 180 tablets
- naproxen 500 mg oral tablet; 500 mg, 1 tablet, oral, 2 times a day, 60 tablets
- nitroglycerin 0.4 mg prn oral tablet; 0.4 mg, 1 tablet, under tongue, every 5 minutes as needed, 25 tablets
- prednisone 20 mg prn oral tablet; 20 mg, 2 tablets daily, oral, prn, 10 tablets
- simvastatin 80 mg oral tablet; 80 mg, 1 tablet, oral, daily, 90 tablets
- terbinafine 150 mg oral tablet; 150 mg, 1 tablet, oral, daily for 12 weeks, 84 tablets
- zolpidem 5 mg oral tablet; 5 mg, 1 tablet, oral, at bedtime, 90 tablets

Documented Medications
Documented
- aspirin 81 mg oral tablet; 1 tablet, oral, daily
- omeprazole 40 mg oral tablet; 1 tablet, oral, daily

Figure 2.2 **After: Simple Medication List Makeover**

Medications
Last updated 1 month ago

albuterol HFA 90 mcg/spray 2 puffs every 4 hr as needed
aspirin 81mg 1 tablet daily
beclomethasone HFA (QVAR HFA) 40 mcg/spray 2 puffs daily
carvedilol 25mg 1 twice daily
chlorthalidone 25mg 1 tablet daily
citalopram 20mg 1 tablet daily
gabapentin 600mg 1 twice daily
insulin glargine (Lantus) 40 units 1 at bedtime
losartan 100mg 1 daily
lisinopril 20mg 1 daily
metformin 1000mg 1 twice daily
naproxen 500mg 1 twice daily
nitroglycerin 0.4mg 1 as needed
omeprazole 40mg 1 daily
prednisone 20mg 2 daily as needed
simvastatin 80mg 1 daily
terbinafine 150mg 1 daily
zolpidem 5mg 1 at bedtime

Figure 2.3 **Before: The Frame Creates Visual Noise**

Name of medication	Instructions
albuterol HFA	2 puffs every 4 hours as needed
aspirin 81 mg	1 daily
beclomethasone HFA 40	2 puffs twice a day
carvedilol 25 mg	1 twice daily
chlorthalidone 25 mg	1 daily
citalopram 20 mg	1 daily
gabapentin 600 mg	1 twice daily
insulin glargine 28 units	28 units at bedtime
losartan 100 mg	1 daily
metformin 1000 mg	1 twice daily
naproxen 500 mg	1 twice daily
omeprazole 40 mg	1 daily
prednisone 20 mg	2 daily
simvastatin 40 mg	1 daily
terbinafine 250 mg	1 daily for 12 weeks
zolpidem 5 mg	1 at bedtime

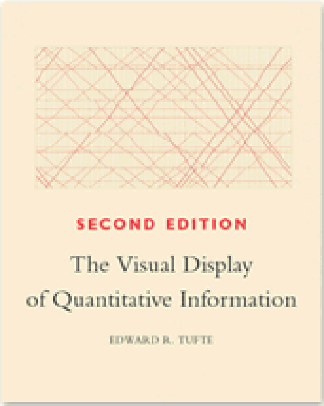
Figure 2.4 **After: Cleaner, Data Takes Center Stage**

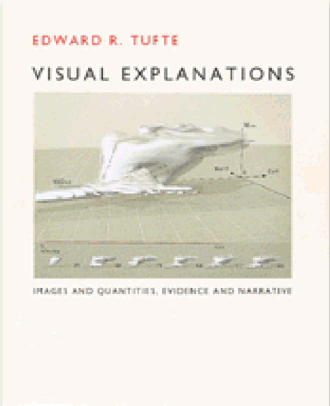
Medication	Instructions
albuterol HFA 90	2 puffs every 4 hours as needed
aspirin 81 mg	1 daily
beclomethasone HFA 40	2 puffs twice a day
carvedilol 25 mg	1 twice daily
chlorthalidone 25 mg	1 daily
citalopram 20 mg	1 daily
gabapentin 600 mg	1 twice daily
insulin glargine 28 units	28 units at bedtime
losartan 100 mg	1 daily
metformin 1000 mg	1 twice daily
naproxen 500 mg	1 twice daily
omeprazole 40 mg	1 daily
prednisone 20 mg	2 daily
simvastatin 40 mg	1 daily
terbinafine 250 mg	1 daily for 12 weeks
zolpidem 5 mg	1 at bedtime

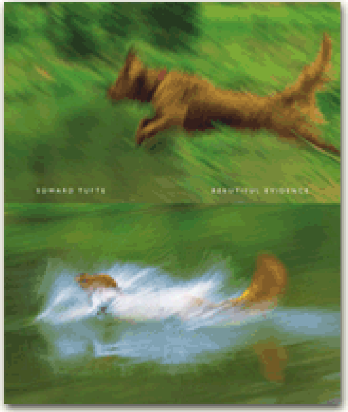
Visual Display of Data

Topic mentioned throughout SHARPC work and critically important to medicine, life sciences, and academia

Perhaps the best-known advocate is Edward Tufte

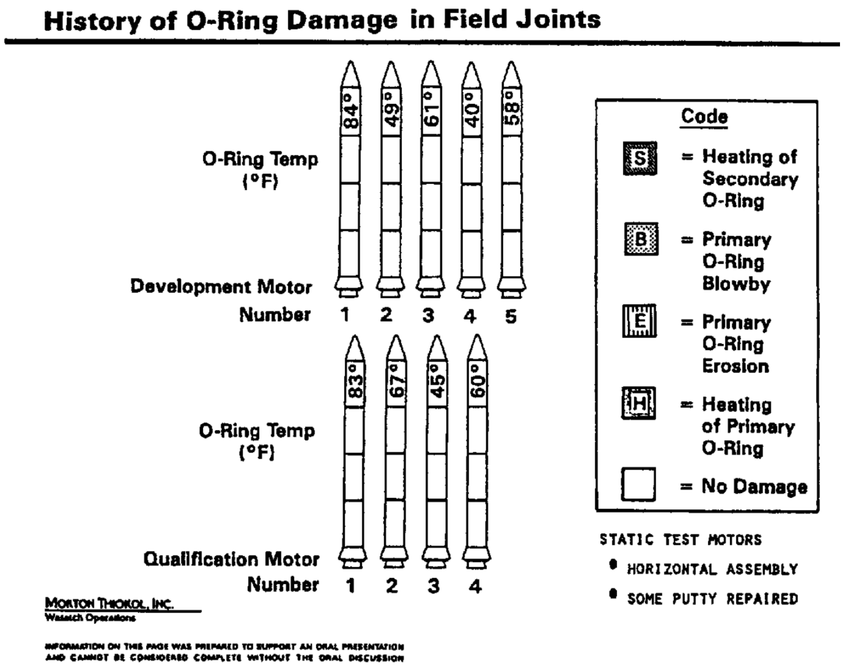






Challenger Disaster

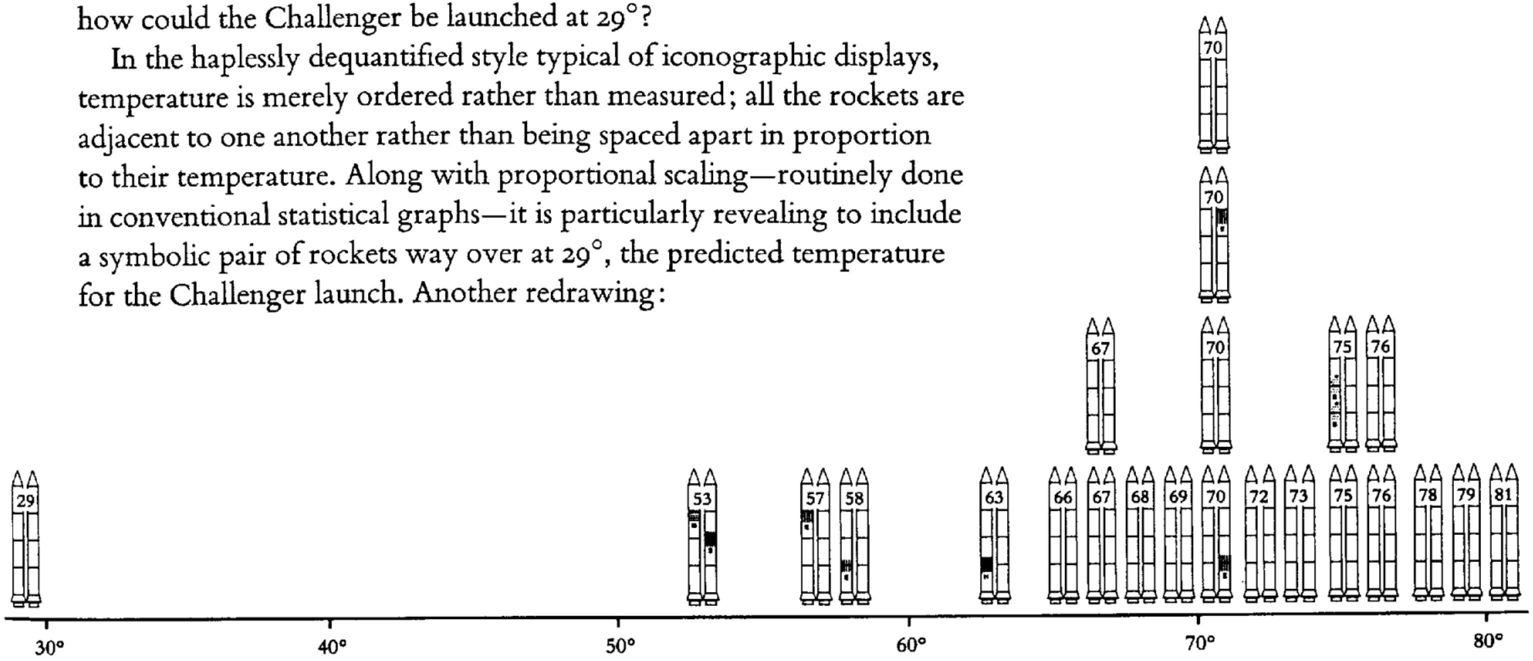
In his book "Visual Explanations", Tufte suggests that the booster rocket O-ring failure that led to the space shuttle Challenger explosion was a failure of telling the right story with data.

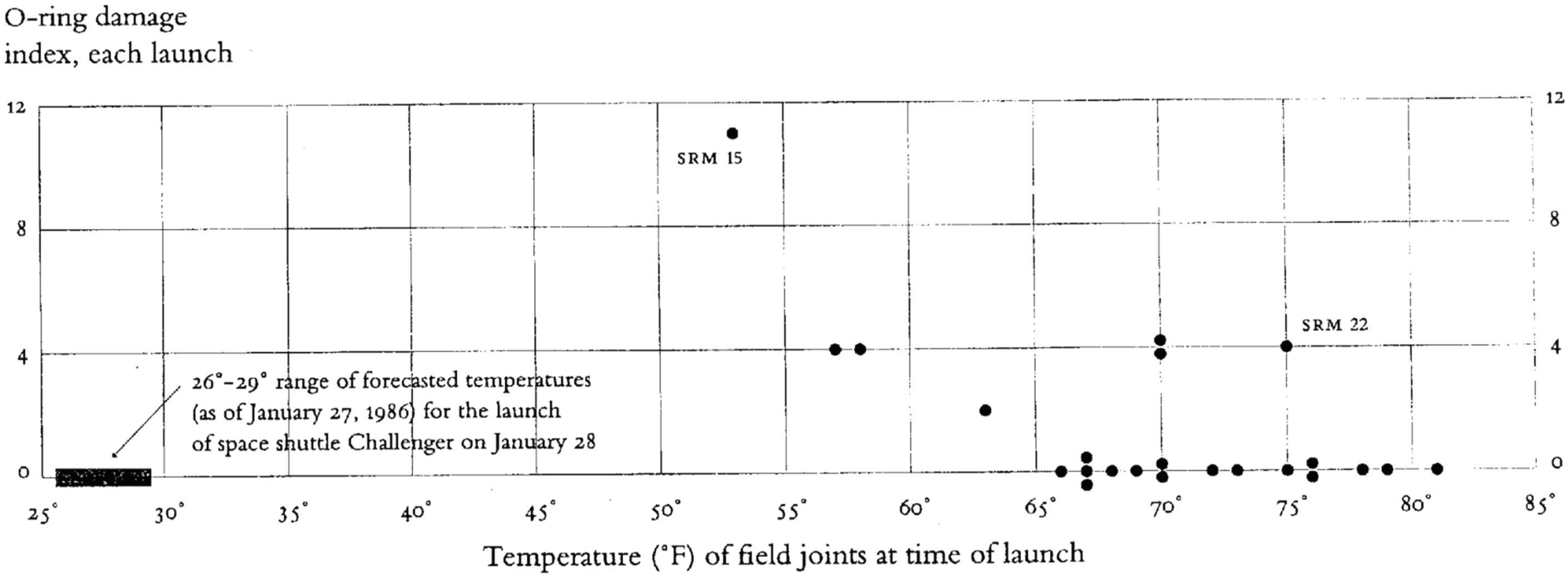


Original graphic obfuscated relationship between temperature and O-ring failure.

Information displays should serve the analytic purpose at hand; if the substantive matter is a possible cause-effect relationship, then graphs should organize data so as to illuminate such a link. Not a complicated idea, but a profound one. Thus the little rockets must be *placed in order by temperature, the possible cause*. Above, the rockets are so ordered by temperature. This clearly shows the serious risks of a cold launch, for most O-ring damage occurs at cooler temperatures. Given this evidence, how could the Challenger be launched at 29°?

In the haplessly dequantified style typical of iconographic displays, temperature is merely ordered rather than measured; all the rockets are adjacent to one another rather than being spaced apart in proportion to their temperature. Along with proportional scaling—routinely done in conventional statistical graphs—it is particularly revealing to include a symbolic pair of rockets way over at 29°, the predicted temperature for the Challenger launch. Another redrawing:





Tufte's final, simplified graphic, showing increasing rates of O-ring failure below 65 degrees.

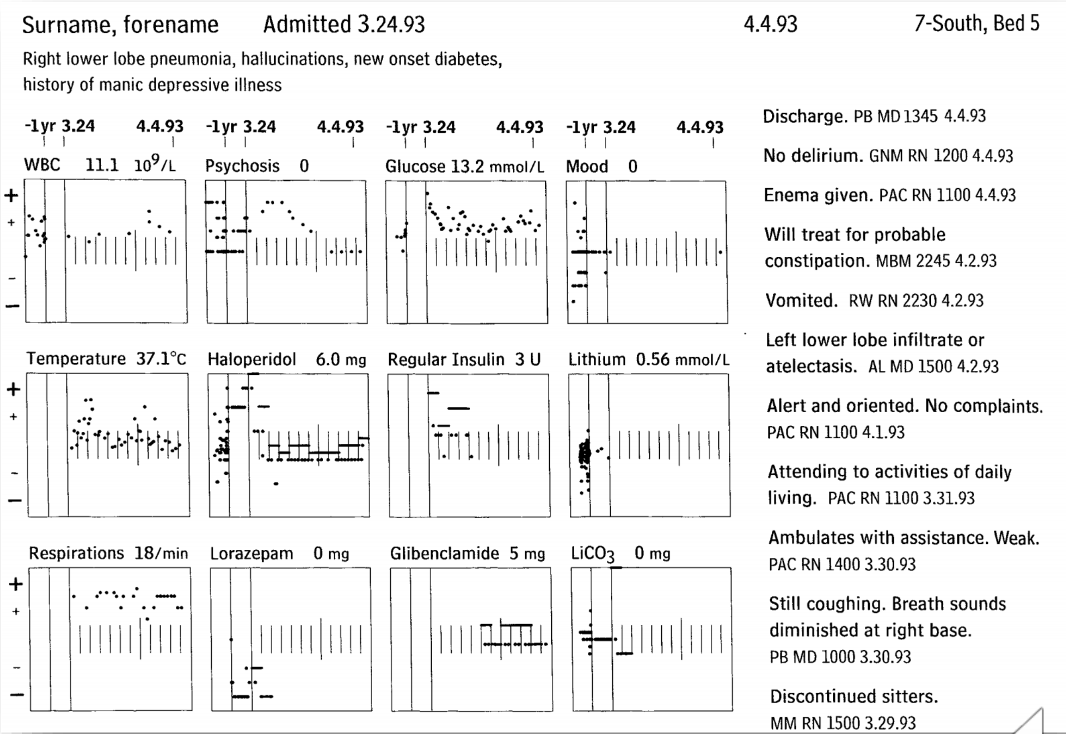
The 26-29 degree bar shows the temperature on the day of the Challenger launch.

If Tufte designed EHRs (you be the judge...)

Tufte dabbled in medical data visualization and published this article in 1994.

Elements of “small multiples”, “sparklines”, and timeline view

Powsner SM, Tufte ER. Graphical summary of patient status. Lancet. 1994 Aug 6;344(8919):386-9. PubMed PMID: 7914312.



Data Visualization

- Field that deals with the graphical representation of data and information.
- Common theme in Tufte, BetterEHR, and usability literature is that how you **represent** data can influence how you **perceive and comprehend** data.
- Data visualization shifts interpretation from a cognitive task (e.g., comparing 2 numbers) to a visual perception task (e.g., comparing the size of two slices in a pie-chart)
- Best Practices
  - Know your audience – consider usability testing!
  - Choose appropriate visuals to convey the information
  - Provide context (e.g., keys, scales, labels)
  - Keep it simple (avoid "chart junk" in the words of Tufte)

Attributes of Form

- Length
- Width
- Area
- Shape
- Angle
- Orientation
- Enclosure
- Blur

Attributes of Color

- Hue (color)
- Lightness
- Saturation
- Intensity

Attributes of Location

- 2-D position
- Spatial Grouping

Attributes of Motion

- 2-D direction of motion
- Speed of motion

Source & Additional Reference: https://www.perceptualedge.com/articles/visual_business_intelligence/the_visual_perception_of_variation.pdf

Choosing a Chart Type

- What type of relationship are you trying to show?
- How many variables are you comparing?
- Are there special features of the data you're trying to highlight (cycles, composition, change over time)?
- Keep in mind the usability guidelines in the "Design Briefs" (how to use color, font, size, line width, etc.) all apply here as well.
    - Ex: population density → 1 color, vary saturation
    - Ex: political leaning → 2 colors
- Avoid "tricks" like inaccurate scales, truncated axes.

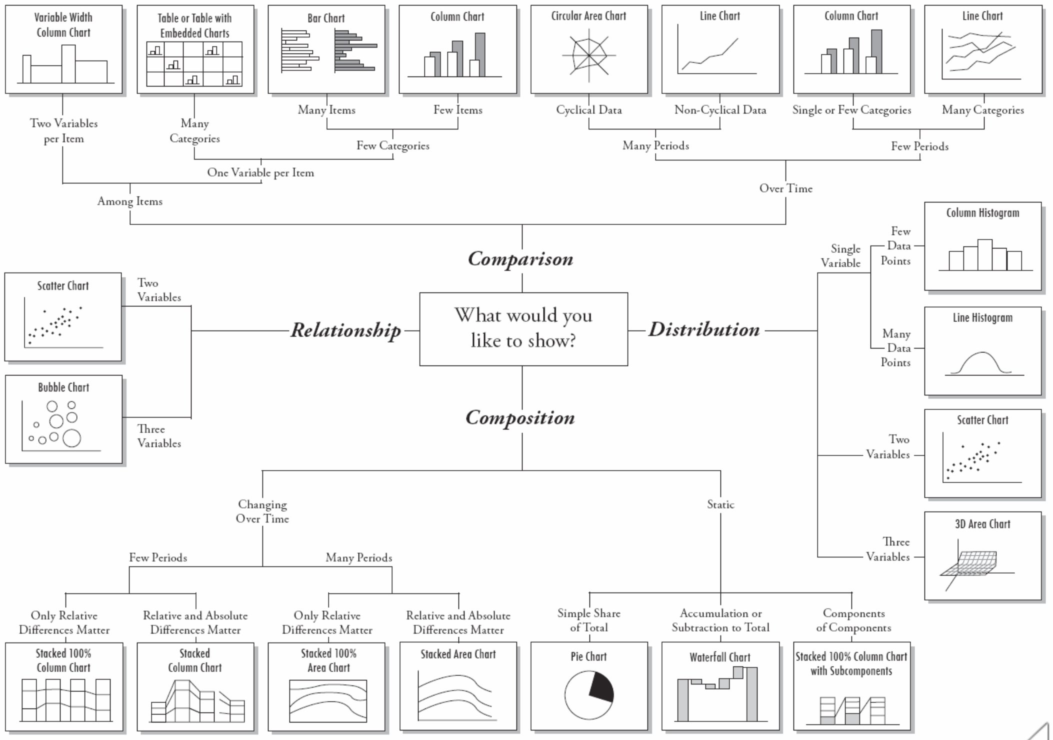
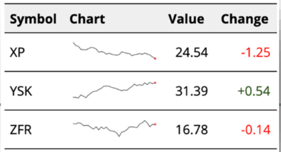


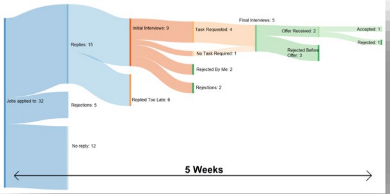
Image credit: [Andrew Abela, PhD, 2006]

Specialized Visualizations

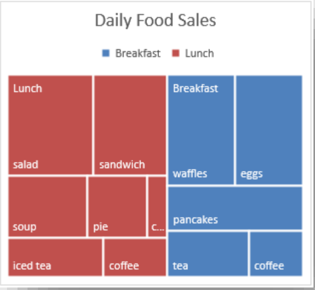
- **Sparkline** – small line chart without axes, typically to show a trend (your EHR may have these!)
- **Sankey Diagram** – flow chart in which width of bar conveys information about amount, and branches indicate additive/subtractive events
- **Heat Map** – graphic using saturation to convey content of a variable, overlaid on a table, map, or chart
- **Mekko Chart** – alternative version of bar chart in which both axes encode an attribute (width of bar and height of bar have meaning)
- **Treemap Chart** – shows relationship between parts to a whole as a series of grouped boxes
- **Geospatial Maps** – tabular data visualized on a map
- **Small Multiples** – term coined by Tufte, shows comparison between small data visualizations
- **These can be combined, made interactive, animated, and more…**



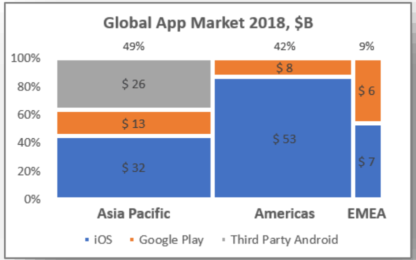
[Sparkline]



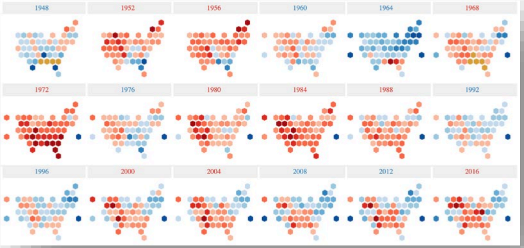
[Sankey]



[Treemap]

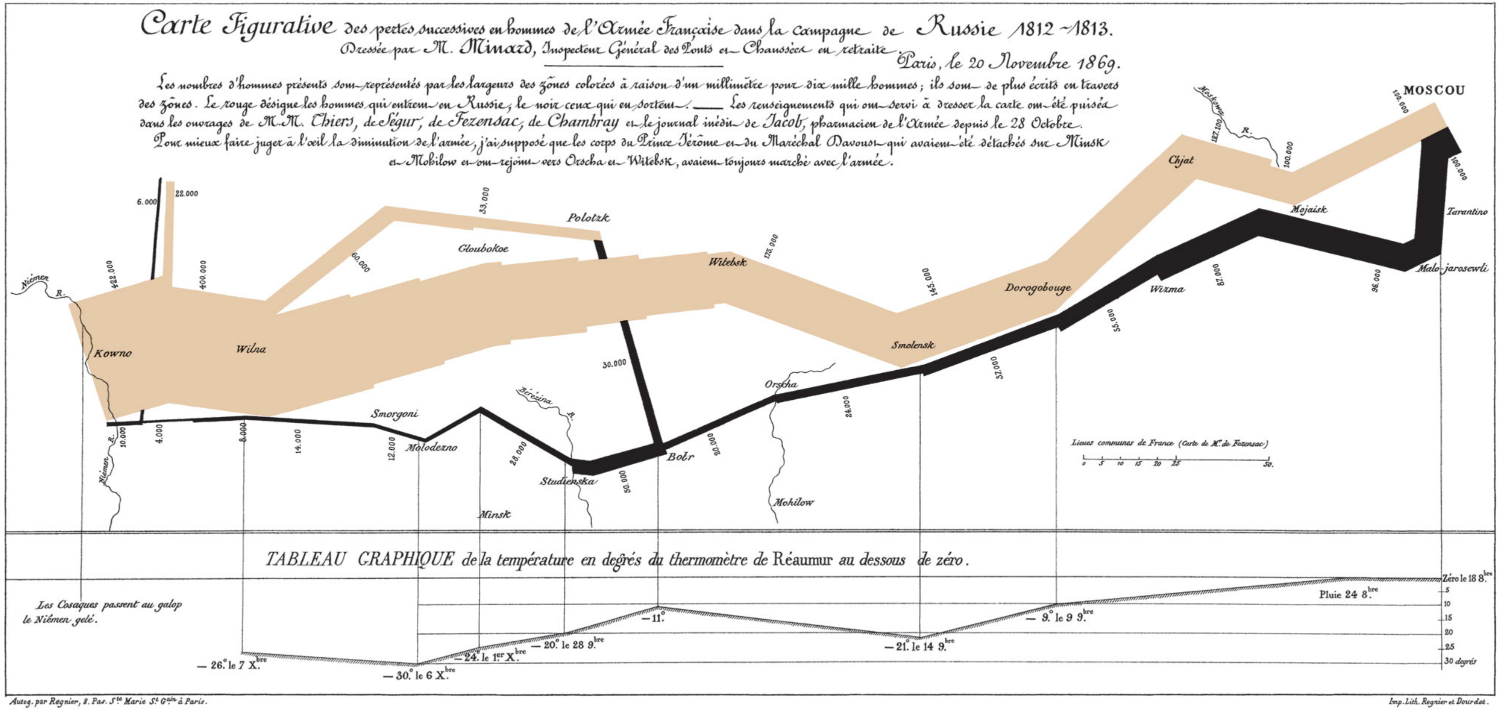


[Mekko]



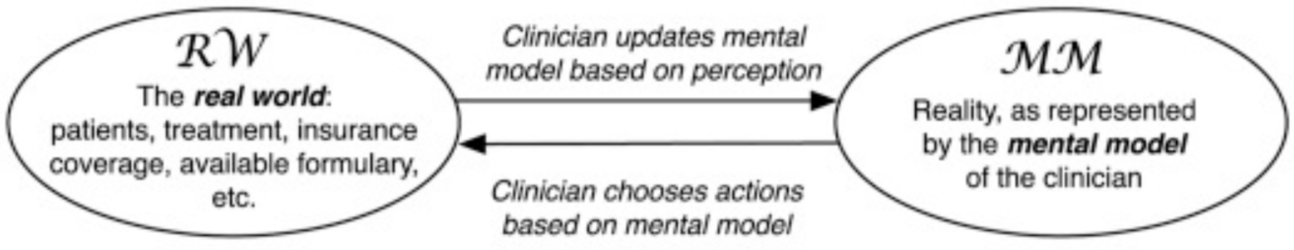
[Small Multiples] (each individual graphic is a map + heatmap)

Sankey + Map + Timeline + Secondary Graph



This graphic from 1861 was designed by Charles Minard. It describes the march of the Russian Army during the war of 1812 and how they succumbed to battle, cold, and starvation as they marched from Poland to Moscow and back. 422K soldiers left Poland, only 100K reached Moscow, and only 10K returned. The graph shows **six(!)** attributes: geography (map with landmarks), historical events (key battles), temperature (secondary graphic), attrition over time (line thickness), the advance of the army (tan line), and the return (black line). Tufte calls it “the best statistical graphic ever drawn”!

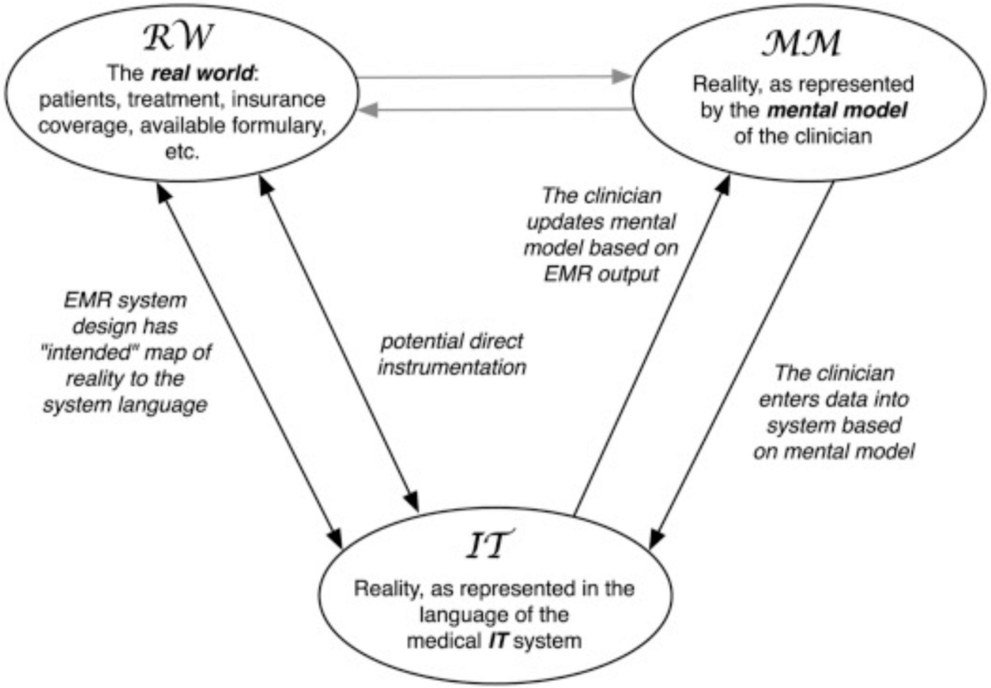
Mental Models in Real World



Clinician's understanding of a "real world" concept influences "reality," actions, choices.

Citation: Koppel. JAMIA, 2014

Mental Models With EHR



Citation: Koppel. JAMIA, 2014

Mismatched Models → Errors

Usability Errors can be Attributed to Mismatch Between These Three Models

Type I: IT is too coarse

- Not enough ICD-9 terms to represent conditions on problem list

Type II: IT is too fine

- ICD-10 is painfully granular, more so than mental model

Type III: IT systems do not account for reality

- Process requires data entry on computer, but there's a wifi deadspot

Type IV: Conflicting mental models

- Primary Care and Specialist think about a disease entity differently

Type V: Mental model based on a false reality as represented in IT

- Vital signs are automatically added to EHR from monitor, but are clearly artifact

Citation: Koppel. JAMIA, 2014

Which of the Koppel Usability Errors

does the UCSF TMP/SMX error highlight?

Does it relate to more than one?

Alerts vs. Projection Displays

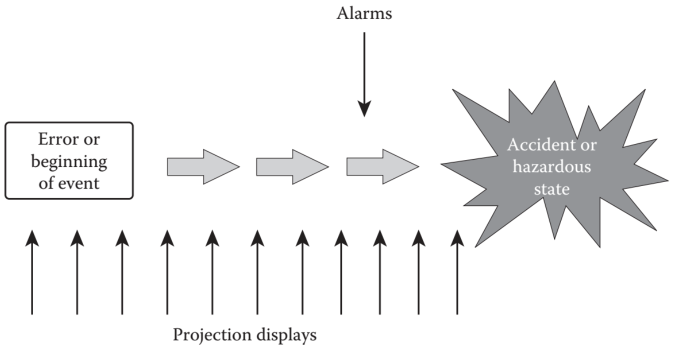


FIGURE 9.10 Projection displays support strategic and tactical needs while alarms are best for back-up support such as last ditch maneuvering.

Alerts assume a known risk, expected action, and responsible party

Situational Awareness acknowledges distributed decision-making and responsibility

- Everyone should be on the ”same page” about a decompensating patient
- That decompensation may precede an alert

Endsley, *Designing for Situation Awareness* 2003.

Situational Awareness

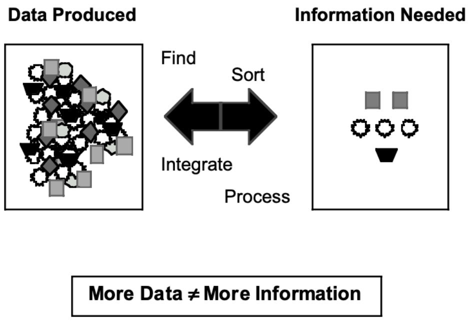


Figure 1. The Information Gap

*"[T]he **perception** of the elements in the environment within a volume of time and space, the **comprehension** of their meaning, and the **projection** of their future status"*

-Endsley, Human Factors, 1995

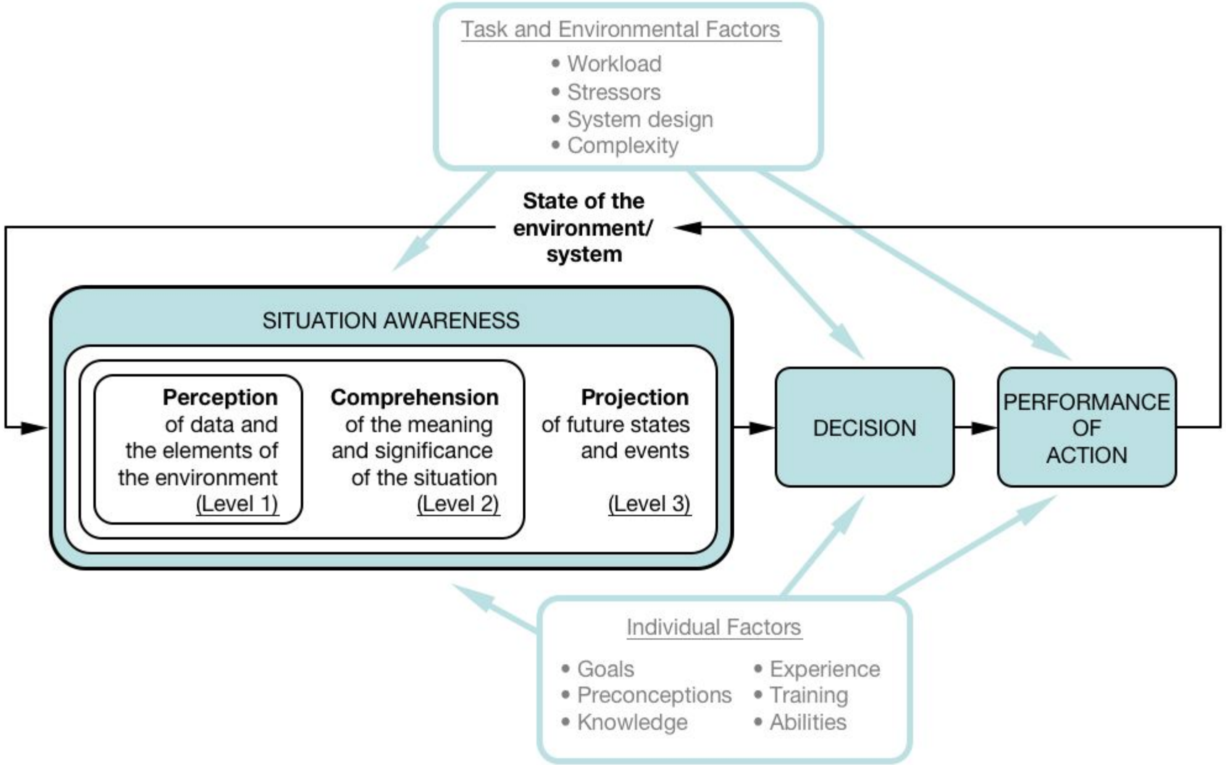
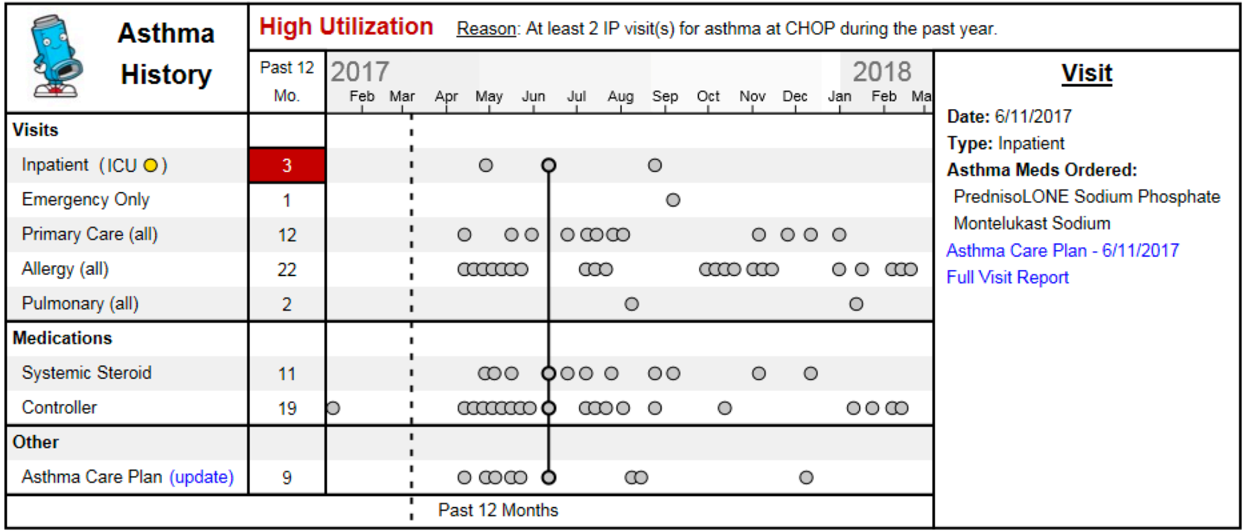


Image credit: https://en.wikipedia.org/wiki/Situation_awareness



CHOP Asthma Timeline Visualization generated in real-time from EHR data using webservices. UX is embedded in EHR. All "dots" are hoverable and link to source document/encounter.

ATV was evaluated against standard EHR interface using the **NASA Task Load Index** (10.8 vs 45.1, $p<0.002$)

Consider how this representation better promotes **situational awareness** for a given patient's medical history, not to mention how much time it saves in synthesizing over a year of health record data.

In what way does this support projection/forecasting? In what way does it support the user's mental model?

Source: Ferro D, Thayer J, Karavite D, Miller J, Zorc J, J Am Med Inform Assoc. 2021.

*"Design is really an act of **communication**, which means having a deep **understanding** of the person with whom the designer is communicating"*

–Don Norman

End of Lecture

Suggested Additional Reading

Wachter, B. The overdose: harm in a wired hospital. Mar 2015. [Backchannel.com]

Zhang, J. & Walji, M. ***Better EHR***. NCCD 2014. [Free PDF Download]

Belden B et al. **Inspired EHRs.** U Missouri, 214. [Online and PDF]

http://www.usabilityhome.com/FramedLi.htm?PerfMeas.htm

https://www.nngroup.com/articles/ten-usability-heuristics/

Lowry SZ, Quinn MT, et al. **Technical Evaluation, Testing, and Validation of the Usability of Electronic Health Records**. NISTIR 7804. National Institute of Standards and Technology, US Department of Commerce. February, 2012. [Link]

Caroll JM. **HCI Models, Theories, and Frameworks: Toward a Multidisciplinary Science**. Morgan Kaufmann: San Francisco; 2003. 579 p.

Sittig DF, Wright A, Osheroff JA, et al. **Grand challenges in clinical decision support.** *J Biomed Informatics.* 41 (2008) 387-392. [Article]

Buxton, W. **A Three-State Model of Graphical Input**. In D. Diaper et al. (Eds), *Human-Computer Interaction - INTERACT '90*. Amsterdam: Elsevier Science Publishers B.V. (North-Holland), 1990. 449-456.

Self-Directed Learning

The curriculum on Usability.gov is a great resource

https://www.usability.gov/how-to-and-tools/index.html

For board review, consider:

- Modules on Usability Evaluation
- Wireframing & Prototyping

Jakob Nielsen on Paper Prototyping

- https://www.nngroup.com/articles/paper-prototyping/
- https://www.nngroup.com/reports/paper-prototyping-training-video/