Understanding and improving diagnostic skills under time pressure is a crucial aspect of patient safety and quality for physicians in many clinic and acute care settings. To make effective treatment choices, clinicians have to answer the question, “What is going on here?” Developing a differential diagnosis in a measured, rational fashion in which the clinician carefully considers options, evaluates the baseline probabilities of various possible diagnoses, and then makes a choice of diagnosis that best fits the available data is often held as an ideal\(^1,\)\(^2\). While this ideal sounds appealing, unfortunately it rarely captures the challenging character of diagnosis "in the wild."\(^3,\)\(^4\)

Diagnosis is inherently a dynamic problem solving process that rarely takes place under ideal conditions. Diagnosis usually takes place in a context of tightly constrained resources, ambiguous and uncertain information, high stakes, multiple simultaneous problems, goals that are vague and often conflicting, and time pressure from both clinical urgency and performance metrics\(^4,\)\(^5\). Moreover, effective performance often requires the coordination of multiple providers across different specialties and status levels.

Launched with a grant from the National Patient Safety Foundation, we set out to understand diagnostic problem solving in realistic, high-stakes situations. High fidelity healthcare simulations provided a convenient laboratory to study dynamic problem solving. We examined a rich data set comprising observations, videos, transcripts, and post-scenario debriefings from a study of 39 subjects taking part in a high fidelity medical simulation as part of routine training\(^6,\)\(^7\). In the simulated scenario, the anesthesiologist (the subject of the study) is called to the operating room to take over anesthesia for a 29-year-old female who urgently needs an appendectomy. Soon the anesthesiologist notices that the ventilator bellows is straining, the patient's breathing sounds are distant, and the monitor indicates that the patient’s blood oxygen levels are falling to levels below the desired range. The anesthesiologists all recognize this as a potentially life-threatening situation that calls for quick resolution in order to restore the patient's breathing. In the 25 minutes that followed the onset of this crisis, the anesthesiologists attempted to solve this diagnostic challenge, but only 18% of them did so in time to save the patient. The dynamic patterns in the "failure modes" of the others give us an illuminating look into the challenges of dynamic problem solving\(^8\).

### The Failure Mode of Fixation: Premature Closure

Our first example is Dr. Poggioli (a pseudonym), who noticed a problem ventilating the patient. Based on the symptoms he observed and his likely prior expectations, Dr. Poggioli began
treating bronchospasm, a fairly standard post-intubation problem and a highly plausible
diagnosis given the timing and constellation of presenting symptoms. Over the course of the next
25 minutes, he appeared to consider only one alternative diagnosis. On at least 10 occasions, he
made statements reflecting his belief that the patient was in bronchospasm. Like other clinicians
in this failure mode (28% of the subjects), Dr. Poggioli conducted tests that largely aimed to
confirm his presumed diagnosis. The core weakness in this mode is that they continually
interpreted data in favor of their current diagnosis (e.g., they heard the distant breath sounds as
wheezes; they assumed the unchanging inspiratory pressure of the lungs had improved when
they give medicine to reduce that pressure).

To explain why fixation and the other failure modes occur, we developed a model of dynamic
problem solving that incorporates two core ideas. First, the process of gathering and
interpreting information (e.g., diagnostic tests) that is used to update current beliefs takes place
in the context of considering competing diagnoses that may displace the current diagnosis as the
preferred one. Second, the clinician’s belief (or confidence) in the current diagnosis sometimes
biases the interpretation of ambiguous information in favor of the current diagnosis. The process
unfolds as diagrammed in Figure 1. The diagnostician begins with some initially plausible
diagnosis. As her Belief in Current Diagnosis begins to increase, she is more prone to
Interpretation Bias that will influence the interpretation of new information. As new Diagnostic
Cues Arriving continue (both from her actions and from the evolving situation), the biased
interpretations lead to more Interpretations to Support Diagnosis, further strengthening the Belief
in Current Diagnosis and still more Interpretation Bias. This forms a self-reinforcing feedback
process that lies at the heart of fixation error. When the interpretation bias is strong, the
diagnostician is at great risk of committing fixation error - clinging to a single presumed
diagnosis despite mounting cues that he or she is on the wrong track.

Figure 1: Self-fulfilling feedback in the interpretation of diagnostic cues. The "R" signifies a reinforcing
feedback loop. When a variable changes in the upward (downward) direction, the loop acts to reinforce the
change resulting in further change in the upward (downward) direction.
Typical remedies for the fixation problem are to step back, expand the frame, and broaden the set of options to consider\textsuperscript{9,10}. But, these steps to avoid fixation may increase the risk of the most common failure mode in the study - vagabonding, a pattern of jumping from one diagnosis to the next without fully evaluating the merits of the rejected ones.

**The Failure Mode of Vagabonding: Jumping and More Jumping**

Soon after putting the patient to sleep, Dr. Vayanos (a pseudonym) reported that he was having difficulty ventilating the patient. The mechanical ventilator was straining, so he switched to "hand bagging," squeezing air into the patient's lungs himself, and adjusted the placement of the breathing tube to assure this was not the problem. Talking with the second anesthesiologist he had called to help, he noted that the airway pressures were very high and wondered aloud if the problem could be asthma or not enough muscle relaxation in the patient.

This was the beginning of a hunt for the source of the ventilation problem. Vayanos considered everything from a collapsed lung to a broken Y-piece in the mechanical ventilator. He mentioned or discussed each of these problems. He performed partial treatments to address some of them or diagnostic tests (e.g., listening to breath sounds) to explore them. The oxygen saturation level continued to drop slowly. By the end of the scenario, Vayanos had partially pursued eight diagnoses and was still adding candidates to his list as the oxygen saturation dropped into the 80’s. Vayanos was one of the 44% of the study subjects whose failed problem solving was classified as diagnostic vagabonding.

Why do clinicians fall prey to vagabonding? The self-fulfilling interpretation loop of Figure 1 is once again the key to understanding this failure mode. Surprisingly, there is a risk of having interpretation bias be too weak. When the interpretation bias is weak, the clinician tends to prematurely reject a diagnosis - even if it is correct - in favor of another emerging idea. Alternative diagnoses become erroneously attractive if early evidence is not favorable to the current diagnosis.

**The Adaptive Mode: Striking a Dynamic Balance**

So, what can we do to decrease the likelihood of these diagnostic errors? First, clinicians can learn to recognize repeat treatments as a signal of fixation and multiple disconnected actions as a signal of vagabonding. Second, to avoid fixation, they can accelerate generating new cues, hold diagnoses less confidently, or speed up the cultivation of alternatives. To avoid vagabonding, they can stick to treatment algorithms until they are complete, hold diagnoses more confidently, or slow down the cultivation of alternatives.

Fixation error, and its cousin confirmation bias, have long been seen as the bad guys in diagnostic problem solving. Our analysis shows that the willingness to "stick with it" fostered by the self-fulfilling interpretation loop is, paradoxically, also a boon in diagnostic problem solving.
This is the dynamic challenge of diagnosis: while too much bias is harmful (as a recipe for fixation), too little bias is also problematic (as a recipe for diagnostic vagabonding). Using a mathematical model, we showed how these diagnostic failure modes as well as the adaptive (i.e., successful) mode of diagnosis can emerge by varying only the strength of the interpretation bias. The results show that the adaptive mode of diagnostic problem solving requires striking the right balance between the strength of self-fulfilling interpretation and the pacing of both cultivating alternative diagnoses and gaining access to and interpreting new information.

3. Graber M. Educational strategies to reduce diagnostic error: can you teach this stuff? Advances in Health Sciences Education. 2009;14(0):63-9.