Improving care of vulnerable elders through computerized clinical decision support
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Chapter 2

Modeling information flows in clinical decision-support systems: A first step towards understanding CDSS effectiveness

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Abstract

A fundamental challenge in the clinical decision support field is to determine what characteristics of systems make them effective in supporting particular types of clinical decisions. However, we lack such a theory of decision support, and a model to describe clinical decisions and the systems to support them. This article outlines a first step toward building such a framework. We present a two-stream model of information flow within decision support systems: reasoning about the patient (the clinical stream), and reasoning about the user (the cognitive-behavioral stream). We propose that CDSS “effectiveness” be measured not only in terms of impact on clinical care, but also by the system’s effect on work processes and whether it facilitates appropriate decisions by clinicians. Future research into which factors improve the effectiveness of decision support should not regard CDSS as a single entity, but should rather differentiate systems based on their attributes, users, and the decision being supported.

Problem

Friedman stated that one fundamental theorem of medical informatics is that a person working in partnership with an effective information resource is “better” than that same person working unassisted [42]. In the field of clinical decision-support systems (CDSS), this means a clinician working with the aid of a CDSS makes better decisions than a clinician working without one. However, it is clear that not all CDSSs are effective. A recent review showed that only 58% of published randomized clinical trials of CDSSs led to improved processes of care or patient outcomes [4], and some have even led to poorer outcomes [43]. This is surprising as only systems that are sufficiently well engineered to be clinically usable are evaluated in randomized trials. Thus, a fundamental challenge to CDSS research is to identify those characteristics that lead to failure or success. This should also help developers produce systems whose impact can be reliably predicted. However, until now we lack a vocabulary to describe and differentiate decision support systems, and thus to predict which systems are likely to succeed. Published studies on CDSS effectiveness report on only a small number of factors, often arbitrarily chosen and defined.

To put it simply, despite over five decades of research, our discipline lacks a theory of decision support. This means that we do not know the full range of issues to teach our students about CDSSs, cannot predict which systems will prove effective, and — most importantly — cannot give evidence-based advice to CDSS designers about how to maximize their chances of creating effective systems that improve care processes or patient outcomes. Worse, we cannot even describe all relevant features of a specific CDSS using language or criteria that are well accepted and that others will understand. Potentially relevant factors originate from disparate fields such as computer science and psychology, which are often considered in isolation. Accordingly, in this article we introduce a fundamental model of information flow in clinical decision support, based on Ahituv’s generic model of information flow [44]. This model, termed the “Two-Stream Model” (2SM), describes the range of issues encompassed by the field of CDSS and can help identify factors likely to influence effectiveness.
Modeling a clinical decision

Ahituv proposed a simple information flow model in which an object is observed by a decision maker to collect data about it, the data are interpreted to obtain information, the information is used to make a decision, and the decision is used to act on the object [44]. Figure 2.1 shows a first naive instantiation of this model for healthcare domains, based on Wyatt [45]. Here the object of the decision is the patient. We can measure the patient’s temperature (data), interpret this temperature as a fever (information), and decide whether treatment is needed (decision). A CDSS uses a formalized knowledge base to interpret the data [46]. The CDSS can either offer a conclusion about the state of the patient (“what is true”, e.g., a diagnosis) or can offer an explicit recommendation (“what to do”) [1].

Figure 2.1: Ahituv model applied to a clinical decision. The doctor (or the CDSS) observes the patient, resulting in data which are interpreted using clinical knowledge to reach a conclusion about the patient (“what is true”), which can be used as the basis for a decision about “what to do”.

In much work on CDSS, the advice is simply presented to the user, with the implicit assumption that this is sufficient for the recipient to act appropriately. However, we know from decades of psychology research [47] that this assumption is naïve. The fundamental function of a CDSS is to support the clinical decisions of the user. Consequently, the system’s interaction with the user is a fundamental part of the system’s design, as we now recognize. Recognition of the importance of this in early CDSSs led to adding features such as explanation of the reasoning behind the advice [48, 49].
Modeling the presentation of advice

We can use a second instantiation of Ahituv’s model to represent this interaction with the user (Figure 2.2). We can observe user activity such as a mouse click (data), use our knowledge to interpret this activity as reading the patient record (information), and decide how to present the message (decision). Data about the user may also include more permanent information such as demographics (e.g., expertise) or the user’s interaction history (e.g., response to earlier messages). In most CDSSs the decision on how and when to present the advice is based on only knowledge of the problem domain and the workflow. However, CDSSs can also incorporate models of cognition in medical decision making that include memory, reasoning strategies, and domain knowledge [50], as it interacts with socio-cultural behaviors and behavior-change theory, as well as domain epistemology and work related policies [51], and potentially mental models of the CDSS and interaction with it [52]. We have labeled this body of knowledge “cognitive-behavioral knowledge”. This knowledge can be used to improve our model of the user, the interaction, and the decisions that the system is designed to support.

Figure 2.2: Ahituv model applied to a decision on how to present the advice to the user. The system collects data about the user, interprets this information to reach a conclusion about the user’s activities, and then determines if, when, and how the advice should be presented as a message to the user.

Modeling a decision support system

The two information flow models we have presented are joined together to create our new model of a decision-support interaction, incorporating both “streams” (Figure 2.3). The conclusions of the CDSS form the basis for the content, but can be combined with
Figure 2.3: The completed model. The clinical advice is the basis for the content of the message delivered by the CDSS, but can also influence the decision of how the message should be presented. When it is delivered to the user, this message has the potential to affect the user’s thoughts and behavior. The user then may or may not act on the advice in their interaction with the patient, depending in part on how the message containing the advice is presented. If the user is the patient (self-management systems), then the message has the potential to act directly on the patient.

data and knowledge about the user to decide on other aspects of the message (the *timing*, *channel*, *format* [53], *form of notification*, and *interaction functions*). The *content* may also include an explanation of the system’s reasoning, evidence, etc. The *timing* is the time of delivery of the message (in the workflow or relative to the time of decision, e.g. before the decision in a consulting system and after in a critiquing system), and the *channel* is the venue in which the message is delivered (e.g. the electronic patient record). The *format* includes aspects such as color, placement, or whether it is presented in a dialog box [54]. The *form of notification* is the way of notifying the user that new advice is available, and the *interaction functions* are the options the user has for interacting with the message (e.g., a “click-to-order” option). Aspects of the advice, such as clinical intent [55, 56] or severity of harm [57] can also determine how the advice should be presented [58].
the user is presumed to be a clinician, and thus includes both the individual's cognitive factors and the clinical context, along with associated workflows and organizational factors. The information cycle is closed when the user interacts with the patient. Most patient data comes from clinical documentation, although increasingly patients can add their own data. The model may easily be modified to represent decision support in patient self-management by combining the role of patient and user. The encoded knowledge (both clinical and cognitive-behavioral), combined with the inference engine used to interpret the data constitutes the decision-support system. The full CDSS has properties that cannot be attributed to any one of its component parts [1, 46]. The cue for the system to begin its reasoning process is the trigger [59], which can be a specific piece of user data (such as a mouse click triggering a passive system) or patient data (such as the arrival of a blood test result in an active system). The choice of trigger determines whether the system can operate in real-time.

**Implications**

We believe that this model has direct utility for educators, researchers and system developers, and will indirectly benefit CDSS users, patients and health systems (see Table 2.1).

<table>
<thead>
<tr>
<th><strong>CDSS stakeholder group</strong></th>
<th><strong>Likely benefits of the new CDSS model</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Medical informatics educators and students</td>
<td>Clarity about how to think about, describe and classify decision support systems; emergence of a robust knowledge base about which factors determine acceptability and impact</td>
</tr>
<tr>
<td>CDSS researchers</td>
<td>A language to describe and classify CDSS; a principled underlying model of CDSS that helps them frame experimental studies</td>
</tr>
<tr>
<td>CDSS developers</td>
<td>A typology of CDSS; identification and linkage of key design features with typical use cases; emergence of an empirically-based set of predictive design principles for effective CDSS, analogous to the principles of materials or construction used by engineers when they design bridges or aircraft.</td>
</tr>
<tr>
<td>CDSS users</td>
<td>CDSS that fit better with user needs, habits and workflows and require less cognitive work; more accurate and consistent decisions, leading to safer, more effective care and improved patient outcomes</td>
</tr>
<tr>
<td>Patients</td>
<td>Clinicians who pay more attention to me and less to the computer; decisions that are more reliable and lead to better outcomes and fewer complications.</td>
</tr>
<tr>
<td>Health systems</td>
<td>CDSS that are predictably more cost effective and less disruptive to clinical work.</td>
</tr>
</tbody>
</table>

Table 2.1: Likely benefits of the new CDSS model for different stakeholder groups
As an educational tool its value is clear, in defining the scope of topics in the field and the relationships among them. For researchers and developers, the model suggests a categorization for properties of the system that can influence its effectiveness. This is useful in understanding the success or failure of a particular implementation as well as in addressing emerging CDSS issues, such as automation bias [60]. It can also assist system developers in making conscious choices about what kind of support should be offered and even whether a CDSS should be implemented at all. For example, one should not expect CDSS to ever lead to a complete desired behavior change by studying the barriers to correct action, but each result will contribute to modifying the model in an iterative manner [61]. In this situation, we must consider how best to frame the advice, how to present evidence, whether to repeat the message and “escalate” its delivery if it is not followed, etc. For patients, CDSS users and health systems, this will lead to more acceptable, sustainable and effective decision support, better decisions and ultimately more effective, safer health care systems. The model suggests two ways of classifying decisions and thus types of decision support, and two types of knowledge. Decisions may be differentiated on their clinical content (e.g., diagnostic, workup, or treatment advice), or on cognitive-behavioral properties such the use of explicit vs. implicit reasoning, or the nature of the errors that the system is intended to prevent. Likewise, types of decision support may be divided by the clinical intent (the clinical stream) or the type of presentation (the cognitive-behavioral stream). Incorporating data about specific users (e.g., medical specialty in the case of physicians or health literacy in the case of patients) and relevant knowledge about how to use this data should allow us to tailor the advice further. For example, individual users may have different approaches to the same decision and consequently need different kinds of support. Currently, we cannot make evidence-based recommendations about what types of support are effective for which types of decisions, but our proposed model opens up these topics for research exploration.

These same two streams suggest two categories of measure for evaluating the effectiveness of a CDSS. On the clinical stream, we assess the quality of advice generated by the system as a process measure [21], and sometimes clinical outcomes. On the cognitive-behavioral stream, we often measure guideline adherence or other process indicators, but mainly as an intermediary of clinical outcomes. We rarely assess the quality of the presentation as a process measure, or the effect of the CDSS on the clinical user and on the workflow of the clinical unit. One can imagine a system that improves a process measure (such as guideline adherence), but at the cost of a great deal of time and cognitive overload. Likewise, one can imagine a CDSS that has no net effect on guideline adherence, but allows clinicians to achieve the same adherence rate with considerably less effort. Such a system may be very effective at supporting decisions, but if we neglect to make the right process and outcome measurements, its success may be overlooked.

Future work includes creating a typology for each element of the model, populating this typology with potential effect modifiers drawn from the literature, and using the model to characterize new potential factors. The direction and strength of relationships
between these factors and the impact of specific CDSSs can then be hypothesized and tested, which should lead to a principled, theoretical basis for describing the numerous distinct types of decision-support systems, and predicting the circumstances under which each type is likely to be effective.

The Two-Stream Model as presented in Figure 2.3 offers a classification of factors that can contribute not only to success or failure in a CDSS implementation but also can suggest conditions under which such events occur. Although we cannot yet provide evidence-based recommendations to CDSS designers on how to design effective systems, this model should act as a checklist of aspects to consider in the system-design process. The model has clear utility for education by defining the competencies and range of issues encompassed by the field of CDSS. It also provides a framework and common vocabulary to guide future research and to create an evidence base. It implies that rather than looking for factors that influence the effectiveness of CDSS as a single homogenous entity, future systematic reviews should instead investigate which types of decision support will be effective for supporting which types of clinical decisions, and, in turn, what factors define those types. Researchers should strive toward measuring the impact of the system on both patient and cognitive-behavioral outcomes, including the user’s cognitive load and work processes. This will allow us to recognize and learn from successful systems as we seek to create systems that effectively help both patients and clinicians.

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**Contributors**

The model was conceived by SM, AA, and JCW, and evaluated and improved by EHS and VLP. All authors contributed to the writing of this manuscript.

**Competing interests**

The authors have no competing interests to declare.