REVIEW ARTICLE

MEDICAL EDUCATION

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Educational Strategies to Promote Clinical Diagnostic Reasoning

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CLINICAL TEACHERS DIFFER FROM CLINICIANS IN A FUNDAMENTAL WAY. They must simultaneously foster high-quality patient care and assess the clinical skills and reasoning of learners in order to promote their progress toward independence in the clinical setting.[1] Clinical teachers must diagnose both the patient's clinical problem and the learner's ability and skill.

To assess a learner's diagnostic reasoning strategies effectively, the teacher needs to consider how doctors learn to reason in the clinical environment.[2-4] Medical students in a classroom generally organize medical knowledge according to the structure of the curriculum. For example, if pathophysiology is taught according to organ systems, then the student's knowledge will be similarly organized, and the recall will be triggered by questions related to specific organ systems or other contextual clues. In the clinical setting, the patient's health and care are the focus. Clinical problems may involve many organ systems and may be embedded in the context of the patient's story and questions. Thus, in the clinical setting, the student's recall of basic science knowledge from the classroom is often slow, awkward, or absent. Only after learners make new connections between their knowledge and specific clinical encounters can they also make strong connections between clinical features and the knowledge stored in memory.[5,6] This report focuses on how clinical teachers can facilitate the learning process to help learners make the transition from being diagnostic novices to becoming expert clinicians.

DIAGNOSTIC REASONING

There is a rich ongoing debate about our understanding of the complex process of clinical diagnostic reasoning.[2,3] In this report, some of the basic processes involved in clinical reasoning, as understood according to current knowledge, are translated into practical and specific recommendations for promoting the development of strong diagnostic reasoning skills in learners. The recommendations are illustrated by a clinical case presentation.

Clinical teachers observe learners gathering information from patients, medical records, imaging studies, results of laboratory tests, and other health care providers. On the basis of their observations, and through the discussion of clinical cases, teachers draw conclusions about the learners' performance, including their reasoning processes. A hypothetical case provides an example of a conversation involving a patient, two learners with different levels of expertise, and the clinical teacher (see Box). In this case,[7-9] a patient with knee pain makes an urgent visit to an ambulatory care practice. A novice resident (with relatively little experience with this patient's problem, which is gout) and an expert resident (who is familiar with this problem, having seen other patients with gout) each independently interviews the patient, performs

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an examination, presents the case to the preceptor, and separately discusses the case with the preceptor. As becomes evident, the expert resident has transformed the patient's story into a meaningful clinical problem. The novice resident has also transformed the patient's story, but less elaborately. What the teacher hears from both residents differs substantially from what the patient told them.

The expert resident brought two sets of skills to the encounter with the patient. First, this resident probably formed an early impression — a mental abstraction — of the patient's story. Although possibly unaware of this formulation, the resident's mental abstraction influenced his diagnostic strategy. Guided by his early impression, the resident probably asked a series of questions, and the patient's responses guided both further questioning and the planning of a focused physical examination. The resident's approach involved a search for information that could be used to discriminate among any number of diagnostic explanations of the patient's problem. The novice resident might not have formed a mental abstraction of the case and probably was not sure which questions to pose to the patient.

Second, the expert resident's clinical case presentation was a succinct summary of the findings, providing the teacher with a clinical picture of the patient as seen through the resident's eyes. On the basis of the case presentations by both the expert and the novice residents, the teacher may or may not have had a firm idea of what was wrong with the patient. Rather than offer an opinion, however, the teacher asked the expert resident to reason aloud about the case, thereby providing the teacher with additional clinical information about the patient as well as considerable insight into the resident's clinical reasoning skills. The teacher used the same strategy with the novice resident, and although the result added little information about the patient, the teacher learned something about the novice resident's limited clinical reasoning.

Key elements of clinical diagnostic reasoning are shown in Figure 1. The first step in diagnostic reasoning, which is based on knowledge, experience, and other important contextual factors,[10] is always data acquisition. Data acquisition, depending on the setting, may include elements of the history, the findings on physical examination, and the results of laboratory testing and imaging studies. Another early step is the creation of the mental abstraction or "problem representation,"[2,8,11] usually as a one-sentence summary defining the specific case in abstract terms. Clinicians may have no conscious awareness of this cognitive step. The problem representation, unless elicited in the

The Case as Seen by a Novice Resident and an Expert Resident.

Patient's story: My knee hurt me so much last night, I woke up from sleep. It was fine when I went to bed. Now it's swollen. It's the worst pain I've ever had. I've had problems like this before in the same knee, once 9 months ago and once 2 years ago. It doesn't bother me between times.

Novice resident's presentation: My next patient is a 54-year-old white man with knee pain. It started last night. He does not report any trauma. On examination, his vital signs are normal. His knee is swollen, red, and tender to touch. It hurts him a lot when I test his range of motion. He's had this problem twice before.

Expert resident's presentation: My next patient is a 54-year-old white man with a sudden onset of pain in his right knee that awakened him from sleep. He does not report any trauma and was essentially asymptomatic when he went to bed. His history is remarkable for two episodes of similar, severe pain 9 months and 2 years ago. He is pain-free between episodes. He is afebrile today. His knee is swollen, tender to touch, and erythematous.

Teacher's inquiry: What do you think is causing this patient's knee pain?

Novice resident's response: It could be an infection. It could be a new onset of rheumatoid arthritis. It could be Lyme disease. Since he doesn't recall falling, I doubt it's an injury. I don't know whether osteoarthritis ever presents like this, but he does have a history of knee pain.

Expert resident's response: The patient has acute gout. He has had multiple discrete episodes with abrupt onset of extremely severe pain involving a single joint with evidence of inflammation on examination. Before all his episodes, he is asymptomatic. I would have expected gout to affect the first metatarsophalangeal joint, but it can present in the knee. Nothing suggests any ongoing, chronic problem in the knee. I don't see any portal of entry to suggest acute infectious arthritis and he looks quite well for that. His other joints are normal on examination. I doubt that he has a flare-up of osteoarthritis with pseudogout or a systemic, inflammatory arthritis such as rheumatoid arthritis.

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teaching setting, is rarely articulated. Rather, the teacher infers the learner's problem representation from the learner's presentation of the case.

For the case used as the example, the expert resident's problem representation, had it been elicited, might have been the following: "The acute onset of a recurrent, painful, monoarticular process in an otherwise healthy middle-aged man." The problem representation illustrates the transformation of patient-specific details into abstract terms. "Last night" became "acute onset," "I've had problems like this before" became "recurrent," "same knee" became "monoarticular," and the patient's age, sex, and medical history are summarized as "otherwise healthy, middle-aged man." In this transformation, the characterization of the problem facilitates the retrieval of pertinent information from memory.[7] The novice resident may be less able than the expert resident to develop an accurate problem representation.

When prompted by the teacher to reason about the case, the expert resident used abstract semantic qualifiers to describe the case findings. Semantic qualifiers are paired, opposing descriptors that can be used to compare and contrast diagnostic considerations. The resident used several implied pairs when considering hypotheses for a diagnosis of gout: multiple (not single) and discrete (not continuous) episodes, abrupt (not gradual) onset, severe (not mild) pain, and a single joint (not multiple joints). The use of such semantic qualifiers is associated with strong clinical reasoning.[7-9]

To create a concise, appropriate problem representation and to reason succinctly, the resident must have clinical experience with similar patients and must be able to recognize the information that establishes gout as the diagnosis while ruling out other possibilities. The way the clinical experience is stored in memory either facilitates or hinders the ability to formulate the problem representation. Expert clinicians store and recall knowledge as diseases, conditions, or syndromes — "illness scripts" — that are connected to problem representations.[2,4,12,13] These representations trigger clinical memory, permitting the related knowledge to become accessible for reasoning. Knowledge recalled as illness scripts has a predictable structure: the predisposing conditions, the pathophysiological insult, and the clinical consequences (Fig. 2).

Constructed on the basis of exposure to patients, illness scripts are rich with clinically relevant information. Their content varies for each physician and among physicians. Some illness scripts are conceptual models, such as groups of diseases, whereas others are representational memories of specific syndromes. With experience, clinicians also store memories of individual patients, and the recollection of a particular patient often triggers the recall of relevant knowledge.[14] The defining and discriminating clinical features (Fig. 3) of a disease, condition, or syndrome become "anchor points" in memory. In the future, recollection of such stored experiences expands the clinician's ability to recognize subtle but important variations in similar cases.[13]

When prompted to reason aloud, the novice resident listed possible causes of knee pain. The expert resident, however, compared and contrasted several relevant hypotheses — acute gout, infectious arthritis, osteoarthritis with pseudogout, and rheumatoid arthritis — and included the discriminating features of each possibility. Such reasoning may represent the mental processes of searching for and verifying an illness script, with the elimination of hypotheses for which the defining features of a specific illness script are absent.[2,4,12,13] Such comparisons often take place in the expert clinician's mind during the data-acquisition phase and form the basis of a focused strategy for ques-

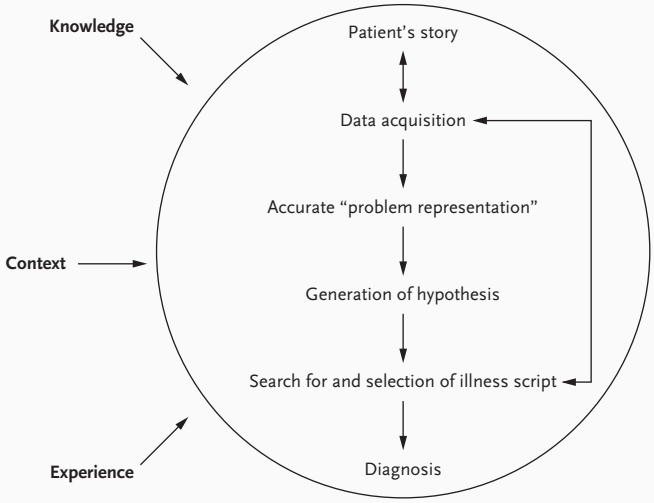

Figure 1. Key Elements of the Clinical Diagnostic Reasoning Process.

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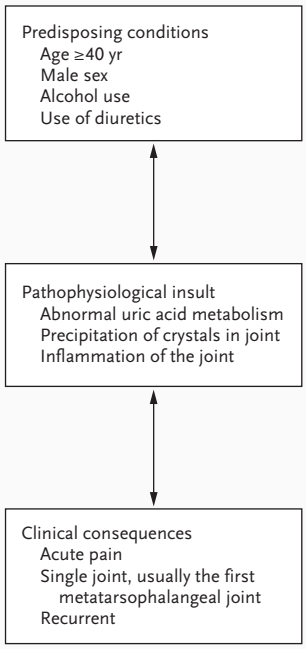

Figure 2. Example of an Illness Script for Gout.

tioning the patient and for the physical examination. Additional data gathering is purposeful: it is a search for the defining and discriminating features of each illness script under consideration.

Clinicians familiar with the clinical presentation of gout will recognize the pattern of symptoms and signs of gout in the expert resident's case presentation. Such rapid, nonanalytic clinical reasoning is associated with experience with the type of problem, in this case gout. The defining features for a diagnosis of gout are associated in memory as an illness script and, for some clinicians, are also associated with memories of individual patients. Access to these memories is easily triggered when the clinical findings of gout are present. The expert resident recognized the pattern of symptoms and signs of gout and selectively accessed the illness script constructed on the basis of experience.

The novice resident's clinical experience with gout was limited; perhaps knowledge gained from prior cases of gout failed to be transferred to memory. The novice resident used a slower, more deliberate method of testing a hypothesis for this clinical problem, generating multiple plausible hypotheses for acute arthritis. Additional data gathering would be useful either to confirm or to rule out these diagnostic considerations in a conscious, analytic fashion.

Both nonanalytic and analytic reasoning strategies are effective and are used simultaneously, in an interactive fashion.[3] Nonanalytic reasoning, as exemplified by "pattern recognition," is essential to diagnostic expertise,[2-4,6,12,13] and this skill is developed through clinical experience. Deliberative analytic reasoning is the primary strategy when a case is complex or ill defined, the clinical findings are unusual, or the physician has had little clinical experience with the particular disease entity. Clinicians often unconsciously use multiple, combined strategies to solve clinical problems, suggesting a high degree of mental flexibility and adaptability in clinical reasoning.[3,4]

By prompting the learner to reason aloud or eliciting the learner's uncertainties, the clinical teacher can uncover the reasoning process used by the learner. In responses to the teacher's questions "What do you think?" or "What puzzled you?" weak and strong diagnostic reasoning can be readily distinguished.[15] As was true of the novice resident in the case example, learners whose discussion is poorly organized, characterized by long, memorized lists of causes of isolated symptoms, or only weakly connected to information from the case are reasoning poorly.[16] They do not connect stored knowledge with the current clinical case because they lack either experience with such cases or basic knowledge.

Learners with strong diagnostic reasoning skills often use multiple abstract qualifiers to discuss the discriminating features of a clinical case, comparing and contrasting appropriate diagnostic hypotheses and linking each hypothesis to the findings in the case. The discussion between such a learner and the clinical teacher is often quite concise and may be so abbreviated that its result, the diagnosis, appears to be a lucky guess. In such situations, the teacher may need to ask additional questions that probe the learner's reasoning or uncertainties to be sure that reasoning, rather than luck, brought the diagnosis to light. Strong diagnosticians can readily expand on their thinking.[15,16]

RECOMMENDATIONS FOR CLINICAL TEACHERS

Clinical teachers can use several strategies to promote the development of strong diagnostic rea-

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soning skills. The recommendations that follow are drawn from research on how doctors reason.[1-4,6,8,9,11-15,17,18] Although experienced clinical teachers will recognize the validity of some of these recommendations, many of the ideas still need empirical testing in the clinical teaching environment.

Experience with patients is essential for establishing new connections in memory between learned material and clinical presentations, for developing illness scripts, and for developing the ability to reason flexibly with the use of analytic reasoning and pattern recognition.[3] As learners listen to patients' stories, learn to transform these stories into case presentations, develop their own illness scripts, and learn to reason about clinical information, teachers can use case-specific instructional strategies to help learners strengthen their skills (Table 1).

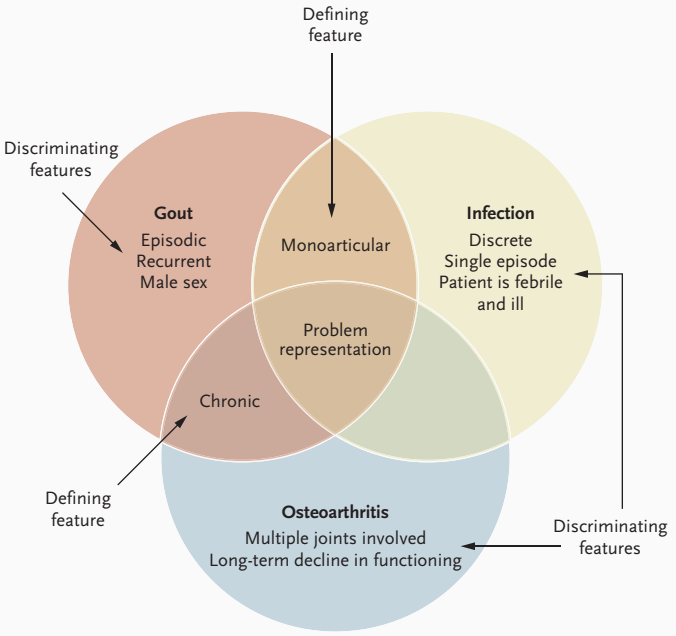

Figure 3. Defining and Discriminating Features of a Set of Diagnostic Hypotheses for Acute Arthritis.

The problem representation is "acute onset of a recurrent, painful, monoarticular process in an otherwise healthy middle-aged man." Defining features are descriptors that are characteristic of the diagnoses (e.g., gout, septic arthritis, osteoarthritis). Discriminating features are descriptors that are useful for distinguishing the diagnoses from one another.

ARTICULATING PROBLEM REPRESENTATIONS

Failure to generate an appropriate problem representation can result in the random generation of hypotheses that are based on isolated findings in the case. When the case presentation or discussion is disorganized, the clinical teacher can prompt the learner to create a one-sentence summary of the case with the use of abstract terms.[9] However, teaching learners to articulate problem representations as an isolated teaching strategy is insufficient.[9] Rather, problem representation must be connected to the type of clinical problem — a connection that facilitates the learner's retrieval of pertinent information from memory.

In the teaching environment, several learners with different levels of expertise may be involved in the same case, and eliciting the learners' various problem representations will help the clinical teacher to understand their different perspectives and learning needs. In complex, ill-defined clinical cases, more than one problem representation may need to be considered. The discussion of the different problem representations will help novice learners to appreciate the complexity of the case as well as their own early, limited understanding.

Teachers should articulate their own problem representations to demonstrate the type of abstract summary they seek from learners. Teachers can then reason aloud, linking the summary statement to their own illness scripts and highlighting the discriminating features clinicians seek in the history and physical examination for the consideration of appropriate diagnostic possibilities.[17]

STRATEGIES FOR COMPARING AND CONTRASTING

Novice learners often generate numerous possible diagnoses for any given case. To prioritize such a lengthy list, they should be encouraged to compare and contrast possible diagnoses on the basis of the relationship among the actual clinical data on the case, typical presentations for each diagnostic possibility, and the relative probabilities of different diagnoses.[17,18] Forcing learners to prioritize the list of diagnostic possibilities and explain their justifications helps them to create linkages between the clinical findings in the case and relevant diagnoses, bolstering their ability to develop pertinent illness scripts.

The development of elaborate illness scripts and pattern recognition involves knowledge of the typical presentation of a problem as well as the many atypical presentations or variations on the typical one. It is important for novice learners

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Table 1. Strategies for Diagnosing a Learner's Skills and Addressing Problems in Clinical Reasoning.

Skill	Clue in Case Presentation	Diagnosis	Educational Strategy	Example of Strategy
Data acquisition and reporting	Presentation lacking important information.	Learner has not identified what is important, obtained important information, or both.	Go to the bedside, examination room, or medical record and model the acquisition of important findings; request that the learner revise the presentation accordingly.	"I'd like you to watch me take the history and examine this patient. Look for things I do that are particularly useful in eliciting information. Then let's discuss your observations."
Problem representation	Disorganized presentation, discussion, or both.	Learner has no experience with this clinical problem or lacks a conceptual approach to it.	Go to the bedside, examination room, or medical record and elicit or confirm important findings; think aloud with the learner, linking important findings to your own problem representation.	"Now that we've reviewed the important findings, let's think together about how they point to acute arthritis as the likely problem. I'm considering acute arthritis because. . . ."
	Summary statement only loosely related to the case.	Learner has not identified a problem representation, lacks a coherent understanding of the case, or both.	Instruct the learner regarding the importance of the problem representation; ask for a summary statement (if necessary, compare and contrast it with your own).	"Concise, accurate problem representation is a critical entry point to differential diagnosis. Can you give me a one- or two-sentence summary of this case? Here's how I think it might be put together. . . ."
Generation of hypothesis: Search for and selection of illness script	Multiple diagnoses generated in a random order with no attempt to prioritize them.	Learner has not identified a problem representation or formulated illness scripts for the diagnostic considerations.	Ask the learner to list all important findings from the case, create a problem representation based on selected findings, and prioritize diagnostic considerations that identify discriminating features for each consideration.	"What are the main findings? Can you summarize these in abstract terms in one or two sentences? What are the diagnostic considerations for patients with acute arthritis? Which cause of acute arthritis is most likely to be correct in this case? Why?"
	Discussion of differential diagnosis not linked to findings from the case.	Learner has not formulated illness scripts for the diagnostic considerations or is unable to compare and contrast relevant illness scripts.	Ask the learner to support his or her diagnosis using findings from the case; then ask for at least one additional plausible diagnosis and have learner compare it with alternative diagnostic possibilities. If necessary, provide your own analysis of the case.	"What are your main and alternative diagnoses? What features of the case helped you to discriminate between them?"

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Cognitive feedback	Far-fetched diagnosis.	Learner has a poor understanding of the case or lacks a sense of relative probability.	Ask the learner to describe the prototypical presentation for this particular diagnosis, to be followed by a comparison with the findings in this case; identify additional data that would be needed to rule in the diagnosis.	"What is the classic presentation for your diagnosis? What findings in this case fit the typical presentation? Are there enough key features present to continue with this line of reasoning? What else do we need to know about this patient?"
Developmental stage	Presentation or reasoning below the expected level for a common problem.	Learner has not created an "anchor" prototype in memory, has too little experience with this type of problem to create illness scripts, or both.	Ask the learner about his or her experience with this type of case or problem; assign the learner patients who have common problems and prototypical presentations; instruct the learner when reading about the case to compare the primary diagnosis with at least one other consideration, identifying relevant key and discriminating features; and have learner follow up to explain what was learned. Determine whether the learner's difficulty is an isolated or recurring one.	"Have you taken care of other patients with acute arthritis? What do you remember about those patients? I want you to read about the typical presentation of gout and compare it with the typical presentation of infectious arthritis. Identify key and discriminating features for both diagnoses. Tomorrow, tell me what you have learned."
Contextual considerations	Disorganized presentation of a complex and ill-defined clinical problem.	More than one problem representation is possible, there is a risk of premature closure (learner may be making a lucky guess), or both.	Elicit some plausible problem representations; ask the learner to identify and defend primary and secondary diagnoses, using key and discriminating features of the case; articulate your own problem representations and clinical reasoning.	"Tell me how your primary diagnosis is supported by the clinical findings. Choose a reasonable alternative diagnosis and tell me why it does not fit the clinical findings." (Repeat this procedure for each plausible problem representation.)
	Evidence of varying levels of understanding.	Within the group, there is likely to be a broad range of case experience (the stage of training may only partially predict the learner's ability to reason about a case).	Elicit problem representations from two or three other learners present; ask questions to assess each learner's level of expertise; ask more senior learners to reason aloud; articulate your own problem representation and clinical reasoning.	Ask the group: "Does anyone have a different problem representation?" Ask each learner: "What questions do you have about this case?" Ask the senior resident: "Tell us your primary diagnosis and how it is supported by the clinical findings. Did you consider any other diagnosis, and if so, how did you rule it out?"

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to begin by creating in memory an anchor prototype of the typical presentation, rather than giving equal consideration to a number of undifferentiated possibilities.[17,19] Early in their training, medical students should be assigned to evaluate patients with common problems — ideally, problems for which there are prototypical presentations. After the features of the prototype have been solidified in memory, additional clinical exposure to similar problems can offer a basis for comparison with the prototypical case, providing learners with an appreciation of atypical or subtle findings.[18,19]

VARYING EXPECTATIONS ACCORDING TO DEVELOPMENTAL LEVEL

The teacher's expectation of evidence of strong reasoning should vary according to the stage of training of the learner, but the learner's developmental level is often related more to the extent of clinical experience with the case at hand than to the year of training. First-year residents, for example, may have clinical reasoning skills that are as advanced as those of senior residents when it comes to common clinical problems that they saw frequently as medical students.[20] Thus, although the stage of training is somewhat helpful to the teacher in determining expectations of and roles for learners, specific questioning strategies are necessary to probe the understanding and elicit the uncertainties of learners at any level.[15] Several different strategies can be used, but open-ended questions are especially useful for assessing the learner's clinical reasoning ability.[21,22] Using this or other similar frameworks, clinical teachers can evaluate a learner's performance on the basis of the expected performance at different developmental levels.

PROVIDING COGNITIVE FEEDBACK

The clinical teacher should provide the learner with specific cognitive feedback. The teacher should point out diagnostically meaningful information in the data on the case, identify redundant or irrelevant findings, and highlight the discriminating features, including their relative weight or importance for drawing conclusions as to the correct diagnosis.[17] When a learner suggests a possible but not plausible diagnostic consideration, the teacher can ask the learner to describe the key features of a prototypical case and then to compare the prototype with the findings in the case at hand.[16]

ENCOURAGING USEFUL READING HABITS

Learners should be encouraged to read about their patients' problems in a way that promotes diagnostic reasoning, rather than to read about topics in a rote-memorization fashion, without context. The organization of knowledge stored in memory facilitates the recall of key concepts for application to the next relevant clinical case.[5] To enhance their organization of knowledge and their understanding, novice learners should read about at least two diagnostic hypotheses at the same time (e.g., gout and infectious arthritis), comparing and contrasting the similarities and discriminating features. Clinical teachers should encourage reading that promotes conceptualization rather than memorization and provides learners with an opportunity to share what they have learned, testing what has been understood well enough to be explained[19] and reinforcing the importance of self-directed learning.

Some medical textbooks are better organized than others to encourage learning by comparing and contrasting diagnostic considerations.[23] The judicious use of the original literature, even by novices, can be an effective clinical learning tool, especially when it provides important new organizing principles or pathophysiological insights that have yet to permeate textbooks. Learners should be encouraged to identify progressively broader and more complex issues, explore them more deeply, and apply the principles of evidence-based medicine in arriving at answers.

In summary, clinical teachers can promote the development of diagnostic reasoning while simultaneously diagnosing both the patient's disorder and the learner's abilities. To do so, however, they must have an appreciation of clinical learning theory and practice and an accurate understanding of the clinical problem in question. Such an undertaking requires that the teacher accompany the learner to the bedside or examination room and perform an independent assessment of the patient and, at the same time, assess the developmental stage and clinical reasoning ability of the learner. Ensuring the quality of patient care and modeling professionalism while promoting diagnostic reasoning skills constitute the true art of clinical teaching.

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REFERENCES

1. Irby DM. How attending physicians make instructional decisions when conducting teaching rounds. Acad Med 1992; 67:630-8.
2. Schmidt HG, Norman GR, Boshuizen HP. A cognitive perspective on medical expertise: theory and implications. Acad Med 1990;65:611-21. [Erratum, Acad Med 1992;67:287.]
3. Eva KW. What every teacher needs to know about clinical reasoning. Med Educ 2005;39:98-106. [Erratum, Med Educ 2005; 39:753.]
4. Norman G. Research in clinical reasoning: past history and current trends. Med Educ 2005;39:418-27.
5. Mandin H, Jones A, Woloschuk W, Harasym P. Helping students to think like experts when solving clinical problems. Acad Med 1997;72:173-9.
6. Coderre S, Mandin H, Harasym PH, Fick GH. Diagnostic reasoning strategies and diagnostic success. Med Educ 2003; 37:695-703.
7. Bordage G. Why did I miss the diagnosis? Some cognitive explanations and educational implications. Acad Med 1999; 74:Suppl:S138-S143.
8. Chang RW, Bordage G, Connell KJ. The importance of early problem representation during case presentations. Acad Med 1998;73:Suppl:S109-S111.
9. Nendaz MR, Bordage G. Promoting diagnostic problem representation. Med Educ 2002;36:760-6.
10. Koens F, Mann KV, Custers E, Ten Cate OT. Analysing the concept of context in medical education. Med Educ 2005;39: 1243-9.
11. Bordage G, Lemieux M. Semantic structures and diagnostic thinking of experts and novices. Acad Med 1991;66: Suppl:S70-S72.
12. Elstein AS, Schwarz A. Clinical problem solving and diagnostic decision making: selective review of the cognitive literature. BMJ 2002;324:729-32.
13. Custers EJ, Regehr G, Norman GR. Mental representations of medical diagnostic knowledge: a review. Acad Med 1996;71: Suppl:S55-S61.
14. Hatala RM, Norman GR, Brooks LR. Influence of a single example upon subsequent electrocardiogram interpretation. Teach Learn Med 1999;11:110-7.
15. Connell KJ, Bordage G, Chang RW, Howard BA, Sinacore J. Measuring the promotion of thinking during precepting encounters in outpatient settings. Acad Med 1999;74:Suppl:S10-S12.
16. Bordage G. Elaborated knowledge: a key to successful diagnostic thinking. Acad Med 1994;69:883-5.
17. Wigton RS, Patel KD, Hoellerich VL. The effect of feedback in learning clinical diagnosis. J Med Educ 1986;61:816-22.
18. Hatala RM, Brooks LR, Norman GR. Practice makes perfect: the critical role of mixed practice in the acquisition of ECG interpretation skills. Adv Health Sci Educ Theory Pract 2003;8:17-26.
19. Bordage G. The curriculum: overloaded and too general? Med Educ 1987;21:183-8.
20. Irby DM. What clinical teachers in medicine need to know. Acad Med 1994; 69:333-42.
21. Neher JO, Gordon KC, Meyer B, Stevens N. A five-step "microskills" model of clinical teaching. J Am Board Fam Pract 1992;5:419-24.
22. Aagaard E, Teherani A, Irby DM. Effectiveness of the one-minute preceptor model for diagnosing the patient and the learner: proof of concept. Acad Med 2004; 79:42-9.
23. Bordage G, Lemieux M. Which medical textbook to read? Emphasizing semantic structures. Acad Med 1990;65:Suppl: S23-S24.

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