Chapter 15
Decision Support During Inpatient Care Provider Order Entry: Vanderbilt's WizOrder Experience

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Abstract In this chapter, the authors describe a pragmatic approach to the introduction of clinical decision support at the point of care, based on more than a decade of experience in developing and evolving Vanderbilt's inpatient "WizOrder" care provider order entry (CPOE) system. The authors have developed a generic model for decision support within inpatient CPOE systems. The model is based on characteristics of end-user workflows and on decision support considerations that are common to a variety of inpatient settings and CPOE systems. The specific approach to implementing a given clinical decision support feature should involve evaluation along three axes: what type of intervention to create (four categories); when to introduce the intervention into the user's workflow (seven categories), and how disruptive, during use of the system, the intervention might be to end-users' workflows (six categories). Framing decision support in this manner may help both

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This chapter includes an adaptation of portions of an article from the Journal of Biomedical Informatics: Miller RA, Waitman LR, Chen S, Rosenbloom ST. The anatomy of decision support during in patient care provider order entry (CPOE): Empirical observations from a decade of CPOE experience at Vanderbilt, 2005; 38:469–485, reprinted with permission from Elsevier. Vanderbilt licensed the WizOrder CPOE system to McKesson Corporation, which marketed it as Horizon Expert Orders until 2014. This article describes the WizOrder, pre-commercialization, academic version of the system as it was deployed at Vanderbilt from 1995 to 2015. The authors acknowledge the contributions of Dr. Sutin Chen to the previous version of this chapter and of Antoine Geissbuhler, MD, as the primary author of the WizOrder system from 1994 to 1999.

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developers and clinical end-users plan future alterations to their systems when needs for new decision support features arise.

Keywords CPOE systems • Care provider order entry systems • Computerized physician order entry systems • Vanderbilt • Inpatient care

Practitioners have yearned for clinical decision support systems for at least 2,500 years. Hippocrates noted “Life is short, the art long, opportunity fleeting, experience treacherous, *judgment difficult*.” (*Aphorisms*, sec. I, ca. 460–400 BC). While the basis for clinical decision support has been recognized throughout the ages, careful studies in the recent medical literature document those needs specifically [1–14].

The pioneers developing early care provider order entry (CPOE) systems – e.g., McDonald, Tierney, and their colleagues at the Regenstrief Medical Institute [15–25], Warner, Pryor, Gardner and their colleagues at LDS Hospital [26–28] (see Chap. 14), and many other groups – have confirmed, through controlled studies, the initial report of Shakespeare in 1597: “If to do were as easy as to know what were good to do, chapels had been churches, and poor men’s cottages princes’ palaces. . . . I can easier teach twenty what were good to be done than to be one of the twenty to follow my own teaching” (*The Merchant of Venice*, Act I, Scene ii). Busy healthcare providers have so many diverse tasks to perform that they are constantly distracted from being able to accomplish what they understand to be good medical practice. “Men are men; the best sometimes forget” (Shakespeare, *Othello*, 1605; Act II, Scene iii). Reminding systems and other forms of clinical decision support have been shown to be effective in overcoming such lapses of memory in a number of clinical situations [15–40]. However, the success of even the best-designed CPOE systems is not guaranteed. The socio-technical (people, workflows, and human factors) aspects of system implementation are critically important. Many clinical informatics systems (not all documented in the literature) implemented with good intentions have been met with anger and resentment [41–44]. Providing decision-support capabilities in a timely and convenient manner can add value to otherwise lackluster or marginal systems, and improve quality of care and reduce costs [15–40].

This chapter addresses the following questions: (1) What steps or stages in CPOE represent appropriate breakpoints (both computationally and with respect to end-user workflows) at which one can introduce clinical decision support? (2) What categories of decision support are relevant during CPOE sessions? and (3) What methods for workflow interruption should one consider when implementing decision-support interventions based on balancing end-user tolerance and clinical urgency?

The authors have used the Vanderbilt WizOrder CPOE system as the primary context for discussing decision support interventions, primarily because it provides a convenient example with which they are familiar. Through longstanding partnerships with clinician end-users, Vanderbilt Biomedical Informatics faculty members, fellows, and Informatics Center staff developed a CPOE system (WizOrder) in 1994–1995, implemented it on the wards of an academic teaching hospital, and evolved it in response to ongoing feedback (1995–2015) [45–55]. The approach to decision support described in this chapter was derived through generalization from that experience. While the authors have drawn heavily on their Vanderbilt past, the above questions and their answers are sufficiently generic that other developers in both academic and commercial settings may find value in the ensuing discussion. Further, the description of WizOrder functionality here serves as a historical reference as the landscape of order entry systems evolves in an increasingly vendor-based environment.

The authors describe herein the pre-commercial, academic version of WizOrder at Vanderbilt. The WizOrder CPOE system was commercialized in June of 2001. At that time, Vanderbilt University entered into a marketing agreement with McKesson to sell and distribute the WizOrder Care Provider Order Entry System commercially. McKesson rewrote large portions of the WizOrder code, adapted it to run on their preferred computer platforms, to share a common database with their nurse charting system (Horizon Expert Documentation), and recast it as Horizon Expert Orders in McKesson's product line. In early 2015, McKesson announced that it would discontinue the Horizon product line, including Horizon Expert Orders. The authors have herein refer to the system by its name at Vanderbilt, WizOrder. All descriptions are of system components developed at Vanderbilt University Medical Center and not by the commercial vendor.

15.1 Basic Care Provider Order Entry System Functionality

Order entry within many CPOE systems was initially designed to parallel traditional, manual paper chart-based order creation. Manual ordering involves: (1) physically locating the patient's chart; (2) finding the topmost blank order page; (3) handwriting a series of new orders as a block; (4) signing the orders to assert authorship and validation, thereby making them legal; (5) after setting a flag indicating presence of new orders, placing the chart where clerical unit staff expect to find charts with new orders; and (6) finding and verbally informing unit staff (patient's nurse, others) when life-critical or extremely urgent orders have been written. For the corresponding order entry performed in a typical CPOE system, the user, in some sequence: (1) authenticates with user name and password; (2) invokes the CPOE application; (3) selects a patient; (4) enters and modifies orders, using an electronic scratchpad (buffer) that holds orders but does not deliver them to ancillary departments (e.g., lab or pharmacy) for immediate action; (5) indicates when he or she is ready to finalize the set of orders on the scratchpad to send them out for processing; and (6) reviews and edits orders on the scratchpad before they are signed electronically and dispatched to be carried out. Unlike paper-based order entry, providers using CPOE can enter orders from sites remote from the patient location, without the need to have a physical chart. This may occur away from supporting

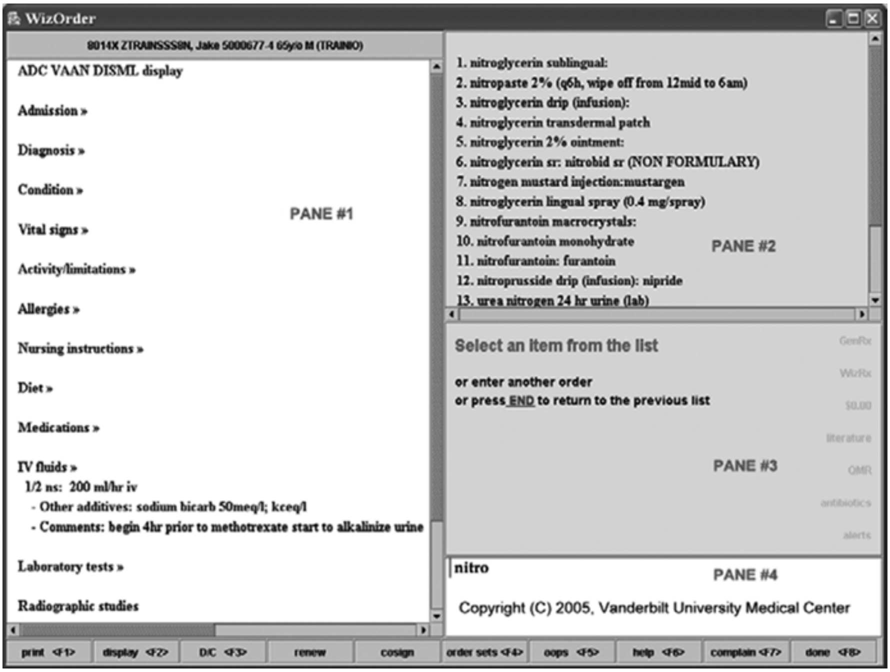

Fig. 15.1 WizOrder primary user interface screen panes: PANE #1, current and recent orders display; PANE #2, selectable "pick list" display; PANE #3, in-context instructions; PANE #4, user input text entry area. User had previously typed "nitro" into completer in PANE #4; PANE #2 shows results

staff, such as nurses. As a result, electronic CPOE without manual, person-to-person follow up may impair communication of life-critical, or otherwise very urgent, orders and thereby introduce patient safety concerns.

The panes of Fig. 15.1 present the WizOrder approach to implementing key components of an order entry interface. During initial WizOrder development, Vanderbilt beta-test users strongly recommended that the CPOE system interface should have "geographical consistency"- i.e., a given type of clinical information should always appear in the same location on the screen. This also implies that pop-up windows and pull-down menus that might obscure display of clinically important information should rarely appear. WizOrder's left-sided window displays currently active orders (and those expired in the previous 24 h) for the current CPOE patient (PANE #1). The upper right window presents context-dependent pick lists of options available for order creation or modification (PANE #2). The middle right window represents a context-sensitive help window that instructs the user on available next actions (PANE #3). The bottom right window contains a text input region (PANE #4).

15.1.1 Creating Orders

A key CPOE system design consideration involves how clinicians specify what they want to order. Many CPOE systems [56–59] use a hierarchical organization of orders, illustrated by the following example (bold font indicates hypothetical selection made at each level):

. . . *Orderable Pick List Level 1*: *Pharmacy*, ***Laboratory***, *Radiology*, *Dietary*, *Nursing* [*orders*], . . .
. . . *Orderable Pick List Level 2*: ***Hematology Tests***, *Serum Chemistry Tests*, *Urinalysis*, . . .
. . . *Orderable Pick List Level 3*: ***Complete blood count*** (***CBC***), *platelet count*, *blood Rh type*, . . .

CPOE systems also commonly have a "completer" or search engine function that allows the clinician-user to type shorthand word fragments derived from the desired order name (or its synonyms). The completer then searches for potentially matching orderable items from the system's dictionary, and provides the user with a pick list of those that the user can select. For example, typing "nitro" into a CPOE completer (Fig. 15.1, PANE #4) would result in the CPOE presenting a pick list (PANE #2) of orderable items' names, with "nitroglycerin sublingual" at or near the top of the list, and lesser/partial/wordier matches (e.g., nitrogen mustard, urea nitrogen blood) farther down the list. Vanderbilt users typically specify new orders using the completer function, and only rarely use WizOrder's hierarchies for order entry, usually when they do not know the specific name for the item they want to order. Users can also select pre-configured "order sets" using the completer function to find the grouping, and then clicking on individual orders within the group to select them.

After selecting the orderable item itself, users must then specify (enter) its component information (e.g., dose, route, frequency, etc, for a medication order). Many CPOE systems formally define orderables and their components using a data dictionary with structured templates that specify necessary and optional fields required to fully create an individual order. Figure 15.2 illustrates WizOrder sequential prompts for building an order for sublingual nitroglycerin (based on stored templates), and Fig. 15.3 indicates how the order, once fully specified for WizOrder, transfers to the left-sided active orders area (PANE #1). Another mechanism for generating new orders (used often, but less than half the time at Vanderbilt) is order sets – groupings of diagnosis or procedure-related selectable orders often with preset component information (e.g., vital signs q4h) [60]. If the user selects an order set name from a completer pick list or from the WizOrder order set hierarchy, the order set's component orders are retrieved and displayed as selectable items in the upper right pick list window (Fig. 15.4, PANE #2).

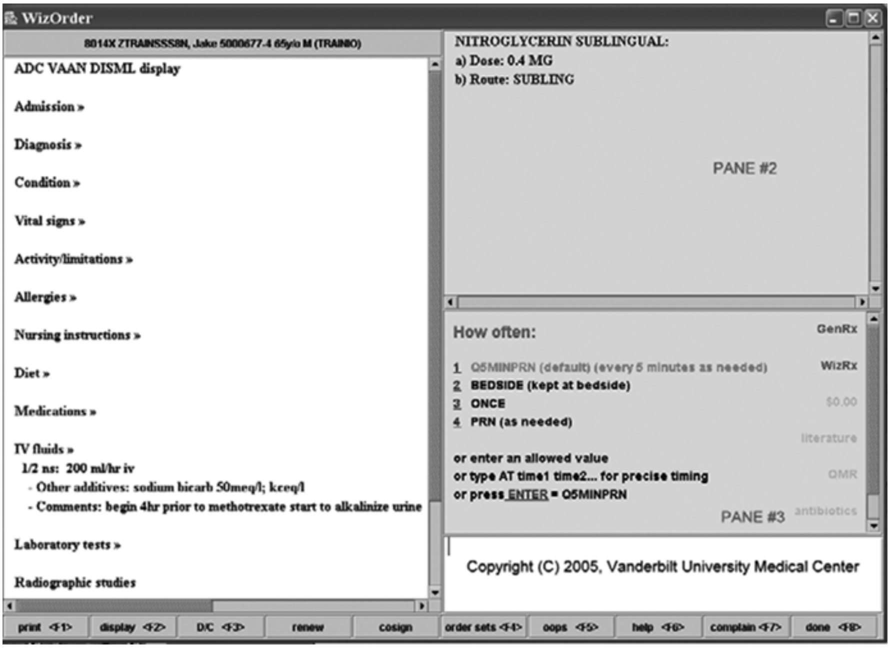

Fig. 15.2 Frequency prompts (medication-specific) for "nitroglycerin sublingual" orderable, after dose already specified by similar process

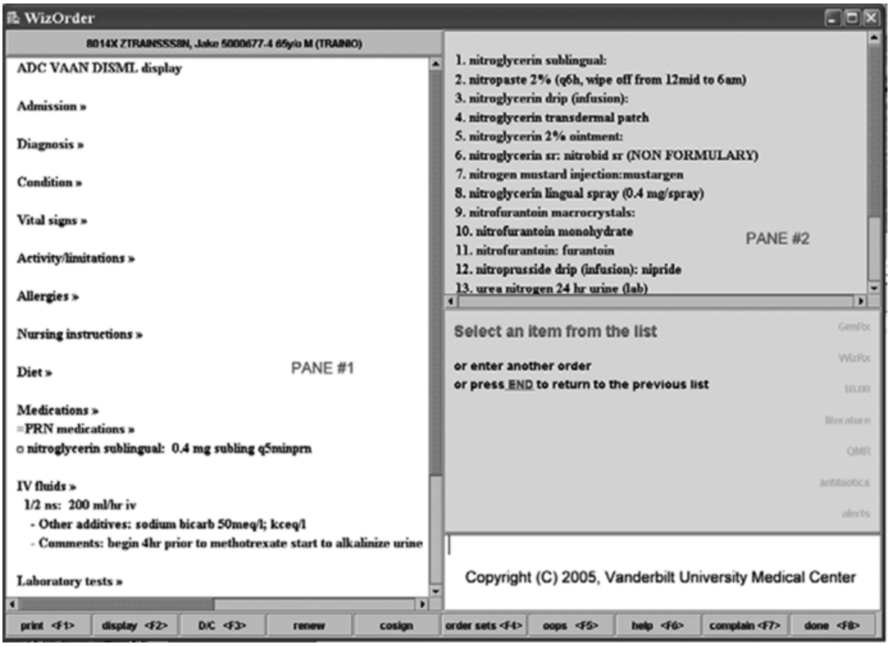

Fig. 15.3 Order for "nitroglycerin" moves to *left* window (PANE #1) once fully completed

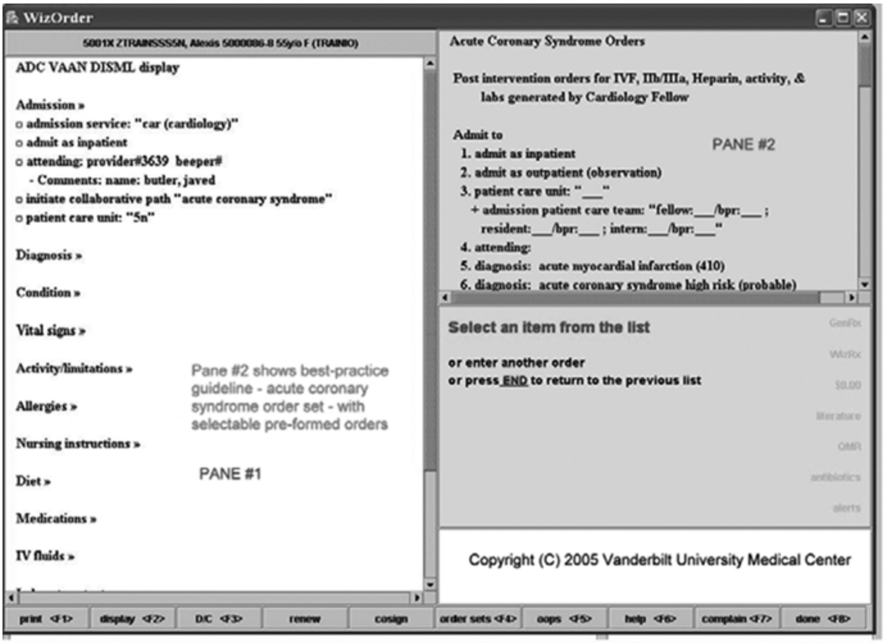

Fig. 15.4 First six orders in the acute coronary syndrome order set

15.1.2 Displaying Active Orders

Most CPOE user interfaces manage the display of currently active orders. In complex patient cases, active order counts can exceed 100. Therefore, simply listing all such orders in a display panel (sorted, e.g., alphabetically by order name) will not be helpful to clinicians unfamiliar with the patient's case, since locating an arbitrarily named specific order within a long list is difficult. Early during WizOrder development, end users requested that a display of active orders follow a grouping sequence based on the ADC VAAN DISML acronym that is familiar to physicians – **A**dmission, **D**iagnosis, **C**ondition, **V**ital signs, **A**ctivity, **A**llergies, and so on (Fig. 15.1, PANE #1). Many CPOE systems use similar methods to segment the active orders display into clinically useful buckets, and some facilitate electronic rearrangements of the active orders display to accommodate different users' typical workflows (e.g., nurses, attending physicians) as well as providing reverse chronological views to display the most recent new or changed orders. For example, Vanderbilt's specialized intensive care units and the emergency department required location-specific specialized views of active orders. As WizOrder displays active orders, it also displays recently expired orders (within the past 24 h) with a special symbol in the left margin to indicate those orders that have expired; a different left-margin symbol indicates orders soon to expire.

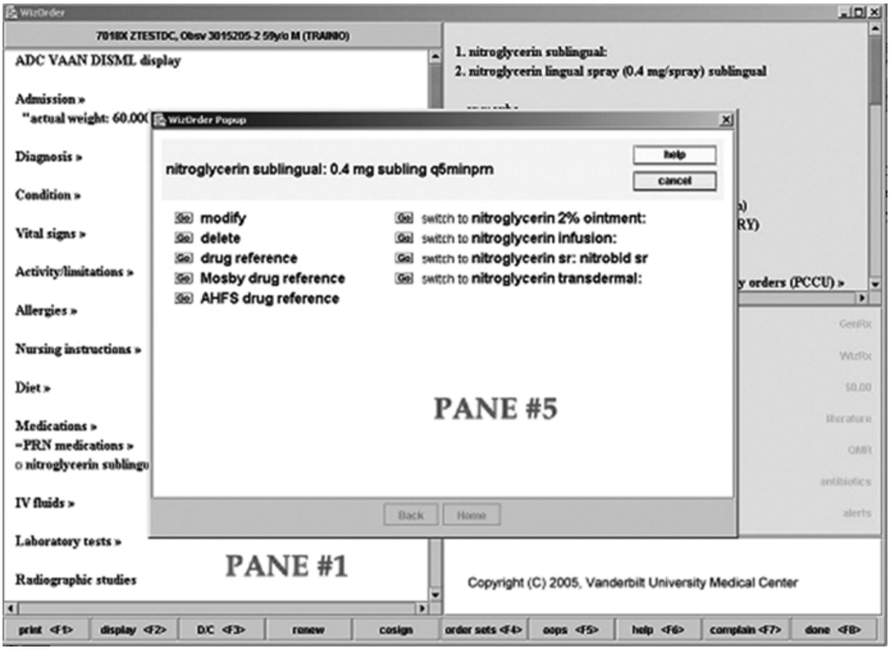

Fig. 15.5 "Pop-up" options (PANE #5) after selecting nitroglycerin order from PANE #1

15.1.3 Modifying and Finalizing Orders

Figure 15.5 illustrates the result of a mouse click on an order in the left WizOrder pane. WizOrder displays a series of options listing what the user can do to the order at that point (modify, discontinue, renew, etc.) When the WizOrder user completes generating or modifying orders during a session, clicking a designated button on the CPOE screen transfers the user to a final accept screen (see Fig. 15.6). This screen gives users a last chance to verify (or to change) their orders from the current ordering session. Once final-accepted, the orders are sent to the appropriate ancillary systems for action and committed to a relational database for archiving. Similar features are available in most CPOE systems.

15.1.4 Displaying Information and Providing Complex Decision Support

A final WizOrder component consists of an intermittently displayed, popup window that contains an internal HTML browser (labeled "PANE #5" in various figures). The WizOrder program uses this capability to display static Web documents with educational content or dynamically generated CPOE-related pages that provide complex, patient-specific decision support capabilities [49, 50].

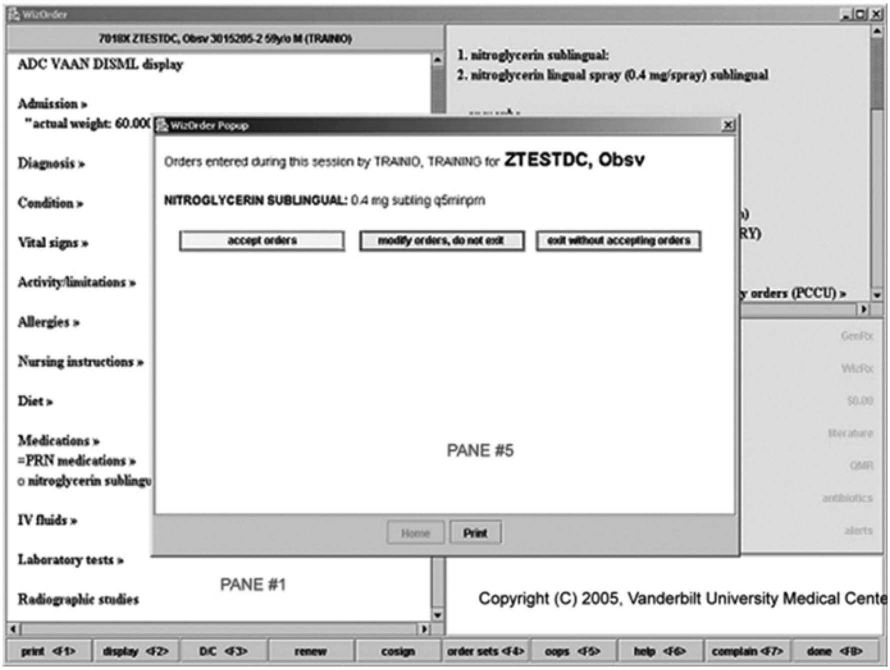

Fig. 15.6 Final accept screen (PANE #5) allows user to verify orders at end of ordering session

15.2 Philosophy Underlying Decision Support During Care Provider Order Entry

Use of a CPOE system during patient care provides a unique opportunity to interject decision support features that improve clinical workflows, provide focused relevant educational materials, and influence how healthcare providers make decisions about patient care. It is somewhat of an art to be able to provide clinical decision support that is well accepted and used widely. Key considerations in the approach to providing decision support include: what content to provide; when to intervene in the clinical workflow process; and how to intervene, in terms of both degree of disruption of workflows and mechanism of interruption. A major goal of decision support is to guide healthcare providers' decision-making as it takes place, rather than to identify errors after the fact. These considerations are addressed later in this chapter.

The nature of each clinical specialty determines what specific types of decision-support content to provide. In addition, the timing of each decision support intervention in a user's workflow is critical. For example, a decision support system should not allow a clinician to spend 1–2 min constructing an intricate medication order, only to then inform the clinician that the medication is contraindicated due to a known allergy. Allergy warnings should occur at the time the clinician first indicates the name of a new medication order. Conversely, delivering an interruptive warning to order a partial thromboplastin time (PTT) monitoring test, immediately as the clinician completes an order for unfractionated heparin, would likely cause frustration and a lost sense of autonomy – especially when that is what the clinician intended to order next. Rather, during an order entry session in which the clinician ordered intravenous unfractionated heparin, the system should check whether PTT monitoring was ordered at the end of an order entry session, after the user has indicated that all intended orders have been issued. Oppenheim et al. observed that permitting the physician to enter an order with feedback provided only at the conclusion of order construction, and then only if the order is possibly incorrect, serves dual purposes [61]. First, delayed warnings make clinicians first commit to a preferred course of action, thus discouraging reliance on CPOE systems to make clinical decisions for the users. Second, delayed warnings give the clinician user the opportunity to correct problems they detect spontaneously, whereas early warnings may impart negative reinforcement by underscoring clinicians' errors [61].

In the authors' experience, busy clinical users value CPOE system accuracy, responsiveness and intuitiveness. A key aspect of responsiveness involves creating orders at an appropriate clinical level (both for users' levels of training and for their knowledge of their patients). The physicians and nurses entering orders into a CPOE system typically have a different mindset than individuals who will carry out the orders in ancillary areas (e.g., pharmacy, radiology, and dietary departments). Problems in creating CPOE system orderable item names can occur when the technical terms used in ancillary departments are carried forward as the orderable items vocabulary for clinicians. So while radiology billing clerks might think in terms of "chest X-ray 2 views" and "knee X-ray 3 views", clinicians are more comfortable ordering "chest X-ray PA and lateral" and "knee X-ray AP, lateral and oblique." Similarly, if the CPOE system asks the physician ordering a chest X-ray how the patient should be transported to the radiology department, the physician is unlikely to give an optimal response because physicians are rarely involved in determining a patient's transport. Thus, CPOE systems should not ask clinicians to perform tasks that fall outside of their usual job responsibilities, or about which they have little knowledge. Structuring orderable items with the clinician in mind helps to overcome major barriers to adoption and can prevent errors.

Intelligent system interfaces can dramatically decrease the burden of ancillary departments in dealing with CPOE system-generated orders. For example, pharmacists use the pharmacy system to fill and dispense the clinical orders specified within the CPOE system. When a physician issues a high-level clinical order, such as gentamicin 70 mg IV, the pharmacist and pharmacy system convert the order into its dispensable form (e.g., one 80 mg ampule of injectable gentamicin) with administration instructions – e.g., draw 7/8 of ampule (70 mg) into syringe for administration. An intelligent decision support interface – provided within the CPOE or pharmacy system – can evaluate both the pharmacy's electronic formulary and the database detailing the floor stock inventory on the patient's unit, and then automatically determine the correct dispensable within the pharmacy system (done at the time of order transmission to the pharmacy, with no need for physician review). Currently, the intelligent pharmacy interface within WizOrder guesses the correct pharmacy-level dispensable item over 90 % of the time. This allows the pharmacist to devote more time to evaluating each order's clinical validity, safety, and efficacy.

An institution's CPOE system determines the workflows that will capture providers' intentions as they generate key clinical instructions. As a result, CPOE may become a target for administrators and researchers wishing to capture additional information from providers at the point of care. System administrators must avoid overburdening clinicians with requests that interrupt their workflows. In situations that require capturing extra information, the system should only ask clinicians for information about which they are the definitive source. For example, at Vanderbilt, upon patient admission, the name of the attending physician of record was originally entered into the admission, discharge, transfer (ADT) system by an admitting clerk. However, the admitting clerks were not always informed of the specifics of physician group coverage schedules, and often did not know the correct name to enter. The problem was addressed by finding a more definitive data source – the admitting house staff team, who must discuss each admission with the attending physician. Having the house staff enter the attending name into the CPOE system improved accuracy. Conversely, if one wants to record whether a patient received aspirin in the emergency department just prior to admission, asking an intern who is entering discharge orders for the patient several days later (and who did not admit the patient) could be viewed as a nuisance, and cause lower-than-optimal data quality.

While some decision support functions not directly related to order entry can be delivered during an order entry session, they will not be discussed in this chapter: for example, a laboratory system that generates alerts whenever abnormal patient results occur might notify clinicians responsible for the patient's care either by paging them or via e-mail or an asynchronous pop-up alarm that occurs when the clinician is currently logged into the CPOE application [62]. Such alerts originate outside of the CPOE session context. Many CPOE systems, including WizOrder, display permanent taskbars, comprising an array of useful links, continuously during the order entry session; [45, 59, 63–65] however, such taskbars rarely provide context-specific decision support of the sort described here. Instead, they allow the user to access common CPOE functions. For instance, the mid-1990s to early 2000s BICS (Brigham Integrated Computer System, in Boston) toolbar allowed the clinician to quickly view orders and search for patients, among other functions [64, 66].

15.3 Roles for Decision Support Within Care Provider Order Entry: Categories of Interventions

15.3.1 Creating Legible, Complete, Correct, Rapidly Actionable Orders

A CPOE system can avert problems previously associated with handwritten order creation [67], for example, illegibility, incompleteness, and incorrectness. Improved legibility not only reduces errors, but also saves staff time because nurses, pharmacists, and medical technicians need not spend time and energy as they decipher the meaning of ambiguous handwritten orders and they no longer make phone calls to clarify what was meant. Complete orders contain all the necessary parameters to make an order actionable (order name, start date and time, duration, frequency, etc.). Correct orders have parameter values that meet requirements for safe, prudent patient care (e.g., drug doses are appropriate for the patient's age, weight, and renal function). Most CPOE system interfaces ensure completeness and promote correctness of orders [67–69].

15.3.2 Providing Patient-Specific Clinical Decision Support

An important CPOE system capability is generation of decision support recommendations customized to individual patients' specific conditions. A CPOE system can provide a safety net through behind-the-scenes reconciliation of patient-specific information (laboratory results, age, allergies, current medications [70]) with stored best practice rules. For example, most CPOE systems screen patient orders against safe dosing rules and drug interaction references to reduce medication prescribing errors [53, 66, 71–74]. A CPOE system can also facilitate clinical care improvement by promoting use of evidence-based clinical practice guidelines [58, 75, 76] through end-user order generation via diagnosis or procedure-specific order sets [56, 59, 65, 70, 76] or via computer-based advisors [58, 64, 73, 77, 78], as detailed below.

15.3.3 Optimizing Clinical Care (Improved Workflow, More Cost-Effective and Regulatory-Compliant)

End-users of complex software systems learn to combine sequences of steps into a higher-level "programming language" to make the system do things that system developers neither foresaw nor intended. Clinicians regularly using a CPOE system begin to make suggestions about how to modify it to make their work easier and more effective. For example, early CPOE users at Vanderbilt requested printed rounding reports to facilitate patient care during work rounds and attending (teaching) rounds. The rounding reports concisely summarize, on the front and back of an 8.5×11 in. piece of paper, both the patient's active orders and all laboratory results reported in the prior 72 h with highlight markers next to significant (e.g., abnormal) results. In another instance, to improve workflows, several surgical services at Vanderbilt encouraged WizOrder developers to create "registry" orders. Such orders placed patients into a local, CPOE-associated registry database that allowed clinicians to track diagnoses and procedures performed on registry patients (e.g., patients on the neurosurgery service). At the same time, registries enabled efficient transfer of appropriate information to the registry's specialty-related billing office, relieving physicians of that responsibility.

After several years of CPOE implementation, the institution's administration began to view the system as a tool to implement quality of care, cost containment, and compliance initiatives [52–54]. Institution-wide CPOE interventions, if implemented with the minimal degree of disruption required (see details below), can: discourage the ordering of inappropriate, recurring tests; [20, 52, 79] advise against costly tests or require further justification before allowing them to proceed; [22, 55, 80] display formulary information; [55, 57] and help the ordering clinician to enter requisite third party payer compliance codes (e.g., ICD-10 or CPT) for diagnostic tests. Clinicians are not always familiar with compliance rules, and they tend to write reasons for tests based on suspected diagnoses (e.g., "rule out MI" for an electrocardiogram, or "possible pneumonia" for a chest X-ray) rather than indications for testing approved by third party payers. Orders that require specific reasons for compliance can be made to trigger the WizOrder internal Web browser to display and capture order-specific compliance-related reasons for testing. This can increase the rate of third party payer reimbursements for those tests due to more accurate, complete capture of compliant reasons.

Clinical decision support features within CPOE systems can also promote implementation and enforcement of local hospital policies. The Regenstrief Medical Record System (RMRS), successfully used computer reminders circa 1997 to increase discussion about, and completion of, advanced directives (end-of-life, "do not resuscitate" related orders) [81]. Previous studies had indicated that too few patients completed advance directives [82]. In Boston in the mid-1990s, the BICS was modified in order to prevent the appearance of vancomycin-resistant microorganisms by requiring clinicians ordering vancomycin to enter a reason for using the antibiotic [83].

The challenge for CPOE system developers is to honor the care improvement goals while keeping the system responsive and intuitive. Developers must strike a proper balance between clinical improvements versus cost containment. At times, both goals may be achieved in a single intervention – judiciously ordering fewer tests does not mandate a lower quality of care [52]. However, care improvement interventions may themselves have unintended consequences that require continuous monitoring and feedback for optimal results [54].

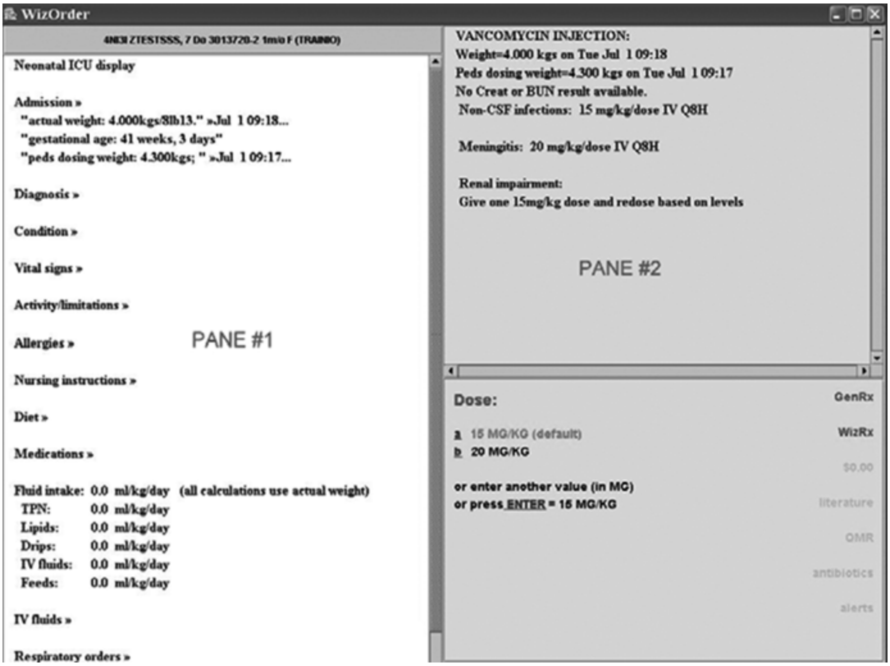

Fig. 15.7 In-line recommendations for dosing vancomycin in NICU include: (**a**) PANE #2, suggested doses for regular use, for meningitis, and for renal impairment; (**b**) PANE #1, passive display of weight, dosing weight, and gestational age; and (**c**) PANE #2, display of renal function test results (not available for training patient in this example)

15.3.4 Providing Just-in-Time, Focused Education Relevant to Patient Care

Many CPOE systems provide relevant prompts for educational materials targeting system users. Often, the materials are fairly terse, with hyperlinks to more detailed educational information resources [55]. Educational prompts can be introduced as in-line summaries that appear while prescribing a medication. Figure 15.7 shows in the upper right WizOrder panel in-line suggestions for vancomycin dosing adjustments in neonates with meningitis or with renal impairment. An embedded CPOE Web browser content can also provide effective educational information, for example, presenting a summary of disease-specific national guidelines, links to educational monographs, or a summary of indications and contra-indications for a specific therapy. Educational links can assist clinician users to perform complex ordering, such as for total parenteral nutrition (TPN) in a neonatal intensive care unit. The design of a CPOE system user interface can significantly influence the rate at which users follow educational links and read the related materials. Simply having an option for decision support may not be sufficient to command users' attention, and stronger cues, such as different visual displays as to the relevance of the information, may be needed [55].

15.4 Critical Points at Which to Implement Decision Support Within Care Provider Order Entry

Each stage of use of a CPOE system permits a focused repertoire of decision support interventions, both in terms of user community affected, patients affected, and appropriateness of the intervention for the task the end user intends to perform. For example, as the CPOE system is launched from a clinical workstation desktop, system-wide messages may appear, but patient-specific advice should not (since, typically, the user has not yet selected a patient). Below, authors discuss the type of decision support that is appropriate and feasible for each stage of order entry.

15.4.1 Stage of Care Provider Order Entry Session Initiation

Upon launching a typical CPOE application, the system will know the identity of the clinician user, but not of the patient. As a result, patient-specific decision support is inappropriate here. Rather, at this stage, the system can advise users about new CPOE system features, e.g., on a once-only basis for this user. Such interventions should appear sparingly. One-time announcements of general interest to all users might appear, e.g., describing a new method to enter a specific group of commonly used orders. Once the alert is displayed, the system removes the current user from the list of users who still must see that message. At launch, the CPOE system can also inform users of information related to their personal use of the system, such as the number of old orders (and number of patients) requiring their countersignature, and provide a link to facilitate completing the task.

15.4.2 Stage of Selecting Care Provider Order Entry Patient from Hospital Ward Census

After CPOE system launch, users typically select an individual patient for order entry. A number of alerts can occur at the stage of displaying the census of available patients for CPOE. Similar to the 1990s BICS system in Boston (and other CPOE systems), WizOrder provided, via the patient census screen, an inpatient, unit-wide view of the status of recently issued orders (see Fig. 15.8). A map view of the given hospital ward shows all beds and uses color coding to indicate which beds have new unacknowledged, urgent (i.e, STAT) orders and which beds have unacknowledged routine orders. A care provider wishing to enter new orders (or acknowledge recent orders) can click on a bed on the display screen to initiate an order entry session for that particular patient.

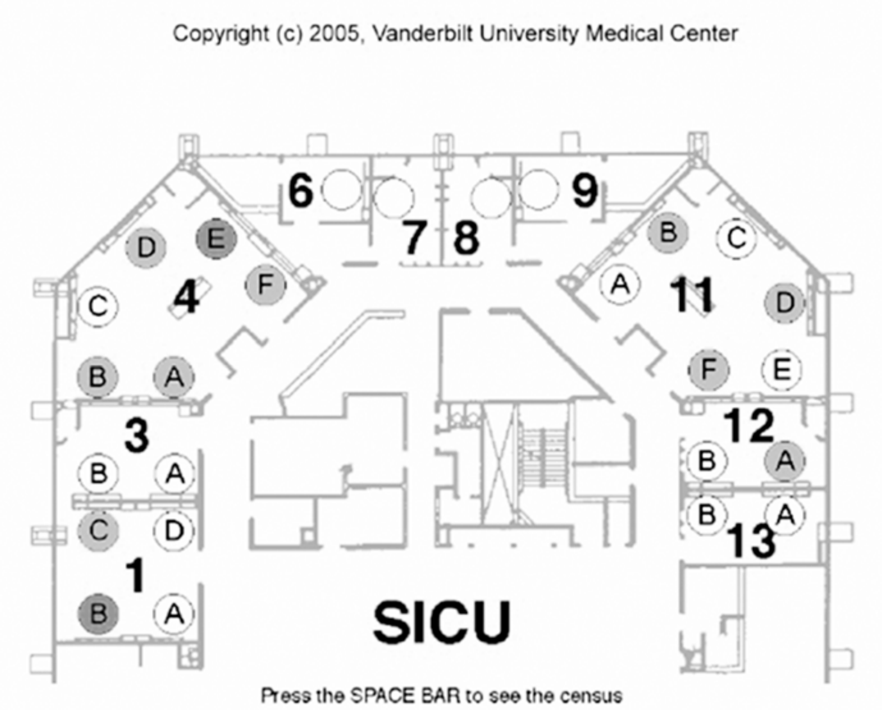

Fig. 15.8 CPOE "map" view of hospital ward. *Map* indicates beds (*circles*) with different shading to indicate new, urgent "stat" orders or those with new "routine" orders; *right border shading* indicates highest priority of new orders not yet acknowledged (across all beds) by nursing staff

An alternative to the map view of a hospital unit census is a list view that includes patients on the unit, and that can be sorted by patient name or by ascending bed number. In WizOrder, icons located beside patients' names in the list view provide useful information (Fig. 15.9). Using a similar list census screen, the 1990s BICS system presented a renewal reminder next to the patient's name when a medication order for a given patient nears expiration [84].

15.4.3 Stage of Individual Patient Session Initiation

Once the user has selected an individual patient and the order entry session focuses on that patient, several additional types of decision-support related events become feasible. In WizOrder, once the patient is identified, the system retrieves all relevant past (active and inactive) orders for the patient, and previously stored patient-specific information such as weight, height, coded allergies, and active protocols (with dates of each protocol initiation). As the user waits for the initial patient-specific CPOE screen to appear, WizOrder queries the patient data repository. The

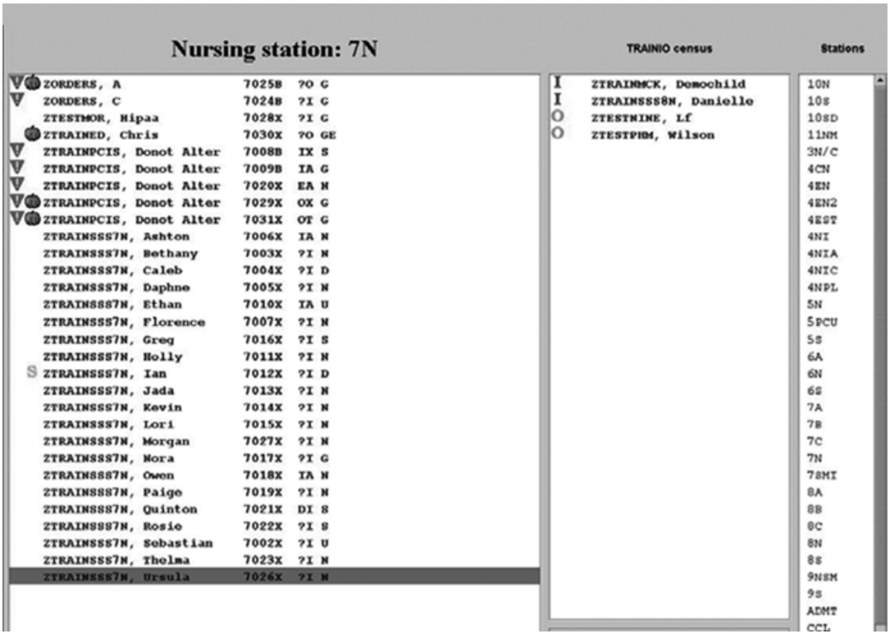

Fig. 15.9 "Patient list" view of CPOE ward census. Several graphical "icon" alerts (*left* margin next to patient name) provide useful information regarding ward census at a glance. The *inverted triangles* provide duplicate last name warnings; "S" indicates patients for whom medical students have entered orders that must be reviewed by a licensed medical doctor to become "activated;" and pumpkins indicate patients who have been bedded as outpatients long enough that conversion to inpatient status (or discharge to home) should be considered

system, to prepare to assist with subsequent CPOE decision support requirements, uses this "delay" to obtain the patient's recent laboratory results for common important tests.

Ability to recover from an interrupted CPOE session without loss of work (time and effort) is critical to busy clinicians' acceptance of such systems. Lost sessions can occur due to system bugs (such as the users' workstation crashing), environmental factors (such as network outages or power failures), and user factors (such as abandoning a workstation during a medical emergency, with a subsequent session timeout). Figure 15.10 shows the alert that occurs upon initiation of a patient-specific CPOE session for a patient with a previously interrupted session. The user is then given the option to play back and recover the orders from the previously interrupted session.

Among the many other types of alerts that can occur at the stage of initiating a patient-specific CPOE session are: presentation of a summary of past alerts and warnings related to the patient's orders – e.g., allergies and drug interactions; notification of medications about to expire; display of the names of active protocols for the patient (e.g., "Deep Venous Thrombosis prophylaxis protocol"); and promotion, via reminders, of new protocols for which the patient is eligible. Figure 15.11

Fig. 15.10 Interrupted/incomplete previous WizOrder CPOE session warning. Allows user to recover from previously interrupted ordering session

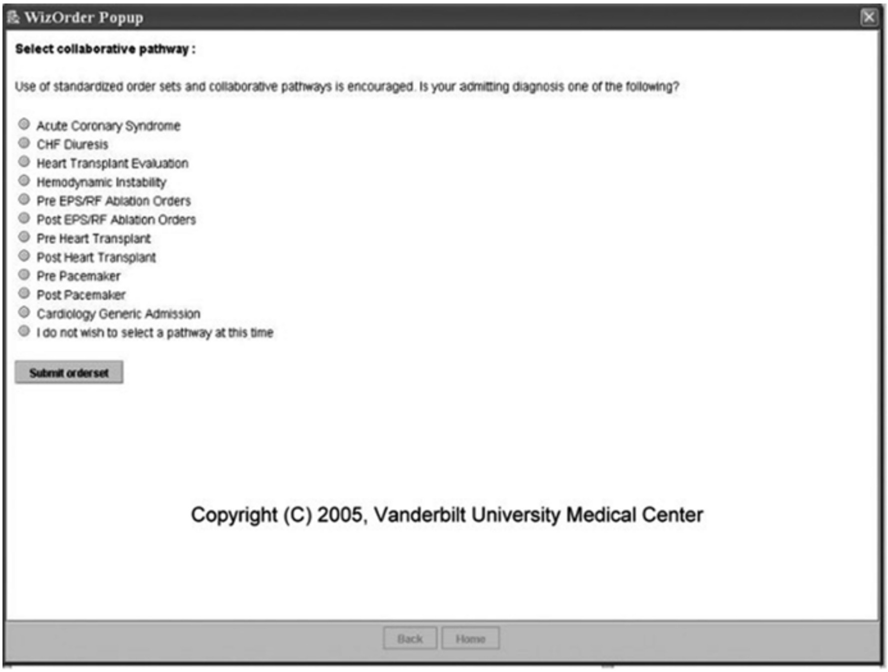

Fig. 15.11 Admission Wizard prompts user to select evidence-based protocol for patient when relevant to case

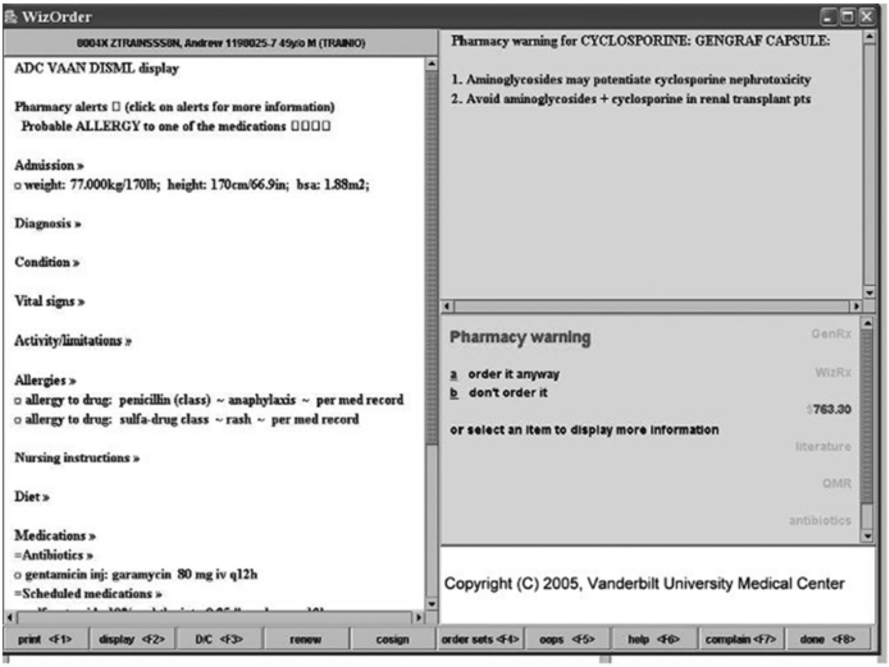

Fig. 15.12 Drug-drug interaction warning after entry of new medication name

illustrates an admission wizard that indicates to the user, for the ward on which the patient is bedded (e.g., Cardiology), the commonly used, evidence-based best-of-care order sets that are available within the system (e.g., acute coronary syndrome), and it encourages the user to select one for use on the patient, if applicable. The structure of such an order set, once selected, is shown in Fig. 15.4 in the upper right window (acute coronary syndrome, PANE #2).

15.4.4 Stage of Individual (Single) Order Selection

Upon selecting a specific CPOE orderable item, and before the user specifies the exact details of the order, certain types of decision support checks become appropriate. For example, at the time the user indicates the next order is a drug, CPOE-based allergy and drug-drug interaction checking should display any relevant warnings. These alerts should appear before the user can specify any details of the drug order (dose, route, frequency, etc) – to avoid wasting the user's time. Figure 15.12 illustrates the latter category of WizOrder warnings, after entry of a new medication name.

Individual order selection can also trigger protocol-based interventions such as recommending drug substitutions (suggesting a less expensive or more effective medication than the one originally selected). Similarly, single order selection can initiate computer-based advisors related to the specific order (Fig. 15.13a, b). An analogous mechanism to redirect physician workflow existed circa 2000 in the BloodLink-Guideline system in the Netherlands [58]. Many CPOE systems offer the capability to link order sets to individual selectable orders (i.e., to transfer the user to an order set when an individual order is selected) [56, 59, 65, 70, 76]. Order sets are described in detail below.

15.4.5 Stage of Individual (Single) Order Construction

Once the user selects an order name, the CPOE system assists the user in completing required steps for order construction (see Fig. 15.14 for an example of instructions during cyclosporine ordering). WizOrder guides medication order construction by highlighting recommended drug doses and common drug administration frequencies; it also presents alerts for potentially incorrect decisions. This is similar to what is described in the literature for the BICS system implemented in Boston circa 2000 [66, 73]. Many CPOE systems also provide computer-based advisors to enforce compliance with established, evidence-based guidelines [58, 77]. As described in Chap. 14, the antibiotic assistant system at LDS Hospital in Salt Lake City recommends therapy options for critically ill patients based on patient vital signs and serology, microbiology, pathology, and radiology results [77].

Based on their research, Bates et al. observed that clinicians generally take the path of least resistance when multiple options are available during decision-making [73, 85, 86]. Providing effective decision support involves not only alerting the provider about a potential error, but providing a correct alternative option as well. For instance, in the BICS system, if meperidine hydrochloride is prescribed for a patient whose creatinine clearance (a measure of renal function), is significantly impaired, an alert notifies the user that the drug might possibly promote seizures in this patient, and suggests a substitute medication rather than stop the user outright. [84] Similar approaches have been used to guide geriatric medication dosing and substitutions.

15.4.6 Stage of Individual Order Completion

Once an individual order's components have been fully specified (and any allergy or other alerts that might have prevented order construction have been dealt with), a number of decision-support functions related to the order as a whole become appropriate. Upon completed order construction, many CPOE systems suggest corollary orders – follow-up tasks clinically indicated after certain orders [73, 84, 87, 88]. For

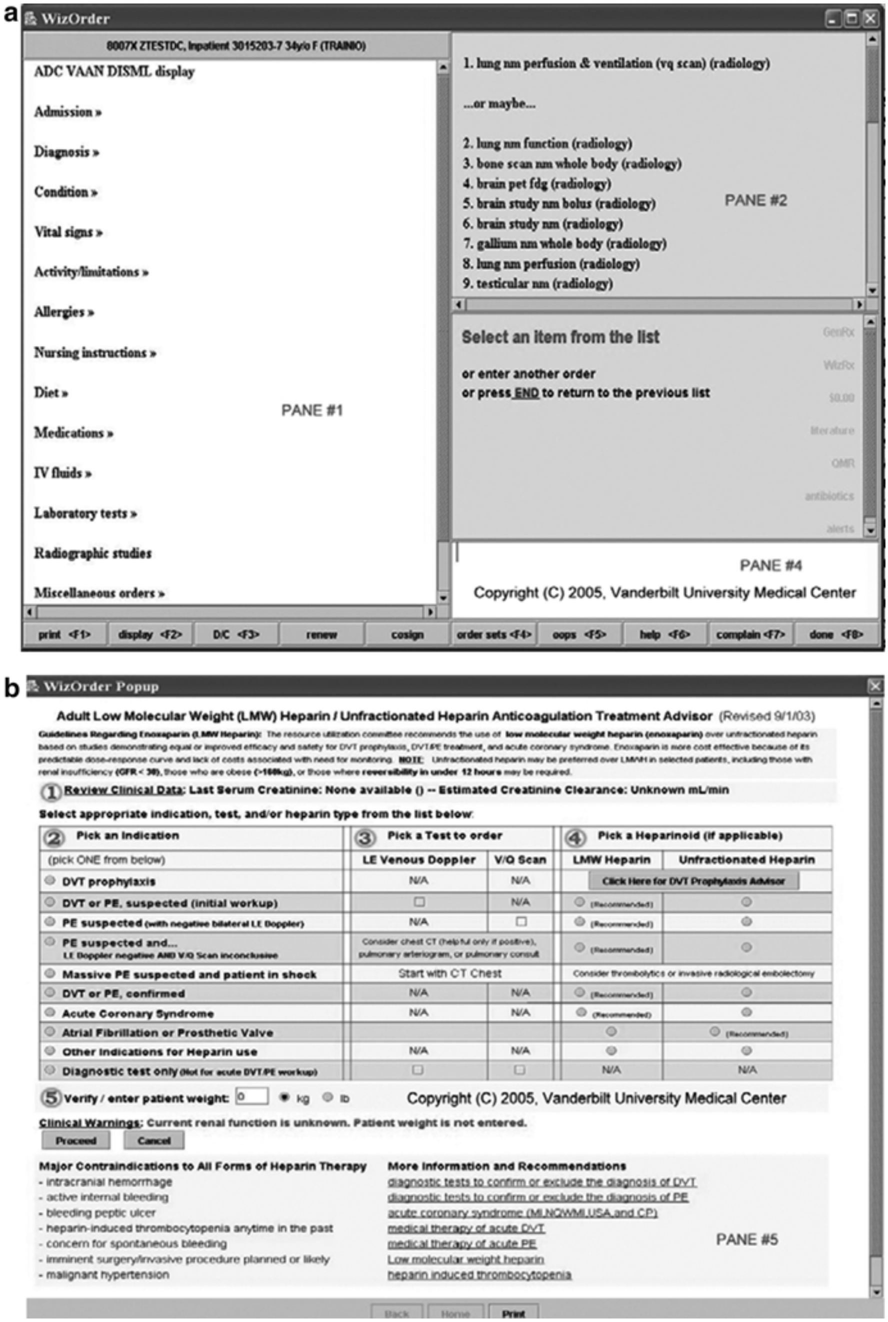

Fig. 15.13 (**a**) Clinician-user initially attempted to order "VQ scan" of lung for pulmonary embolism, and WizOrder completer maps to official name of test (item 1 in PANE #2), which user then selects by typing choice in PANE #4. (**b**) Selecting lung scan order from A launches anticoagulation adviser in WizOrder, helps clinician select appropriate diagnostic workup, and therapy for suspected or confirmed deep venous thrombosis (DVT) or pulmonary embolism (as well as DVT prophylaxis and therapy for other disorders such as acute coronary syndrome)

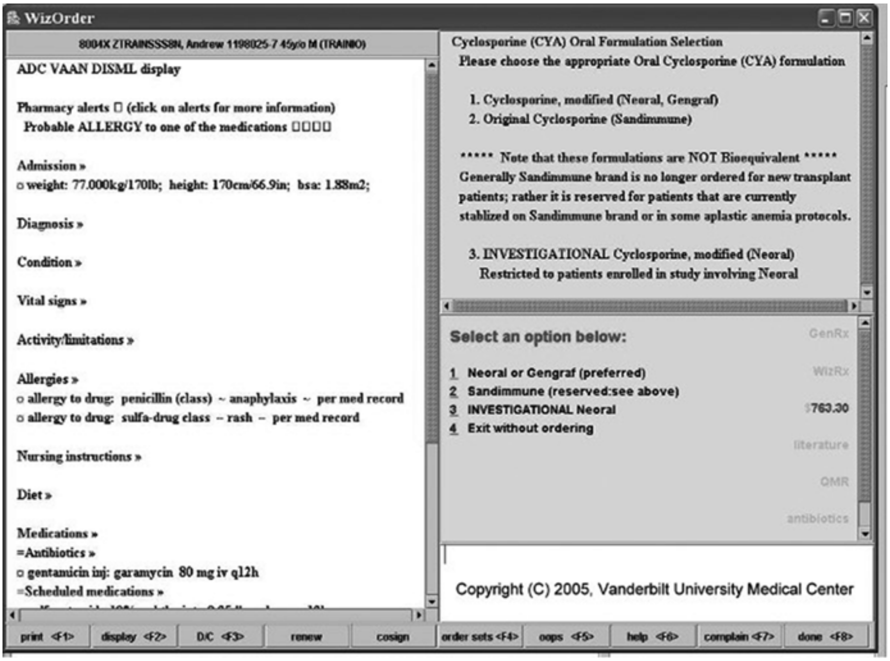

Fig. 15.14 "In-line", patient-specific, interactive advice for clinician while attempting to prescribe cyclosporine for patient; developed by experts in the pharmacy to guide clinician to best choice

example, after ordering gentamicin, an antibiotic, it is often appropriate to order serum drug levels. Figure 15.15 illustrates this capability in WizOrder. In the 1990s the RMRS system similarly presented corollary orders for many drug-drug monitoring test pairs (e.g., warfarin prescriptions and related INR/prothrombin time tests) and for drug-drug side effect pairs (e.g., prescription of class II narcotics and orders for stool softeners to treat/prevent the constipation caused by narcotics) [87]. Another example is offering clinicians the opportunity to order heparin (to prevent DVT) after a completed order for bed rest (which predisposes to DVT); however, this may be more appropriate at the stage of ordering session completion [84]. Research has shown more effective ordering and improved outcomes as a result of such systems [89].

15.4.7 Stage of Ordering Session Completion

Once the user has specified all individual new (or modified) orders and wishes to finalize the ordering session, various decision-support related exit checks are appropriate. As noted above, recurring reminders to do what the clinician user already

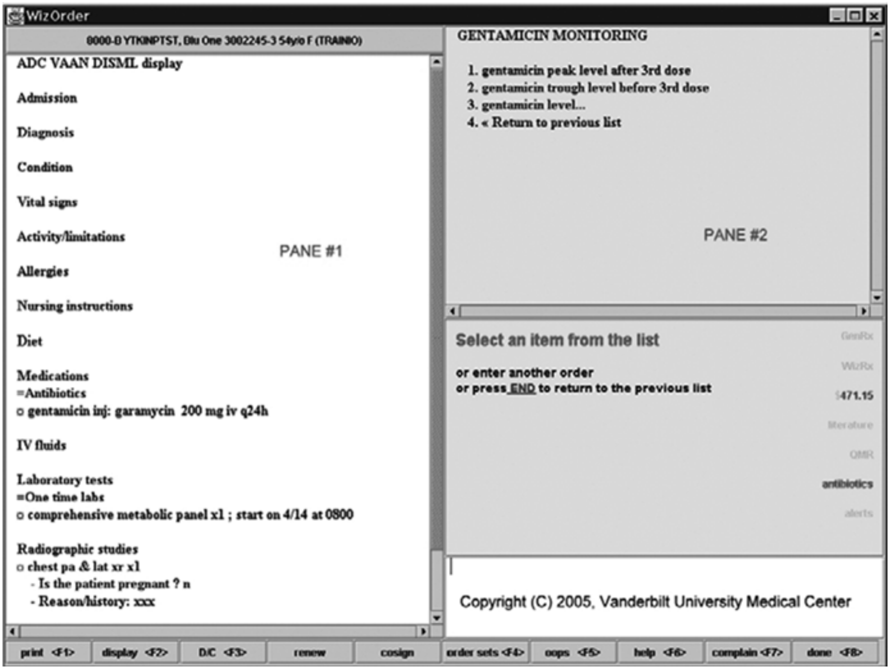

Fig. 15.15 After completing gentamicin order (seen in PANE #1), system offers selectable gentamicin monitoring orders (in PANE #2) as "one click away" for convenience (suggesting best practice, but not requiring it)

intended to do are not well tolerated. Instead of using automatically generated ("corollary") orders to prompt PTT and INR monitoring after orders for heparin and warfarin, respectively, WizOrder waits until the user indicates that the ordering session is complete. At that point, it becomes fair game to issue warnings if appropriate monitoring tests have not been issued. Also at that point, if a recent monitoring test indicates that the prescribed anticoagulant dose is suboptimal or excessive with respect to national guidelines, the system can issue an alert. Conversely, if during a given ordering session, a clinician discontinues either the heparin infusion or the PTT monitoring tests but not the other item of the pair, it is appropriate to use an ordering session exit check that warns the clinician that parallel actions to discontinue both are usually needed. Figures 15.16 and 15.17 illustrate the two-part WizOrder exit check for ordering or updating the Richmond Agitation and Sedation Scale (RASS) target score whenever pain medications or sedatives are ordered for a patient in an ICU.

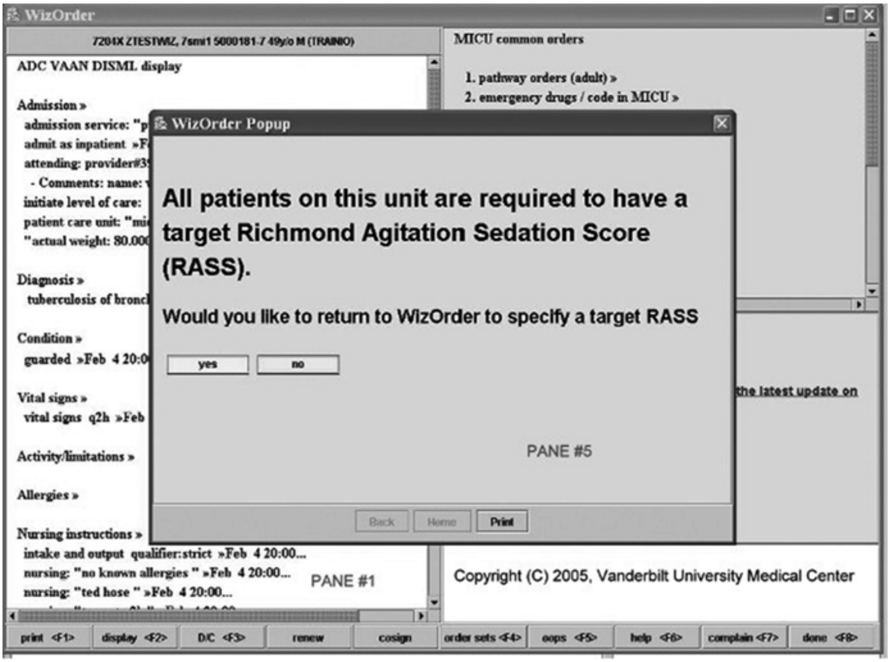

Fig. 15.16 WizOrder "exit check." On completing admission orders on an ICU patient, if the clinician-user has not specified a target RASS (Richmond Agitation Sedation Scale) score, the system uses a pop-up alert to remind the clinician that it is ICU policy to do so

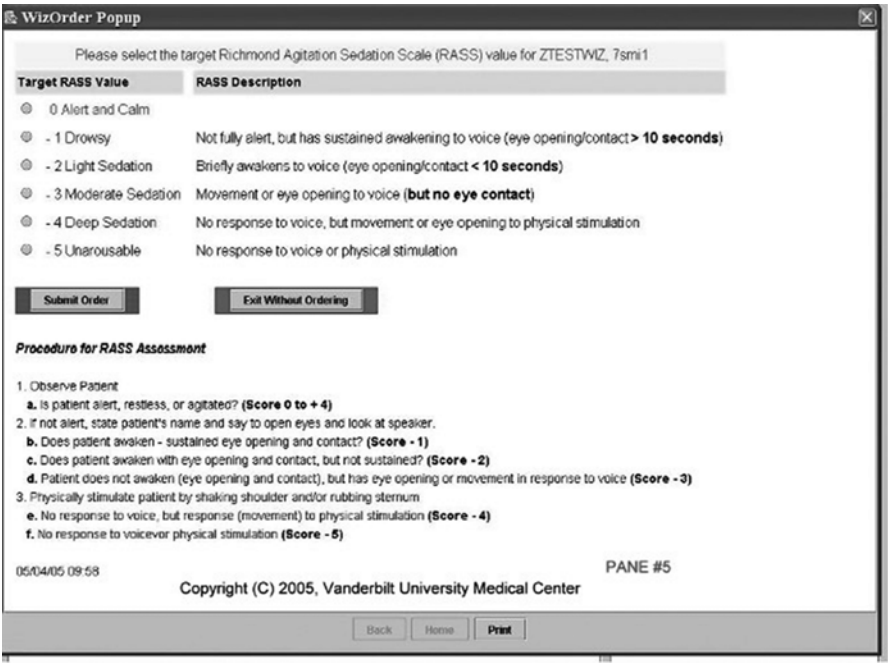

Fig. 15.17 User (from Fig. 15.16) requests assistance in specifying RASS score; web-based advisor assists user with data collection and score calculation

15.5 Care Provider Order Entry Intervention Approaches: From Subtle to Intrusive

While the interfaces of successful CPOE systems are rarely seamless, users adapt to their styles of workflow after training and repeated use. Once acclimated to the CPOE system workflows, users do not appreciate interruptions that deter them from the previously noted path of least resistance [86]. Determining whether, how, and when to disrupt clinician workflows to provide appropriate decision support is critical to end-user acceptance of both the decision support and the CPOE system overall. Below, we describe a number of approaches to introducing decision support, from non-disruptive to very disruptive, and give examples of where each may appropriate. The sections below describe how and when to interrupt workflows.

15.5.1 Incidental Display of Relevant Information

Presentation of additional viewable text on a portion of the usual application screen allows the user direct access to relevant information with minimal interruption to workflow. Because no user input (e.g., acknowledgment of the information) is required, and no additional information is available (e.g., the user cannot click on or select the displayed information to learn more), the clinician is free to read or to ignore the displayed information. WizOrder displays the most recent results of serum electrolyte tests during ordering of intravenous fluid therapy. WizOrder also displays relevant dosing information for prescribing medications, for example, on pediatric units, the patient's actual weight, dosing weight, and pharmacy-recommended dosing guidelines (see Fig. 15.7). When relevant, the system may also display information related to the patient's renal function, or to the medication costs.

15.5.2 Incidental Display of Linked Educational Opportunities

A CPOE system may have order-related educational information that is too voluminous to include in the usual order entry screen. Under such circumstances, the CPOE system can present links for users to select (click on). These lead to a separate screen/window providing the relevant textual information. Examples include links to relevant drug guidelines and formulary information [59]. The Vanderbilt Patient Care Provider Order Entry with Integrated Tactical Support study, [55] provided links to pharmacotherapy-related information (illustrated by the "GenRx" and "WizRx" links on the right margin of PANE #3, Fig. 15.2), and reference material for diagnosis in internal medicine. Figure 15.18 provides an example, in PANE #5, of displaying an evidence-based summary of what is known about a specific

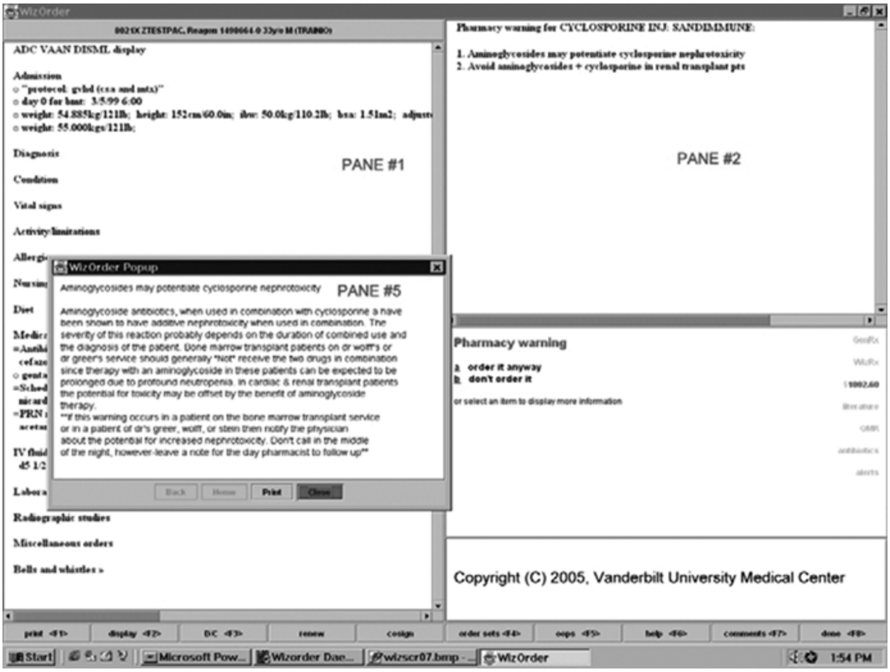

Fig. 15.18 Clinician prescribed cyclosporine while a currently active order for gentamicin was in place. Following a drug interaction alert (PANE #2), user clicks on item 1 to request evidence basis for what is known about the drug interaction (displayed in pop-up window, PANE #5)

drug interaction (selected by the user from the drug interaction warnings list of Fig. 15.18, PANE #2). In other systems, as clinicians review recommended drug doses for patients with renal impairment, they can display the data used to calculate creatinine clearance using a keyboard shortcut link [64].

15.5.3 Interactive Sequential Advice for User-Directed Clinical Activity

By presenting stepwise instructions in context, CPOE systems help users to carry out discrete tasks. Figure 15.2 presents the default minimum type of advice that WizOrder provides for order construction; Fig. 15.14 provides a more complex example whereby the user is sequentially prompted, through questions and answers, to order the most appropriate form of cyclosporine for the patient. Another system, the circa 2000 BloodLink Guideline system [58] directed blood test ordering decisions by first having the clinician select the appropriate guideline, then presenting a menu of related indications, and, finally, presenting a menu of relevant tests for a selected indication.

15.5.4 Recallable Best Practice Guidelines with Actionable Pre-formed Pick List Selections

Order sets are pick lists containing constituent individual pre-specified full (or partially complete) orders, often representing standardized protocols. Figure 15.4 illustrates a portion of the WizOrder order set for acute coronary syndrome. Hierarchies of order sets enable easier end-user access, organized by clinical department, [40, 59] by organ system, or by clinical diagnosis, condition, or procedure [57, 76, 90]. While users may view picking orders from order sets as foreign to, or a diversion from, the usual manner of constructing individual orders, appropriate use of order sets can often increase users' time-efficiency and promote completeness and correctness of orders [58, 60, 91]. Order sets have become a commonly used mechanism for organizations to distribute "actionable" evidence-based medicine practice guidelines across healthcare systems.

15.5.5 Pop-Up Alerts That Interrupt Workflow and Require a Response for the User to Continue

Pop-up alerts can present clinically important information (in a separate user interface window) that must be acknowledged by the user before resuming previous CPOE activity. Use of such interventions is typically viewed by users as disruptive, and should be reserved for only the most severe clinical indications. So called "pop-up alert fatigue" can occur when too many alerts of this type disrupt clinical workflows [92]. In WizOrder and other systems, pop-up windows alert physicians when excessive chemotherapy doses are ordered [48, 93]. Figure 15.19 illustrates how WizOrder notifies the user that the most recent laboratory test ordered will be sent out to a reference laboratory for completion. It provides advice on how to optimize ordering with respect to institutional policies regarding reimbursement for testing. This mechanism is used to display hospital-approved drug substitution regimens. Figure 15.20 shows a WizOrder drug substitution pop-up (implemented as an advisor, see section 15.5.6 below). Figure 15.16 shows how the RASS exit check was implemented as a pop-up alert in WizOrder. Figure 15.12 illustrates how WizOrder uses the pop-up method to present a drug interaction alert.

15.5.6 Complex, Computer-Based Protocols That Interact with the User to Make Patient-Specific Calculations and Recommendations

The most complex form of decision support is an interactive advisor that integrates patient-specific information (laboratory results, active orders, weight, allergies, etc.) with complex guidelines or protocols, and presents calculated/derived

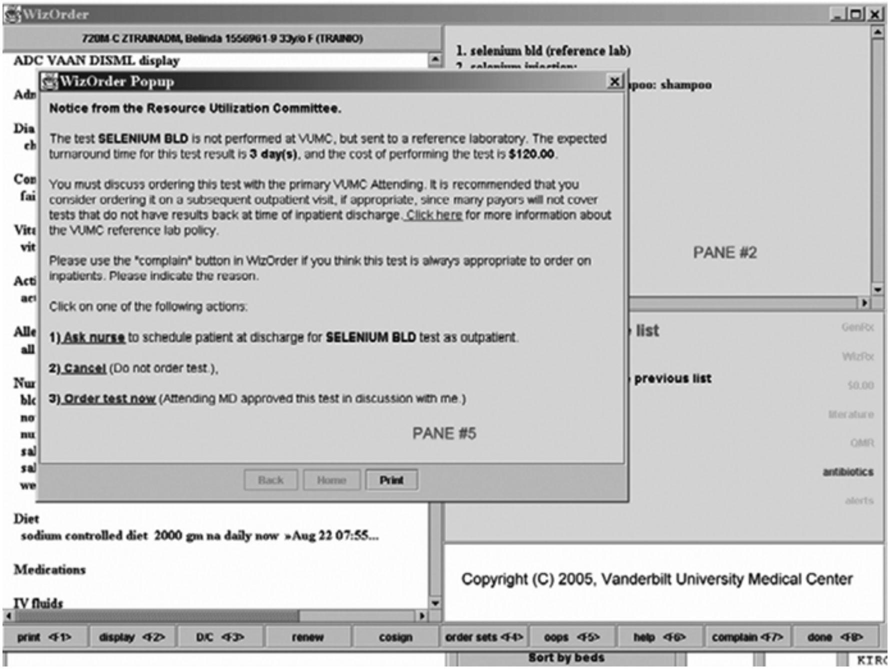

Fig. 15.19 Clinician user begins to order "selenium blood" level (PANE #2), prompting a pop-up warning (PANE #5) that stops workflow and demands attention. The pop-up explains that the test is sent to a reference laboratory and takes 3 days to perform. User is notified that reimbursement may be compromised if patient is discharged before result is known. Pop-up provides instructions for alternative ordering mechanisms (that can be selected directly from pop-up) if clinician believes that obtaining the result of the order is not urgent/emergent for the current patient

information to the user for decision making, typically involving a two-way dialogue between the application and the user. Complex advisors may combine educational advice, calculators for patient-specific dosing, and other functionality in one screen (Fig. 15.20). For example, the Antibiotic Assistant system at LDS Hospital in Salt Lake City is described in Chap. 14. The LDS Antibiotic Assistant analyzes patient data and laboratory results in order to determine likely pathogens, and then determines the optimal treatment for the patient, including factors such as patient allergies and local patterns of antimicrobial functions into its assessment. Using a different but analogous mechanism, WizOrder employs locally scripted Web browser pop-up windows to dynamically generate patient-specific advisory content [49, 50]. Figure 15.21 illustrates the WizOrder TPN ordering advisor for the neonatal intensive care unit (NICU).

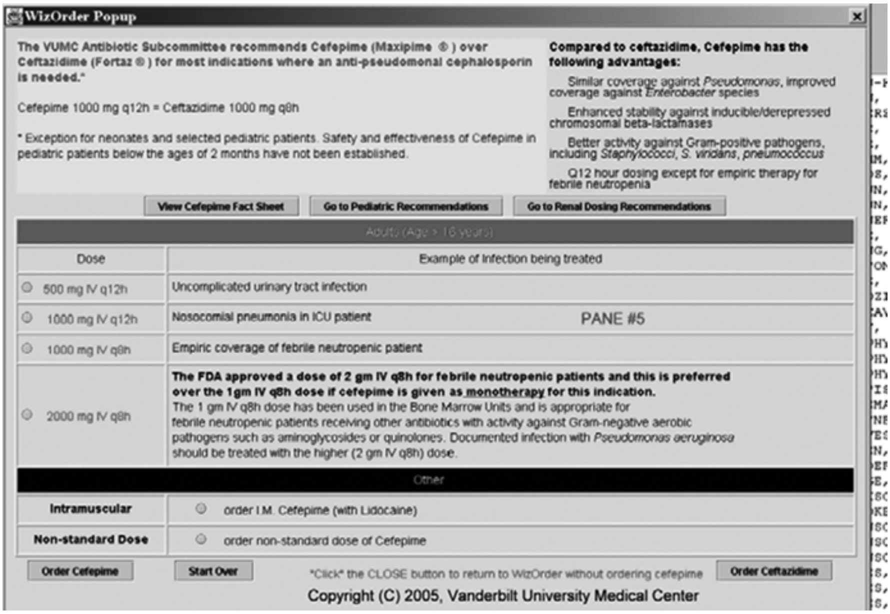

Fig. 15.20 User ordered an antibiotic for which the Pharmaceuticals and Therapeutics (P&T) Committee had recommended a substitution. A variant pop-up, this educational advisor guides the clinician through ordering an alternative antibiotic. Links to "package inserts" (via buttons) detail how to prescribe the recommended drug under various circumstances. A physician who knows little about the recommended drug could learn enough to prescribe it appropriately

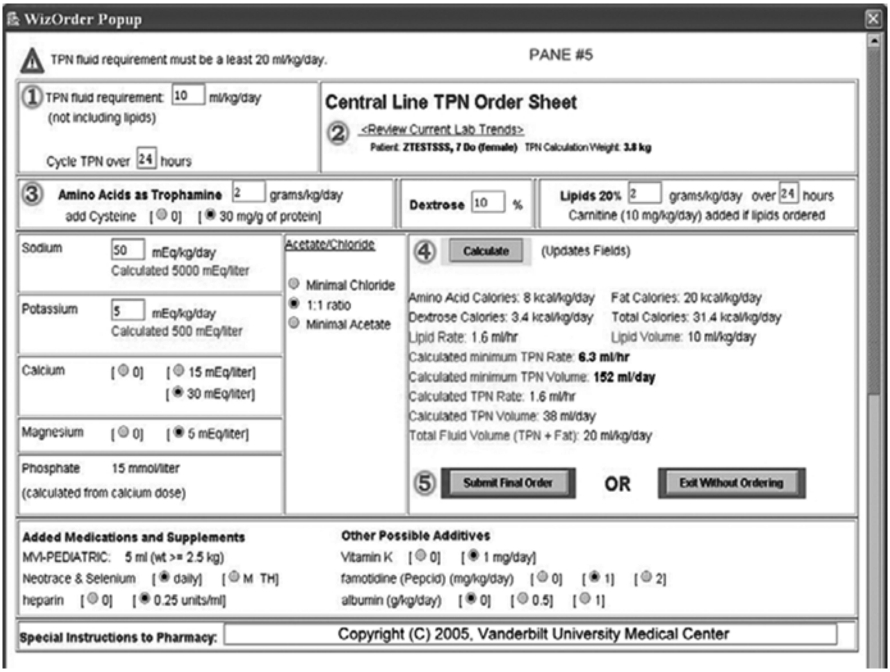

Fig. 15.21 NICU total parenteral nutrition (TPN) advisor provides complex interactive advice and performs various calculations

15.6 CPOE Systems Circa 2015

The foregoing summary discussing how one might approach embedding clinical decision support into a CPOE system remains relevant in 2015. What has changed in the past decade is the likely recipients of such advice. Two to three decades ago, over a dozen academic institutions were actively engaged in the development and/or maintenance of home-grown CPOE systems [94]. Due to several factors such as Meaningful Use system certification requirements, that number is less than a half-dozen in 2015 [95]. The relative demise of academic de novo CPOE and electronic medical record (EMR) system development has occurred in parallel with concurrent adoption of commercial vendor CPOE and EMR systems in both academic and non-academic settings. This suggests that the gap between more flexible, state-of-the-art home-grown academic CPOE and EMR systems and commercial systems may have narrowed substantially.

With respect to CPOE and EMR systems the long-term effects of diminished academic innovation is uncertain. Up to the recent past, many commercial system technologies were patterned after, or licensed from, pioneering academic systems [94]. In the near-term future, responsibility for innovation will increasingly fall to the vendor community. If so, it is unclear if vendors can develop as nimbly and flexibly as previous academic developers. Academic innovation took place in the setting of a single medical center populated by clinician end-users who were faculty colleagues of the developers. In academic settings, the end-user community was immediately available to provide unabashed, frank feedback regarding proposed system changes and their effects once implemented. Academic settings also enabled rapid deployment cycles (new releases of the "live" system every few days or every few weeks). Whether vendors can develop at a similar rate and in a similar manner is yet to be determined. A more deliberate development process is to some extent necessary, as vendors must safely support broad customer bases and maintain meaningful use certification. Additionally, many current high-ranking officers of current CPOE vendor companies learned their trade in academic settings before being recruited to the vendor community. Similarly, the abilities of academic clinical informatics units to teach their trainees how to develop and socio-technically implement innovative clinical systems may diminish. Optimal decision support development requires a deep understanding of clinical practice and of clinical workflows in myriads of care providing settings. Ready access to practicing clinicians who can quickly provide first-hand knowledge about how healthcare providers think and what information they require to make decisions may become less accessible to future developers. The relative decline of academic development may diminish the pipelines that have historically provided innovative technologies and accomplished leaders to the vendor community.

If a small number of future vendors provide the majority of systems to the academic community, benefits not possible with home-grown, one-of-a-kind academic systems may accrue. To the extent that vendors provide open systems, consortia of academic end-user informatics groups using the same vendor system (or the same open-source standards adopted by different systems) may be able to collaborate across institutions. They could develop sharable CPOE and EMR functionality, as well as data-sharing modules, which add capabilities to the base vendor systems. A current example of such activity is the i2b2 consortium work [96–98] pioneered by Kohane and colleagues at Boston Children's Hospital and the emerging SMART and FHIR interoperability standards [99]. Similarly, vendor systems that incorporate programmable external decision support modules may also enable collaborative decision support module development across academic sites. Whether such generic systems can tightly integrate physician-centric decision-making environments into the CPOE systems in the manner illustrated in the discussion and figures above is uncertain.

15.7 Conclusion

System developers, the technologists maintaining the system, and clinical experts must collaborate in managing clinical systems development and implementation. Integrating decision-support capabilities within clinical systems requires an understanding of the clinical significance of a proposed intervention, detailed knowledge of the intervention itself, and a good understanding of the workflows of the clinicians who will be affected by the intervention. The authors have described multiple mechanisms for delivering decision support within the context of CPOE systems using Vanderbilt's WizOrder system for illustration. There are three important axes to consider: the role of decision support, when to intervene, and the method of intervention. Framing decision support in this manner may help both developers and clinical end users to understand how to tailor the system whenever new decision-support needs arise. This framework may also be useful when evaluating and reviewing decision support within CPOE systems.

Offering decision support within a CPOE system provides both clinical end users and institutional administrators with the opportunity to substantially change the way that an institution carries out its work, and to improve patient care processes in terms of quality and safety.

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