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A clinical reasoning curriculum for medical students: an interim analysis

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Abstract

Objectives: Diagnostic error is a critical patient safety issue that can be addressed in part through teaching clinical reasoning. Medical schools with clinical reasoning curricula tend to emphasize general reasoning concepts (e.g., differential diagnosis generation). Few published curricula go beyond teaching the steps in the diagnostic process to address how students should structure their knowledge to optimize diagnostic performance in future clinical encounters or to discuss elements outside of individual cognition that are essential to diagnosis.

Methods: In 2016, the University of California, San Francisco School of Medicine launched a clinical reasoning curriculum that simultaneously emphasizes reasoning concepts and intentional knowledge construction; the roles of patients, families, interprofessional colleagues; and communication in diagnosis. The curriculum features a longitudinal thread beginning in first year, with an immersive three week diagnostic reasoning (DR) course in the second year. Students evaluated the DR course. Additionally, we conducted an audit of the multiyear clinical reasoning curriculum using the Society to Improve Diagnosis in Medicine-Macy Foundation interprofessional diagnostic education competencies.

Results: Students rated DR highly (range 4.13–4.18/5 between 2018 and 2020) and reported high self-efficacy with applying clinical reasoning concepts and communicating reasoning to supervisors. A course audit demonstrated a disproportionate emphasis on individual (cognitive)

competencies with inadequate attention to systems and team factors in diagnosis.

Conclusions: Our clinical reasoning curriculum led to high student self-efficacy. However, we stressed cognitive aspects of reasoning with limited instruction on teams and systems. Diagnosis education should expand beyond the cognitive- and physician-centric focus of most published reasoning courses.

Keywords: clinical reasoning; curriculum; diagnosis; diagnostic errors; undergraduate medical education (UME).

Introduction

The 2015 National Academy of Medicine report *Improving Diagnosis in Health Care* raised the profile of diagnostic error as a major quality and safety issue [1]. Some medical schools have responded to this issue by developing dedicated clinical reasoning courses that emphasize general reasoning concepts (e.g., differential diagnosis generation). Only a few published curricula [2–4] expand beyond teaching the steps in the diagnostic process to guide students in structuring their growing knowledge to optimize diagnostic performance in future clinical encounters. Additionally, reasoning curricula tend to focus solely on the cognition of the individual provider without examining other aspects of the reasoning process such as communication with patients and colleagues which are essential to diagnostic performance [5].

In 2016, the University of California, San Francisco (UCSF) School of Medicine revised its curriculum with the goal of preparing students to meet the challenges of health-care in the 21st century [6]. This new curriculum provided an opportunity to advance clinical reasoning instruction and address the National Academy of Medicine's call for improving diagnosis education. We developed a clinical reasoning curriculum anchored by a pre-clerkship diagnostic reasoning (DR) course that simultaneously emphasizes clinical reasoning concepts and knowledge construction and includes a broad perspective on the diagnostic process, incorporating the essential roles of patients and colleagues, and the centrality of communication.

In this paper we outline the key design principles of our clinical reasoning curriculum and share student

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evaluations of the DR course along with an audit [7] of the longitudinal clinical reasoning curriculum. Our curricular audit was based on diagnostic reasoning competencies developed by an interprofessional group convened by the Society to Improve Diagnosis in Medicine and the Macy Foundation (the SIDM-Macy collaborative).

Materials and methods

Setting and participants

All second year UCSF medical students (approximately 150 per year) take the DR course immediately before clerkships. The DR course is complemented by spaced clinical reasoning learning activities that begin in the first year and extend into students' final year.

Program description

We followed Kern's six-step model for curriculum development [8]. For our problem identification and general needs assessment we reviewed the diagnostic error and clinical reasoning education literature [9–15]. We analyzed the UCSF pre-clerkship curriculum to identify where clinical reasoning instruction was taking place [16], and identified several relevant curricular elements including the hypothesis-driven physical exam (HDPE) framework [17–19], an emphasis on diversity and equity [20], and the importance of interprofessional teams that aligned with our clinical reasoning objectives and became anchors for curricular integration. Our goal was for students to become critical thinkers who promote the health of their patients through accurate, timely, and safe diagnoses and possess skills to continually improve their diagnostic performance. DR course objectives are outlined in Supplementary Table 1. Four guiding principles of our clinical reasoning curriculum – script theory, knowledge construction through reasoning practice, curricular integration, and an expanded conceptualization of diagnosis – are described below.

Script theory: We considered different theoretical frameworks for clinical reasoning, including dual process theory [21], script theory [22], naturalistic decision making [23], and situated cognition [24]. We based the individual (cognitive) reasoning elements of our curriculum on script theory, which emphasizes how mental models (e.g., of an illness) influence how we receive and retrieve information while working through a clinical problem with a patient. In health professions education settings, script-informed teaching emphasizes the relationship between the learners' knowledge organization and their ability to reason in a clinical situation [25]. Script theory also provides a shared vocabulary (e.g., illness scripts, problem representation, diagnostic schema, prioritized differential diagnosis) that facilitates discussion of the reasoning process and helps learners understand the relationship between knowledge structures and problem-solving [26]. We provided professional development on script theory (using in-person sessions and videos) for all faculty leading clinical reasoning sessions [27–29].

Knowledge construction through reasoning practice: Since reasoning is not a generalizable skill that is transferrable to new clinical

problems, teaching reasoning principles in isolation from medical knowledge is not expected to improve performance [30, 31]. This principle of context-specificity, coupled with script theory, led to the development of multiple activities designed to structure students' growing medical knowledge in parallel with opportunities to reason through common clinical problems. For example, one session with the objective of enhancing students' reasoning around altered mental status starts with the development of a schema for altered mental status, asks students to use that schema to enable a hypothesis-driven history, and then encourages them to activate that schema while developing a differential diagnosis for a patient with confusion.

During the DR course students apply reasoning principles to common clinical syndromes in ten case-based small group sessions facilitated by faculty. They practice communicating their analysis through oral and written presentations, and they engage in exercises that organize their medical knowledge in diagnostically useful ways (e.g., schema development) and emphasize contrastive learning [10, 32]. Contrasting illness script exercises were chosen because they highlight differentiating features that will help students distinguish related conditions, which replicates the cognitive tasks of authentic patient encounters [32]. For example, in one session students develop a diagnostic schema for acute dyspnea and then practice contrasting illness scripts (e.g., pulmonary embolus, community acquired pneumonia, and chronic obstructive pulmonary disease) that should be considered when analyzing this problem. Because students were repeatedly challenged to develop and apply, not just recall, clinical approaches and knowledge, and then elaborate their thinking in a structured way during each small group, we conceived of these sequenced exercises as a form of practice.

Curricular integration: The reasoning curriculum features multiple opportunities for students to engage with clinical reasoning concepts from the beginning of medical school with increasing complexity (spiral learning) as students progress in their training [33].

In preparation for DR, students attend four half-day reasoning workshops starting in the first year. These sessions are timed to reinforce and extend medical knowledge synchronously taught in the basic science courses. For example, during a cardiology course, students attend a reasoning workshop on chest pain where the differential diagnosis includes both cardiac and non-cardiac diseases. Basic science concepts, which facilitate understanding and recall of clinical phenomenon [34–36], are reinforced by discussing links between mechanisms of disease and the clinical features that populate students' growing illness scripts.

Four small group reasoning sessions are held in the clinical years (one before acting internships and three before graduation) to reinforce the clinical reasoning framework. These advanced sessions focus on schemas, approaching management reasoning alongside diagnostic reasoning, and heuristics and errors. Figure 1 provides an overview of the clinical reasoning curriculum across all four years of medical school. Curricular activities are described in more detail in Supplementary Table 2.

Expanded conceptualization of diagnosis: In DR, two small group sessions focus on communication with clinical teams, patients, and families about the diagnostic process (discussing diagnostic uncertainty and relationships between goals of care and diagnosis). Three patient and provider panels address the impact of implicit bias on

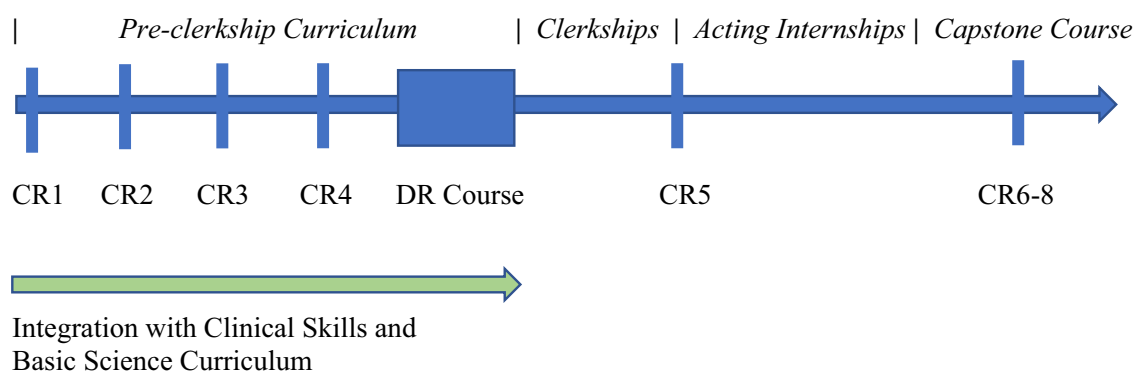


Figure 1: UCSF School of Medicine Clinical Reasoning curriculum.

The clinical reasoning curriculum features spaced sessions anchored by the diagnostic reasoning (DR) course at the end of an 18 month pre-clerkship curriculum. Clinical Reasoning workshops one to four (CR 1-4) are integrated with the clinical skills and basic science curriculum. Clinical skills curriculum elements that reinforce clinical reasoning concepts (e.g., problem representation, diagnostic schema) include sessions on the hypothesis-driven physical exam. CR 5 occurs just before students start their acting internships, re-visiting and extending students' reasoning approaches. CR 6-8 cover advanced reasoning topics during students' capstone course prior to graduation.

diagnosis, interprofessional collaboration, and diagnostic error and its effect on patients and clinicians.

impractical to quantify the distribution of curricular time among the competencies.

Evaluation

Student evaluation: The UCSF School of Medicine randomly invites one-third of the students to complete required anonymous evaluations for each course. The DR course evaluation includes one question about the preceding clinical reasoning workshops, which occur before DR. Student evaluations are not collected for the individual clinical reasoning workshops prior to DR.

Curricular audit with SIDM-Macy diagnostic education competencies:

In 2019 the interprofessional SIDM-Macy collaborative published competencies for health professions education programs to improve the quality and safety of diagnosis [37]. SIDM subsequently published learning objectives and milestones for these competencies [38]. Adapting previously published quantitative [7] and qualitative [39] curricular audits against external standards, we reviewed all activities in the clinical reasoning curriculum to determine which SIDM-Macy competencies were addressed in the objectives and activities of the DR course and clinical reasoning workshops.

Components of each SIDM-Macy competency were rated as included, limited, or not included. A SIDM-Macy competency was rated as "included" if a session-level objective was linked to the competency. A SIDM-Macy competency was rated as "limited" if a session included content linked to the competency, but the competency-related content was not a focus of the session and was not included in session-level objectives. A SIDM-Macy competency was rated as "not included" if it was not represented in a session-level objective or in the content of a session. One investigator (DMC) performed the initial mapping of curricular activities to the SIDM-Macy competencies; a second investigator (SN) reviewed and revised this initial mapping. The authors met and resolved disagreements in classifications. We chose a qualitative approach to mapping since many sessions contained content that overlapped with multiple SIDM-Macy competencies and the time spent within each session on competency-related content varied widely. These factors made it

Results

Student evaluation data

Response rates to the DR evaluation were 100% in 2017 and 2018, 98% in 2019, and 78% in 2020. The overall quality of DR was not measured in the first year. Overall quality of DR (1 = poor, 5 = excellent) was 4.13 (n=46; SD 0.91) in 2018, 4.13 (n=47; SD 0.65) in 2019, and 4.18 (n=39, SD 0.76) in 2020. The average overall quality score of other pre-clerkship courses in the 2018–19 and 2019–20 academic years was 3.87 (range 2.94–4.69). Table 1 shows additional evaluation data from DR from 2017 to 2020.

Many student comments expressed appreciation for the opportunity to consolidate pre-clerkship knowledge through application to clinical cases (e.g., "*DR block helped me formulate everything I have learned in previous blocks into diagnostic schema and illness scripts that will come in handy on the wards.*"). Students also valued building diagnostic schema for common clinical problems and developing and comparing illness scripts (e.g., "*The most useful by far was going through schema for diagnoses. It allowed time to compare and contrast diagnoses while providing a logical framework for thinking about problems. I had been introduced to them before but found it incredibly helpful to do them for each small group and then work through the case. They became easier and easier and truly gave me a good foundation for HOW to think about diagnostic problems.*"). Students emphasized the importance of practicing problem representation

Table 1: Student evaluation data for the DR course from 2017 to 2020.

Evaluation item ^a	Mean ^b	SD	n
I found completing the illness script grids for the small group sessions in the diagnostic reasoning block helpful in reinforcing my clinical knowledge.	3.94/5 4.15/5 4.23/5 N/A in 2020	0.97 0.70 0.63	49 46 47
The lessons on using diagnostic schemas and compare/contrast strategies helped build my clinical knowledge.	4.27/5 4.30/5 4.53/5 4.46/5	0.78 0.81 0.55 0.72	49 46 47 119
I learned how to (1) formulate a problem representation and (2) how to justify my prioritized differential diagnosis.	4.27/5 4.33/5 4.60/5 (1)4.46/5; (2)4.36/5 ^c	0.67 0.76 0.50 0.66/ 0.65	49 46 47 119
I developed a foundational understanding of the biases which can contribute to diagnostic error.	4.22/5 4.22/5 4.34/5 4.34/5	0.80 0.84 0.79 0.67	49 46 47 119
I learned about the importance of self-reflection and practice in the diagnostic process to support life-long learning.	N/A in 2017 4.17/5 4.32/5 4.44/5	0.80 0.78 0.68	46 47 119
I developed the ability to utilize probabilistic reasoning (i.e., pre-test probability, test characteristics such as likelihood ratios) to inform thresholds for diagnostic testing.	4.22/5 4.09/5 4.19/5 4.34/5	0.71 0.89 0.90 0.82	49 46 47 119
I learned about the uncertainty inherent in all diagnostic evaluation.	4.29/5 4.26/5 4.21/5 4.41/5	0.71 0.83 0.93 0.72	49 46 47 119
I can begin to communicate diagnostic uncertainty to my clinical team.	3.86/5 4.07/5 4.32/5 4.13/5	0.71 0.80 0.86 0.82	49 46 47 119
I can begin to communicate diagnostic uncertainty to my patients.	3.80/5 3.91/5 4.02/5 3.99/5	0.79 0.76 0.90 0.85	49 46 47 119
I am more confident in my ability to mentally prepare to see a patient in the clerkships (e.g., by reviewing my diagnostic schema for a given problem).	N/A in 2017 3.98/5 4.02/5 4.26/5	0.54 0.92 0.71	46 47 119
I am more confident in my ability to communicate my diagnostic reasoning orally to my team	N/A in 2017 4.04/5 4.36/5 4.24/5	0.67 0.70 0.74	46 47 119

Table 1: (continued)

Evaluation item ^a	Mean ^b	SD	n
I am more confident in my ability to communicate my diagnostic reasoning in a medical note.	N/A in 2017 4.00/5 4.32/5 4.24/5	0.76 0.69 0.74	46 47 119
I plan to use compare/contrast illness script grids during F2 Clerkships as I build my clinical knowledge.	N/A in 2017 3.91/5 4.34/5 4.00/5	0.89 0.70 0.94	46 47 119
The diagnostic reasoning component of the Clinical Microsystems Clerkship introduced me to a basic framework for how to think through a clinical case (including problem representation and summary statements, illness scripts, diagnostic schema, hypothesis-driven history, and exam). ^d	4.24/5 4.46/5 4.51/5 4.49/5	0.80 0.62 0.50 0.65	49 46 47 119

^aItems on a five-point scale: 1, strongly disagree; 2, disagree; 3, neutral/undecided; 4, agree; and 5, strongly agree; N/A, not asked. ^bEvaluation data presented for each item from 2017 (top row), 2018 (second row), 2019 (third row), 2020 (bottom row). The 2020 data represents student perceptions of the DR course in the midst of the COVID-19 pandemic when all pre-clinical curriculum at UCSF was being delivered virtually. Additionally, evaluation data was collected from more students in 2020 due to a temporary change in UCSF's evaluation policy. ^cQuestion was split into two parts in 2020. ^dQuestion asked students about the foundational reasoning workshops held prior to DR, which are contained within a longitudinal course called Clinical Microsystems Clerkship.

articulation and learning to communicate their reasoning in anticipation of their clinical rotations (e.g., “*I really feel like after [DR] block I have a strong understanding of what makes a good and dynamic problem representation,*” “*I felt that each small group taught me so many different aspects of writing a note and giving oral presentations and I feel prepared to enter the wards.*”). Students also appreciated hearing how clinicians approached diagnostic error and managed its impact. We did not conduct a formal qualitative analysis of student comments [40].

Curricular audit

Table 2 maps DR course and spaced curricular activities to the SIDM-Macy competencies. Supplementary Table 1 maps DR course-level objectives to these competencies. Our audit demonstrated that our curriculum is heavily focused on individual cognitive competencies (with some

Table 2: Audit of UCSF clinical reasoning curriculum with SIDM-Macy competencies.

SIDM-Macy competency ^a [38]	Included in DR (or spaced activities)?		
	Yes	Limited	No Activity
I-1. Accurately and efficiently collect key clinical findings needed to inform diagnostic hypotheses. Use these tools appropriately and efficiently in the diagnostic process:	X		Multiple SP encounters focus on data collection
Communication skills	X		Two small groups focus on communication about the diagnostic process
History-taking	X		Multiple SP encounters focus on gathering findings for diagnosis
Physical examination	X		Multiple SP encounters focus on gathering findings for diagnosis; small group features physical exam as a reasoning tool
Record review		X	Small group focuses on electronic medical record in diagnosis
Diagnostic testing	X		Multiple small groups address diagnostic testing including session on Bayesian reasoning
Electronic health record		X	Small group focuses on electronic medical record in diagnosis
Health information technology resources		X	Small group focuses on electronic resources in diagnosis
I-2. Formulate an accurate problem representation expressed in a concise summary statement that includes essential epidemiological, clinical, and psychosocial information.	X		All reasoning small groups and several SP encounters feature problem representation
I-3. Produce a correctly prioritized differential diagnosis, including “can’t-miss” diagnoses.	X		All reasoning small groups feature prioritized differential diagnosis
I-4. Explain and justify the prioritization of the differential diagnosis by comparing and contrasting the patient’s findings and test results with accurate knowledge about prototypical or characteristic disease manifestations and atypical presentations, and by considering pathophysiology, disease likelihood, and clinical experience.	X		All reasoning small groups feature justifying and prioritizing the differential
I-5. Use decision support tools to improve diagnostic accuracy and timeliness, including:			
Point-of-care resources		X	Small group focuses on electronic resources
Checklists			X
Consultation		X	Two large groups focus on error and address consultation
Second opinions			X
I-6. Use reflection, surveillance, and critical thinking to:			
Improve diagnostic performance	X		Three large groups on error address improving diagnostic performance
Mitigate detrimental cognitive bias throughout the clinical encounter	X		Two large groups on error address mitigating cognitive bias
Discuss and reflect on the strengths and weaknesses of cognition, the impact of contextual factors on diagnosis, and the challenges of uncertainty	X		Multiple small and large groups address cognitive errors, contextual factors, and uncertainty
Demonstrate awareness of atypical presentations, information that is missing, and key findings that don’t “fit”		X	Two small groups address atypical presentations
T-1. Engage and collaborate with patients and families, in accordance with their values and preferences when making a plan for diagnostic evaluation.	X		Two small groups focus on diagnostic collaboration with patients and families
Listen actively, encourage questions, and be alert to new or changing information.		X	Patient video vignettes in several small groups model active listening, encouraging questions
Explain the diagnostic process, including the patient’s and family’s role in helping to identify the most likely diagnosis.		X	Multiple SP encounters emphasize asking patients for input
Share appropriately when diagnostic uncertainty exists.		X	Small group focuses on diagnostic uncertainty

Table 2: (continued)

SIDM-Macy competency ^a [38]	Included in DR (or spaced activities)?			
	Yes	Limited	No	Activity
T-2. Collaborate and communicate effectively throughout the diagnostic process with other health care professionals including:				
Nurses		X		Advanced small group discusses collaboration with nurses
Physicians		X		Two large groups on error emphasize collaboration with other physicians
Physician assistants			X	
Radiologists		X		Two large groups on error emphasize collaboration with radiologists
Laboratory professionals			X	
Pharmacists		X		Large group on error emphasizes collaboration with pharmacists
Social workers			X	
Physical therapists		X		Large group on error emphasizes collaboration with physical therapists
Medical librarians			X	
Acknowledge and challenge authority gradients constructively, especially between clinicians, patients, and their families.		X		Two small groups emphasize communication with patients/families
T-3. Apply effective strategies at transitions of care to facilitate accurate and sufficient information transfer about the diagnosis, including any pending workup and areas of uncertainty. Close the loop on test result communication and clarify expectations with the team for test result follow-up.			X	
S-1. Discuss how human factors contribute to diagnostic safety and error by identifying how the work environment influences human performance. Take steps to mitigate common systems factors that detract from diagnostic quality and safety.	X			Two large groups on error and one small group focus on human factors
Use local resources (including people, teams, and technology – especially the electronic health record) effectively and efficiently to optimize patients' access to health care, diagnostic testing services, and appropriate experts for consultation.			X	
S-2. Advance a culture of diagnostic safety that encourages open dialog and continuous learning from analysis and discussion of excellent diagnostic performance, near misses, and errors.	X			Three large groups on error and one small group emphasize building a culture of diagnostic safety
Give and receive feedback at an individual and team level to improve subsequent diagnostic performance.			X	
S-3. Disclose diagnostic errors and missed opportunities transparently and in a timely manner to patients, families, team members, supervisors, and appropriate quality and risk management staff.			X	

^aLengthier competencies have been split into segments to bring more granularity to their representation in the DR course and related spaced activities. DR, diagnostic reasoning; SP, standardized patient; UCSF, University of California, San Francisco.

gaps such as decision support tools) with less emphasis on team and systems-based competencies. Team competencies that were addressed were present only in a 'limited' fashion. Half of the SIDM-Macy systems-based competencies were not included in the curriculum.

Discussion

Our experience demonstrates that reasoning concepts can be successfully introduced during the pre-clerkship phase of medical school. Evaluation scores were high

and improved over time. After completing the pre-clerkship reasoning curriculum, students reported high self-efficacy with applying clinical reasoning concepts and communicating their reasoning to supervisors.

Our clinical reasoning curriculum differs from other published undergraduate medical education (UME) clinical reasoning curricula in four key ways: 1) an emphasis on building knowledge structures (illness scripts and diagnostic schema) in tandem with reasoning practice, 2) an expanded conceptualization of the diagnostic reasoning process that incorporates the role of teams (patients, families, and interprofessional colleagues) and communication, 3) accordance with recommendations from national and international surveys of educators for UME clinical reasoning instruction to be longitudinal [4, 41–44], and 4) integration with basic science and clinical skills courses.

While we have established a longitudinal footprint in the pre-clerkship curriculum and reinforced reasoning education for senior students, we have not formally integrated reasoning education into clerkships. Filling this gap will require coordination with individual clinical departments. A fully realized integrated reasoning curriculum that spans courses and clerkships over four years, addresses individual cognition, systems, and teams, and explores diagnostic and management reasoning will require training faculty who teach in clerkships about clinical reasoning frameworks. Content and methods from clinical reasoning curricula in graduate medical education may inform sessions for advanced medical students [14, 45–49].

While student evaluations and assessments can help determine whether curricular objectives have been met, they do not provide insight into the objectives themselves. To advance the field of diagnosis education, educators should begin using multi-modal evaluation strategies to update reasoning curricula. Our curricular audit using the SIDM-Macy competencies showed us that we had a disproportionate emphasis on individual (cognitive) competencies with inadequate attention to systems and team factors in diagnosis. This skewed emphasis reflects how script theory, a dominant paradigm in the clinical reasoning literature for the past 30 years, heavily informed our original design.

While some of our objectives mapped with team and systems-based competencies, it is evident that we must expand our instruction in these areas [50]. The SIDM-Macy competencies focusing on transitions of care, systems factors that facilitate timely and accurate diagnoses and diagnostic error avoidance, and the use of local resources to optimize diagnostic care are not well represented in our curriculum. While we included discussions of the roles of

physicians, nurses, pharmacists, and physical therapists on the interprofessional diagnostic team, our audit highlighted the need to incorporate other key team members including physician assistants, social workers, medical librarians, and laboratory professionals [51–53].

Our interim course analysis also provided an opportunity to reflect on another important evolution in health professions education: anti-racism. The reasoning community is beginning to bring long overdue attention to disparities in diagnosis [54, 55]. While our course highlights the connection between patients' backgrounds and identities and the impact of implicit bias on the diagnostic process, we noted an inadequate emphasis on the impact of structural racism and other forms of oppression on the diagnostic process.

Our evaluation data and audit have several limitations. Our evaluation data include information from a random sample of each class. Additionally our data represent student self-perceptions; we have not established that our assessment structure identifies students who will need extra support during clerkships to meet expectations for clinical reasoning such as functioning at the interpreter level in the RIME (Reporter, Interpreter, Manager, Educator) evaluation scheme [56]. Mapping of our curricular objectives would have been enhanced by more precise definitions in the SIDM-Macy competencies, which would have allowed for more granular comparison with our course activities. In their scoping review of curriculum assessment, Khan et al. identify two parallel approaches – the reviewer's approach (comparison against an external standard) and the interpreter's approach (examining why standards have or have not been met) [57]. We did not engage in the latter, which could have yielded insights into enablers and barriers to improvement.

To address the persistent problem of diagnostic error, it is important to update clinical reasoning curricula so that they are situated in the modern practice of healthcare and highlight individuals, systems, and teams. Clinical reasoning curricula must continually improve; this process can be facilitated by interim analyses and comparison to external standards. Course and clerkship directors can analyze the comprehensiveness of their clinical reasoning instruction using both the SIDM-Macy competencies and the future directions we have set for our reasoning curriculum.

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Informed consent: Not applicable (use of anonymous student course evaluations was granted exempt status by the University of California, San Francisco Institutional Review Board).

Ethical approval: Ethical approval for use of student evaluations in this work was granted through exempt status by the University of California, San Francisco Institutional Review Board.

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Supplemental Table 1: Diagnostic Reasoning course objectives mapped to the SIDM-Macy competency domains

Diagnostic Reasoning (DR) Course Objectives	SIDM-Macy Competency Domain [37]
• Explain the role of script theory in the diagnostic process • Apply script theory when working through clinical cases • Develop illness scripts with discriminative power that underpin the differential diagnosis for core clinical syndromes by using vertical reading and a compare/contrast approach • Differentiate related illness scripts in the context of a clinical case • Apply diagnostic schema when preparing for and carrying out hypothesis-driven clinical encounters • Demonstrate the ability to distill patient data into succinct problem representations using medical terminology and culminating in thorough summary statements • Generate prioritized differential diagnoses supported by history and physical evidence • Clearly communicate the problem representation and prioritized differential diagnosis verbally and in writing for core clinical syndromes • Describe how Bayesian reasoning can inform and improve diagnostic reasoning and high value care • Apply Bayesian concepts to diagnostic decision-making in clinical cases • Demonstrate humility in diagnostic reasoning through an appreciation for the uncertainty inherent in all clinical decisions	Individual (I) Competencies: Demonstrate clinical reasoning to arrive at a justifiable diagnosis (an explanation for a health-related condition)
• Summarize how the diagnostic process is impacted when caring for patients across the life cycle (e.g. older adults, children) • Explain the importance of acknowledging and communicating diagnostic uncertainty to colleagues and patients • Recognize the value of seeking feedback on diagnostic decisions and collaborating with interprofessional colleagues to enhance diagnostic accuracy • Apply key aspects of relationship-centered communication throughout the diagnostic process	Team (T) Competencies: Partner effectively as part of an interprofessional diagnostic team. Communicate effectively and solicit information from all members of the team (including the patient and family) to create a shared mental model of a patient's illness and the plan for diagnostic evaluation.
• Describe and recognize implicit bias and other cognitive biases • Describe high-risk situations in the clinical setting that predispose clinicians to make errors in diagnostic reasoning • Recognize the strengths and weaknesses of electronic resources during the diagnostic process	Systems (S) Competencies: Identify and understand the systems factors that facilitate and contribute to timely, accurate diagnoses and error avoidance
• Explain how the tenets of medical ethics integrate with and impact the diagnostic process	<i>No pertinent SIDM-Macy competency</i>

Supplemental Table 2: Diagnostic Reasoning course and associated spaced activities

Curricular Element	Content	Educational Strategies
Foundational Reasoning Workshops (CR 1- 4)	• 4 half-day reasoning workshops, each focused on a core clinical syndrome (chest pain, transient loss of consciousness, red leg, vertigo), linked to subjects covered in concurrent basic science courses • Problem representation, illness scripts, and diagnostic schema are introduced	• Learning is scaffolded by providing partially completed solutions (e.g. partially completed illness scripts and diagnostic schema) in small groups • Student session guides for small groups include just-in-time prompts (e.g. components of a problem representation)
DR Small Groups	• 7 case-based sessions with greater complexity than in foundational workshops: abdominal pain in a toddler, respiratory distress in an infant, dyspnea in an older adult, weakness, altered mental status, hypotension in an older adult, abdominal pain and uncertainty in diagnosis in pregnancy • 1 case-based session on the impact of goals of care on the diagnostic process • 1 case-based session on ethical dilemmas in the diagnostic process • 1 case-based session on communicating reasoning in oral presentations • 1 case-based session on Bayesian reasoning in diagnosis	• Students contrast illness scripts using ‘ScriptSmart’ (illness script grid designed for use on mobile devices) and receive feedback from course leadership • Students present and receive feedback on their Assessment and Plan from faculty during small group sessions • Standardized patients and videos are used in several sessions to practice communication skills relevant to the diagnostic process
DR Large Groups	• 2 case-based ‘Clinical Reasoning in Action’ sessions with master clinicians narrating their diagnostic thinking • 1 case-based session on Diagnostic Error with an emphasis on risks related to the electronic medical record and the value of interprofessional collaboration and diagnostic teamwork • 1 session on Implicit Bias in diagnosis (patient shares family’s story) • 1 session “When we make mistakes” (patient and faculty panel)	• Employ stories to convey clinical reasoning, the impact of diagnostic error on patients, families, and healthcare providers, normalize diagnostic error, and develop personal coping strategies
Advanced Reasoning Workshops (CR 5-8)	• 4 clinical reasoning workshops—1 prior to acting internships, and 3 prior to graduation— where students re-visit core diagnostic reasoning concepts in more complex cases, and learn about management reasoning, heuristics, and cognitive biases	• Sessions include discussion of the interprofessional team in the reasoning process • Clinical topics based on a survey of fourth year medical students; highlight high stress/urgent clinical scenarios
Curricular Links to other Courses	• Clinical Skills Curriculum: Hypothesis-driven physical exam series, preceptorship reflections, and	• Integration of the clinical reasoning curriculum and the general clinical skills curriculum

	clinical skill assessments all reinforce the same CR concepts/terms • Basic Science Curriculum: Foundational clinical reasoning workshops are timed to reinforce and extend content taught in basic science curriculum • Interprofessional Curriculum: Students participate in an experiential, longitudinal interprofessional communication curriculum with learners from other health professions schools • Systems Science Curriculum: Students conduct system improvement projects in the clinical setting and learn foundational systems science components	offers opportunities for students to reinforce reasoning concepts in other contexts throughout the pre-clerkship phase of their education • Intentional integration with the basic science curriculum encourages students to connect their medical knowledge with clinical reasoning skills • Student exposure to an interprofessional and systems science curriculum is linked with the reasoning process during the DR course
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