Electronic Medical Record (EMR) software will soon be widely in use in the U.S. As they exist today, EMRs will not make patients safer or doctors more productive, in part because they are not built using human factors design principles from the outset. EMRs should be designed with attention to work- and user-centered design techniques that have long been used in high-risk endeavors, such as aviation and NASA mission control. The authors propose using Goal Directed Task Analysis (GDTA) and Display Task Description (DTD) to design an EMR "workspace" that enables clinicians to reach and maintain a high level of situation awareness during asthma chronic disease management visits.

INTRODUCTION

Through the end of 2014, healthcare providers have financial incentives to reach the goal set by the U.S. government that everyone in the U.S. should have an electronic medical record (American Reinvestment and Recovery Act, 2009). Within the next two years, it is likely that most hospitals and medical practices nationwide will be using EMR software. Today’s state of the art EMRs, whether homegrown or vendor developed, often fail to apply work-centered and user-centered design principles. As a result, it is unlikely that these EMRs will make clinicians more efficient and patients safer.

Many of today’s EMRs give the appearance that they were built using modern design and development practices. However, closer inspection reveals a different reality. Often web-based user interfaces have simply been glued on top of antiquated technical infrastructure and outdated procedural programming languages.

The medical record must serve two masters—legal and clinical, which exacerbates poor EMR design. Interrupted data entry, the norm in busy clinical environments, becomes even more awkward when EMRs are designed to simultaneously perform audit trail logging and clinical documentation in the presentation layer. Not only is data entry awkward, this design strategy also interferes with cognitive processing. Research has shown that narrative records support cognitive processing of clinical information better than records with highly structured data formats, especially during record reviews (Nygren, 1992; Patel, 1999). The loss of clinically congruent narrative flow that results from such dual-purpose interface design adds to clinicians’ comprehension challenges when reviewing patients’ charts. Poorly designed EMRs may enable medical errors, especially cognitive errors, and thus pose a danger to patient safety.

Current EMRs frequently fail to incorporate basic usability principles. Buttons are not in the same location from screen to screen; additional data is hidden from view with no visual clue to the user; and messages to the user employ inconsistent and unfamiliar terminology. Domain-congruent, cognition-supporting information layout is largely absent. Clinicians must search for necessary information and can easily miss critical data. When needed information is scattered across multiple windows or the user must manually calculate and remember important values, the result is that the user must employ significant working memory to understand a patient’s situation.

Healthcare is high risk and complex. Consequently it requires the use of more sophisticated design principles than is currently the norm. EMR user interfaces should foster perceptual attention and situation awareness. Clinicians need prioritized, timely and relevant alerts. Having the most important information at the appropriate time would reduce data overload and unnecessary interruptions, both of which add to cognitive challenges during patient visits. Clinicians’ time, their scantiest resource, is often wasted wrestling with the EMR when it should be spent caring for their patients.

Human factors design principles and techniques have been used for years in many high-risk industries. In healthcare, with the exception of a few specialties such as anesthesiology, these principles and techniques remain unconventional, if not alien. As a consequence, when hospitals and medical practices select an EMR, human factors, ergonomics and usability rarely play a role in the purchasing decision. Given their value in producing optimal software, they should receive primary consideration.

Using two proven design techniques, Goal Directed Task Analysis (GDTA) and Display Task Description (DTD), which are employed in other high-risk domains, but not generally used in healthcare software development, we prototyped a user interface that meets clinicians’ needs for asthma chronic disease management.

METHODS

Asthma is a chronic disease that affects both children and adults. Studies demonstrate that asthma patients suffer from poor quality of care. Primary care doctors and subspecialists often underestimate asthma control due to failure to incorporate National Asthma Education and Prevention Program (NAEPP) risk and impairment elements. Providers create inadequate clinical documentation of the details of asthma follow-up visits. This impacts continuity of patient care, reliability of EMR clinical decision support, and the performance of clinical research to better understand asthma
Berner, 2005; Diette, 2004; Yawn, 2007). Clearly, clinicians and patients could benefit from improved systems support. Because we envisioned this user interface as a workspace that enables more than visit documentation, we called it the Asthma Workbench.

GDTA, a user-centered design technique developed by Endsley (Endsley, 2003), focuses the user interface designer’s attention on the goals, decisions and information required to support the user’s situation awareness during task completion. It employs interviews, field observation, and analysis of current documents and other work-related artifacts. By using Endsley’s three levels of situation awareness (level 1 - raw data; level 2 - comprehension of the data; and level 3 - projecting future trends based on the data), we identified the cognitive support that would help the clinician make sound decisions on behalf of the patient.

GDTA improved our understanding of how to organize information to support visit goals and decision making and fostered our comprehension of the decisions that would benefit from level 2 and level 3 cognitive assistance (Figures 1a and 1b). The analysis also clarified what needed to transpire to meet the care and outcome goals for a specific patient.

After developing a GDTA, the user interface designer may still be unclear as to how to render the required information in the best way. To gain further insight, we used DTD (Potter, 2002), which assists the designer by focusing on the goals and the scope of the display, along with highlighting what supporting information should be shown to the user (Figure 2). It also helps the designer further understand the cognitive assistance the user needs to comprehend and forecast when using that information.

![Figure 1a. Top Level Goals from Asthma Workbench GDTA](image1.png)

![Figure 1b. Part of the Asthma Workbench GDTA Goal 1.0](image2.png)
Conduct efficient, effective chronic disease management visits for known asthma patients so that asthma has the least negative impact on the patient’s quality of life and the patient achieves good outcomes

<table>
<thead>
<tr>
<th>Decision &amp; Information Requirements</th>
<th>Visualization Needs</th>
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<tbody>
<tr>
<td><strong>G 1.0 Assess Current Level of and Trends in Patient’s Asthma Control</strong></td>
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<tr>
<td>• DR What is patient’s current level of asthma control by NAEPP Risk &amp; Impairment Data? (This forms the basis of categorizing control by NAEPP criteria)</td>
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<tr>
<td>o Daytime symptoms</td>
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<td>o Night symptoms</td>
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<td>o Activity limitation</td>
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<td>o SABA use</td>
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<tr>
<td>o PFT data (FEV1 % predicted, FEV1/FVC ratio)</td>
<td></td>
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<tr>
<td>o Asthma Control test score and sub-item scores</td>
<td></td>
</tr>
<tr>
<td>• DR Do Hospitalizations &amp; ICU stays past 12 mos suggest lack of good control (This flags risk of fatal/near asthma even when control by NAEPP criteria looks good)</td>
<td></td>
</tr>
<tr>
<td>o Number of hospital admissions in the past 12 months</td>
<td></td>
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<tr>
<td>• ICU stays during those admissions?</td>
<td></td>
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<tr>
<td>• Intubated during ICU stays?</td>
<td></td>
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<tr>
<td>• DR Do ED and urgent care/sick visits past 12 months suggest lack of good control (This helps clinician understand response to acute flares and may suggest control requires improvement)</td>
<td></td>
</tr>
<tr>
<td>o Can family successfully control symptoms using their Asthma action plan without the need for acute care visits</td>
<td></td>
</tr>
<tr>
<td>• DR Does the impact on ADLs (school, sports, work) suggest lack of good control (This helps clinician understand impact on quality of life and may present opportunities to convince families about need for better control)</td>
<td></td>
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<tr>
<td>o School days missed</td>
<td></td>
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<tr>
<td>o Days of Sports/gym missed</td>
<td></td>
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<tr>
<td>o Days of work missed by patient</td>
<td></td>
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<tr>
<td>o Days of work missed by parent</td>
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</table>

• Show NAEPP Risk and impairment choices and corresponding level of control
• Show current and several (if available) past PFT results and show what NAEPP category each corresponds to
• Show number of hospital admissions and number of ICU stays and stays with intubation required in the past 12 mos and whether number indicates risk of fatal or near fatal asthma
• Show number of ED, urgent care and sick office visits in the past 12 months
• Show school days, sports/gym events, patient and parent work days missed in past 12 months

Figure 2. For each goal, the Asthma Workbench DTD lays out decisions and rationale along with the information requirements on the left and what should be shown to the user in the display on the right. This figure shows the part of the DTD for Goal 1.0.

![Figure 3a](image-url) Figure 3a. The top section of the GUI shows the current level of asthma control, control components and their trends. It also provides access to currently collapsed sections that are required to accomplish other goals of the visit.

![Figure 3b](image-url) Figure 3b. Here, the current treatment plan section of the GUI is expanded while the remainder of the goals are collapsed.
RESULTS

The Asthma Workbench prototype draws the user’s attention to important aspects of the patient’s situation and prompts the clinician to ask essential history questions, as well as to respond to barriers confronting the patient. For example, if the patient’s asthma is not well controlled, the GUI provides an area that prompts the clinician to delve into potential co-morbid conditions and alternative diagnoses, which may facilitate the clinician’s understanding of additional problems that require distinct evaluation and treatment.

Clinicians need to perform medication reconciliation at each patient encounter. The prototype GUI displays the medications that the patient and/or parent states are currently being used, the medications that were prescribed, as well as the step corresponding to the prescribed medication therapy based on the NAEPP guidelines in order to assist clinicians with this task (Figure 3b). The GUI also supports reconciliation of non-pharmacologic aspects of the treatment plan, such as mitigation strategies for allergens and irritants. This is accomplished by displaying the previously recommended mitigation strategies along with what the family is presently doing to control the patient’s known ongoing environmental triggers. This GUI helps the clinician to optimize the medications and control measures by displaying the NAEPP treatment plan and follow-up interval recommendations appropriate for that patient.

Educating the patient in self-management skills is another critical component of successful asthma management. The GUI shows what topics have been covered to date and enables the clinician to select education items to be addressed by the asthma educator during the current visit (Figure 3c). It also highlights patient barriers and beliefs that may benefit from education as a means to increase the patient’s likelihood for successful self-management. Items to be included in the patient’s after visit summary handout can be easily added by the clinician without requiring the clinician to perform duplicate data entry, which is common practice in current EMRs.

The user interface combines patient-gathered data (e.g. a medication adherence and side effects checklist as well as the Asthma Control Test) and staff-gathered data (e.g. a metered dose inhaler technique checklist). Links enable the clinician to see the details behind the summarized data, if desired. The GUI includes the results of a validated health literacy screen (in this case, Morris, 2006) that has been gathered from the patient prior to the visit. This helps the clinician provide education suitable to the patient’s literacy level. Having readily available literacy information also reminds the clinician to confirm that the patient and/or parent comprehends the treatment plan, the rationale for the use of controller medications, how to use the asthma action plan, etc.

Additional data, such as whether the patient currently is exposed to any known asthma triggers, may also be obtained before the visit, either from the patient and parent directly or from the family via the ancillary staff. Having this information readily available assists the clinician in tailoring the trigger mitigation plan to the patient’s current exposures (Figure 3d). By including responses to validated questionnaires that screen...
for anxiety and for depression—either of which may contribute to adherence problems and to poor chronic disease outcomes—the GUI helps the clinician gain insight into patient non-adherence with the treatment plan and may highlight additional strategies necessary to overcome these obstacles (Whooley, 1997; Birmaher, 1997).

Another important function of this user interface is its ability to translate the data into a narrative note for archiving (Figure 4). The structured data, free text entry data, calculations and other application logic-based information are incorporated into appropriate sections of the final note template by the middle tier software.

**Color Legend – Document Text Source:**
- Clinician, Staff or Patient Free Text Entry
- Structured Data
- Program Calculation or Logic

**Date:** 11/12/2011

CC: Jack Jones comes to clinic today for a planned asthma visit.

HP: This 5 y.o. has had asthma for the past 4 years, mom generally feels that the asthma is not a problem and wishes to decrease the medications.

The child’s A.C.T. score was 18, i.e. not well controlled. Please see the encounter attachment for details about each item in the A.C.T. The step of therapy the child was on prior to the visit was Step 2. His inhaled & spacer use needs improving.

Of note, the child’s medication use is not supervised by an adult.

The child does not use medication prior to exercise, unless he has a head cold. The child reports not cough during exercise only on very cold or smoggy days or when having a head cold. I reviewed the indications for pre-exercise medication use with this family, including for the reported exercise-induced triggers.

By NAEPPI risk and impairment assessment, the child is currently not well controlled. The items that merited the ‘well controlled’ category included: oral steroid courses, FEV1 and FEV1/FVC. The items that merited the ‘not well controlled’ category included: daily symptoms, nighttime awakenings, SABA use and A.C.T. score. The items that merited ‘very poorly controlled’ category included: none.

Using A.T.S. criteria, the child’s baseline spirometry today was normal. He did not perform post-bronchodilator testing.

**Figure 4.** Structured data, free text, data, logic and calculations are translated into narrative format after the note is finalized and signed. The narrative note is available when clinicians review the patient’s EMR.

### DISCUSSION

We propose that the EMR user interface for encounters go beyond the current norm. Rather than glorified word processors or structured forms that duplicate the layout of paper records and require excessive clicks to complete, the user interface should be a goal-directed workspace that enables data fusion and just-in-time decision support, rather than one that is simply formatted for note and data entry. Designing the GUI with clinician situation awareness in mind ensures that the three levels of situation awareness necessary to support decision making are incorporated. By using techniques such as GDTA and DTD in designing the Asthma Workbench we improve the clinician's experience. Data is gathered data in one section would not be the best way to meet the cognitive needs of the clinician. Through iterative work with GDTA and DTD, we uncovered critical areas that helped us to redesign the layout to best support cognition. The decision about where to place the co-morbid conditions and the triggers and mitigation sections were iteratively refined during the process of using these tools.

Prompting clinicians during a visit can help improve quality of care. One study showed that fifty-nine percent of primary care doctors failed to ask historical questions that would be influential in developing diagnostic and treatment plans (Ramsey, 1998). For asthma, in particular, both primary care doctors and subspecialists often underestimate the level of asthma control when they fail to incorporate the risk and impairment elements, including pulmonary function data, recommended by the NAEPPI (Diette, 2004; Nair, 2005). Thus we incorporated prompts for and provided information required for asthma decision making.

Given that asthma is a chronic disease, successful asthma care requires the use of chronic disease management.
strategies, including behavior and lifestyle changes. Patients with chronic disease need to be knowledgeable about self-management which often requires them to change their behavior. The user interface prompts the clinician to consider reported barriers and asthma health beliefs that may be impeding the necessary behavior changes required to improve asthma control. The GUI helps the clinician understand what the patient and parent want to achieve (goals) and what they want to avoid (fears). Such information can be employed to help the patient and family develop strategies to improve their adherence to the recommended treatment plan.

Displaying the various medication options that are consistent with the NAEPP recommendations for the particular step of therapy the patient requires helps the clinician to engage in shared decision making with the patient and parent and to negotiate the ultimate treatment plan with them. Free text data entry areas and behavior change counseling links are provided to help to elicit and document positive behavior change talk from the patient, which can be used to help promote the care plan. When patients talk about positive behavior change, it increases the likelihood that this behavior change will occur (Rollnick, 2008).

Croskerry (Croskerry, 2003) discussed the need to help clinicians avoid cognitive errors by using cognitive forcing strategies. A well-designed GUI can enable these strategies. Such strategies may include prompting the clinician to consider alternative diagnoses, especially in situations known to lead to diagnostic error. The user interface can decrease the user’s reliance on memory by providing necessary information that is organized based on how it will be used; reducing data entry tasks and manual calculations; providing helpful real-time feedback; and making it easier for clinicians to assign responsibility for tasks.

By fusing data from disparate sources such as electronic patient questionnaires, PHR, EHRs, claims and pharmacy databases within the Asthma Workbench, the clinician can achieve a high level of situation awareness concerning the patient’s asthma. The clinician can take advantage of the GUI layout and may clarify and edit pre-obtained data during the visit rather than using valuable time during the visit to obtain this data or to hunt for it in the EMR.

When the initial mockups were complete, we then used the “Brief Heuristic Evaluation” developed at Xerox Corporation (Naughton, 1995) to assess the compliance of the Asthma Workbench prototype with the checklist’s twenty-one fundamental usability criteria. Ten of the criteria were either out of scope or did not apply at this stage of design. Of the remaining eleven criteria, the GUI scored well on nine of them. However, we did uncover two usability issues during this review, which underscored the value of doing a Heuristic Evaluation as early as possible. The usability issues we discovered were: 1) user could not exit from the application and 2) “help button” functionality was missing. These usability issues were addressed in the subsequent iteration shown in Figures 3a through 3d above.

Next steps for this project include using our low fidelity prototype to conduct formative usability testing with clinicians. This testing will gather user information via questionnaire before the usability testing session to better understand clinician comfort with and use of various EMR GUIs. During the testing session, we will observe clinicians working with low fidelity paper prototypes populated with fictitious patient data. The clinicians will use the paper prototypes to work through clinical scenarios using think aloud technique. User situation awareness will be assessed with the use of Situation Awareness Global Assessment Technique (SAGAT) freeze probes during the testing session (Endsley 2000). After completing the session, responses to the NASA Task Load Index will be recorded and feedback from a standardized post-usability testing questionnaire will be gathered. The clinicians will also have the opportunity to participate in a verbal debriefing session.

In addition to subject matter expertise, creating a user interface such as the Asthma Workbench requires system and information architecture that supports gathering and integrating data from various stakeholders and data sources (Figure 5). This architecture is critical to designing an effective user interface. Primary care physicians do not have enough time in a day to perform all necessary chronic disease management tasks (Otsby, 2005). Gathering the necessary data upon which to base their decisions, minimizing their need to search actively for information, reducing their need to use working memory and do data entry tasks that could easily be automated helps physicians provide high quality care for various chronic diseases.

Management of chronic diseases such as asthma requires data from many care settings: home, urgent care, specialty clinics as well as unaffiliated healthcare provider networks. Monolithic EMRs built upon closed, proprietary technology are not designed for data interchange and integration. Vendors of these balkanized systems have resisted calls to modify their design approach and underlying technology because they have a lucrative, captive market once these systems are installed. Also, the people who make EMR purchasing decisions are generally unaware of the impact that
human factors and user-centric design have on usability as well as on patient safety and quality of care. The herd mentality tends to prevail when selecting an EMR, i.e. “what is good enough for Hospital X is good enough for us.”

Patients and clinicians need 21st-century technical infrastructure that is event-driven, real time, standards-based and interoperable in order to surmount the obstacles to delivering optimal care. Context-aware systems that use ontology engines to alert clinicians based on their clinical roles at any given moment, and those that use fuzzy inference engines to help prioritize alerts based on the changing conditions of the patient—such a capability is especially important when caring for patients with multiple chronic diseases—are vital to providing better care. In short, clinicians need systems that help them to be more effective and efficient than is currently possible. Incorporating more sophisticated information architecture than most commercial EMRs provide would also enable Quality Improvement to occur in real time – by identifying adverse events and variations in care, which would enable real time response. This also would allow the notification of supervisors on the fly, as problems arise. Such real-time monitoring would be best implemented by the inclusion of an event stream engine in the architecture.

Ultimately, only by using proven human factors and user-centric design techniques, modern programming languages and 21st-century technical infrastructure will the EMR’s potential to improve quality, efficiency and safety in healthcare be fully realized. Thus, we call for vendors to develop and purchasers to demand EMR software specifically designed using these methodologies.

REFERENCES


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