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'Thinking Like a Clinician:' A Pedagogical Approach for Teaching Foundational Clinical Reasoning Skills within a Pre-Preprofessional Undergraduate Anatomy Curriculum

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Competent clinical reasoning skills are necessary for providing safe and effective health care. Professional level health science education programs are keenly interested in fostering effective clinical reasoning skills. As such, many programs expect students to engage in complex clinical reasoning tasks early in their education. However, early novice students may not be entering programs with the requisite skills to meet those expectations. Pre-professional undergraduate anatomy curricula are prerequisites for professional education programs across the health sciences and could be an appropriate context for developing initial clinical reasoning skills, providing a "cognitive head start" for students matriculating into professional health science education programs. This article describes an evidence-based pedagogical approach for teaching initial clinical reasoning skills within an undergraduate anatomy curriculum. While an undergraduate anatomy curriculum is the context in this case, this approach is based on high-level pedagogical concepts and could be modified and adopted across the spectrum of disciplines that prepare students for professional level health science education programs.

"Thinking Like a Clinician", a pedagogical approach for teaching foundational clinical reasoning skills in a pre-baccalaureate undergraduate anatomy course, emerged from a need and an opportunity. Proficient clinical reasoning skills are critical for providing safe and reasonable treatment and managing patient care (Liou et al., 2016). Students are expected to engage in complex clinical problem-solving tasks very early on in many professional health science education programs (Benner, Sutphen, Leonard, & Day, 2010; Custers, 2018; Christensen, 2016). However, clinical reasoning skills are not inherent (Benner et al., 2010) and early novices may not have acquired the underlying skillset to meet those expectations (Levett-Jones et al., 2010). For example, Norman et al. (2017) found novice students in professional health science education programs struggle to integrate basic sciences, like anatomy, within clinical reasoning tasks. Thus, professional health science education programs have expressed the need for, and are keenly interested in, fostering effective clinical reasoning skills (Liou et al., 2016; Gilland, 2014; Richard et al., 2017). Clinical reasoning (CR) is the process by which health care practitioners assess patients, collect detailed clinical cues, construct a diagnosis, determine the appropriate course of action, and evaluate the outcome of that action (Brown, 2018). Like problem-solving tasks across disciplines, CR both requires critical thinking skills as well as engaging in both deductive and inductive reasoning processes.

There have been calls for CR instruction to begin early in health science curricula (Elizondo-Omaña, et al., 2010; ten Cate, 2018) although this recommendation appears to be aimed at professional and graduate level programs. Therein lies the opportunity. Novice students need intentionally-planned and well-supported practice opportunities in order to progress toward mastery of content and competency in clinical problem solving (Young, Van Merriënboer, During, & ten Cate, 2014). This type of instruction takes time. Yet, professional health science programs are stretched thin as they try to balance increasing curricular demands and compressed instructional time (Drake, McBride, & Pawlina, 2014). Pre-professional undergraduate anatomy courses (henceforth undergraduate anatomy) are prerequisites for professional education programs across the health sciences. As such, undergraduate anatomy courses can serve as an appropriate context for developing initial clinical reasoning skills as a "cognitive head start" for students matriculating into professional health science education programs.

The purpose of this article is to outline a pedagogical approach for teaching students to "think like clinicians" in the context of an undergraduate anatomy curriculum. Specifically, this article discusses the implementation of evidence-based instructional methods and the development of a CR assessment. The "Thinking like a Clinician" approach, developed by an undergraduate anatomy instructional team at a large upper Midwestern research university, was used in a large lecture format with approximately 170-200 students per section. Initial evaluation has demonstrated that this approach positively impacted the development of initial clinical reasoning skills without compromising the acquisition of anatomical knowledge (Anderson, Stamm, Hills-Meyer, & Brown, 2020).

Overview of Clinical Reasoning Processes

The phrase, "Thinking Like a Clinician", refers to the underlying cognitive operations involved in clinical reasoning. Clinical reasoning (CR) is a practitioner's ability to analyze a patient's clinical situation, differentiate salient clinical cues, integrate discipline knowledge, make a judgement, and determine a course of action (Benner et al., 2010).

Current theoretical cognitive models of CR are based on the interplay between analytic and intuitive thought processes (Croskerry, 2009; Custers, 2013; Norman et al., 2017). Croskerry (2009) proposed a "Universal Model of Diagnostic Thinking", grounded in dual-process theory, or System 1 and System 2 thinking. System 1 thinking relies on pattern recognition that derives from experience and a substantial network of prior knowledge. This type of thinking is quick, intuitive, and often occurs without conscious recognition (Croskerry, 2009; Norman et al., 2017). System 2 thinking is a slow analytic reasoning process, which includes a systematic review of available information (Croskerry, 2009).

According to Custers (2013), the cognitive continuum theory (CCT) is a more accurate cognitive model for CR. Like dual-processing theory, the CCT acknowledges that clinical reasoning is based in both analytic and intuitive thought processes. Custers (2013) argues that these are not separate cognitive systems, but a continuum that extends from purely analytic to purely intuitive thinking. In this model, CR tasks fall along the continuum depending on the context of the task and the experience of the practitioner (Custers, 2013, 2018).

Key Principles in Clinical Reasoning Instruction

Regardless of their differences, both dual-processing and the CCT model recognize that novices and experts engage in CR tasks differently. Current research suggests expert clinicians rely primarily on intuitive processes. Extensive experience and highly integrated cognitive schema allow experts to quickly identify patterns and connect illness scripts with little deliberate cognitive effort (Custers, 2013; Ericsson, 2015; Norman et al., 2017).

Novice students lack the well-developed cognitive knowledge networks that enable quick analysis, and efficient knowledge retrieval, manipulation, and application (Norman et al., 2017; Young et al., 2014). Therefore, early clinical reasoning instruction should focus on strengthening foundational analytic thinking processes (Custers, 2018). Over time, students build on that foundation and progress toward the intuitive thinking required for advanced clinical problem solving (Custers, 2018; Ericsson, 2015).

Analytic thinking carries a high cognitive load, which requires extensive cognitive effort and puts high demands on novice students' working memory (Norman et al., 2017, Young et al., 2014). Custers (2018) points out many novice students have underdeveloped analytic schema, which results in problem solving tasks carrying an even higher cognitive load. This can quickly overwhelm novices' cognitive capacity (Sweller, Ayres, & Kalyuga, 2011) and may impede knowledge and skill acquisition, and stymie further CR skill refinement (Kirschner, Sweller, & Clark, 2006; Likourezos & Kalyuga, 2017; Yong et al., 2014). Managing that cognitive load is essential for novice students (Young et al. 2014).

A Foundational Clinical Reasoning Model for Pre-professional Undergraduate Students

As previously discussed, novice students tend to have weak foundational analytic skills, which can detrimentally increase cognitive load imposed by clinical problem-solving tasks. One way to counter this, van Merriënboer (2019) suggests, is to expose novice students to an initial cognitive model as they begin to develop their own preliminary analytic schema. Developing an initial cognitive model requires decomposing problem-solving tasks into component cognitive operations.

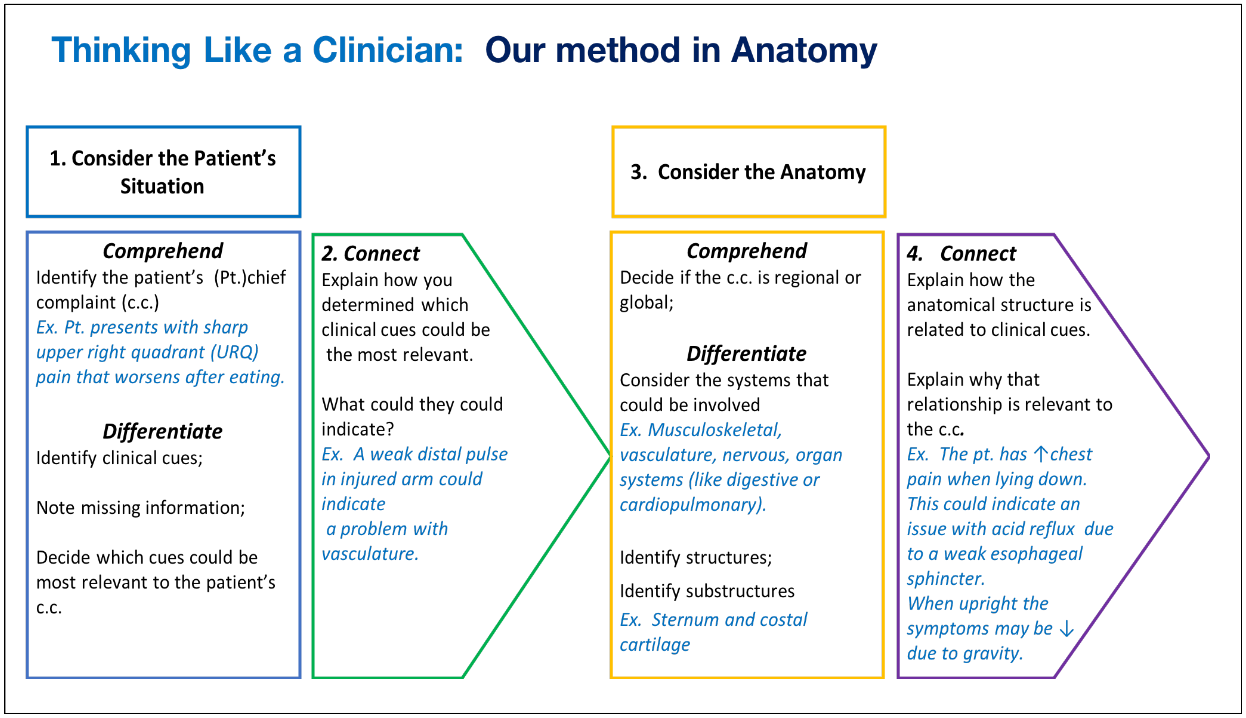
The initial clinical reasoning cognitive model developed for the undergraduate anatomy students is based on the Clinical Reasoning Cycle (CRC) constructed by Levett-Jones et al. (2010). Although the CRC is intended for professional level students in a clinical setting, it provides a conceptual framework that can be adapted and appropriately leveled for use with undergraduate students in a classroom setting. The CRC model consists of two parts: 1) a nine-step CR process which moves from initial patient assessment to making a diagnosis and then deciding on a course of action; and 2) eleven associated cognitive operations embedded within each step.

While the CRC is comprehensive, asking early novice students to retrieve and apply a nine-step process and engage in eleven associated cognitive operations would further burden their cognitive load rather than act as a cognitive scaffold. Therefore, the initial clinical reasoning cognitive model developed for undergraduate anatomy is limited to very four basic analytic clinical reasoning tasks: 1) *Consider* the Patient's situation, 2) *Determine* the most relevant clinical cues, 3) *Consider* the anatomy, and 4) *Draw* a conclusion. Embedded within those steps are three analytic cognitive operations: a) *Comprehend*: survey the situation, develop a broad understanding; b) *Differentiate*: identify salient symptoms or structures, determine which are most likely relevant; and c) *Connect*: synthesize information, make logical evidence-based inferences. Note that each of these steps build on one another, with two cycles (Steps 1 and 2 and Steps 3 and 4) of Comprehend, Differentiate, then Connect.

To operationalize this conceptual model, the instructional team developed an advance organizer that graphically represents the four steps and associated

Figure 1

The Undergraduate Anatomy Clinical Reasoning Model Advance Organizer



cognitive operations (Figure 1). Advance organizers can take many forms, but generally their purpose is to provide, "...a relevant cognitive structure to aid in meaningful learning" (Tennyson & Volk, 2015, p. 710), and positively influence the development of preliminary problem-solving schema (Gurlitt, Dummel, Schuster, Nückles & 2012).

The "Thinking Like a Clinician" advance organizer is designed as a very simple flowchart. Built into the advanced organizer are explicit cognitive prompts known as subgoals. Subgoals provide slightly more procedural direction. By adding subgoals, the advance organizer serves as a concrete heuristic scaffold which can further decrease cognitive load by making the cognitive operations explicit, promoting recall, and providing a structure for information manipulation and application (Margulieux & Catrambone, 2016).

Evidence-based Practices for Teaching Foundational Clinical Reasoning Skills

At the center of the "Thinking like a Clinician" pedagogical approach are evidence-based instructional methods that have been modified for a pre-clinical undergraduate audience. Specifically, these practices are aimed at fostering foundational analytic clinical reasoning skills detailed in the Undergraduate Clinical Reasoning Model while scaffolding instruction to offset cognitive load. Implementing these practices required substantial structural changes to course content organization and delivery methods.

Case-based Instruction

Students practice applying the undergraduate anatomy clinical reasoning model during case-based instruction, which ten Cate, Custers, & Durning (2018) argue should be the standard for pre-clinical students. Additionally, Lazarus, Chinchilli, Leong, & Kauffman (2012) encourage the use of case-based instruction in anatomy education to enhance knowledge acquisition, retention, and transfer.

Effective case-based instruction is intentionally designed to align with students' current knowledge and skill level. As students work through appropriately leveled clinical cases, they begin to crystallize "a systemic analytical reasoning habit" (ten Cate & Durning, 2018, p. 63). While the authors cited above investigated the efficacy of case-based clinical reasoning instruction with medical students, studies have shown case-based instruction generally improved learning outcomes in undergraduate science courses (Kuklak & Newton, 2015). Appropriate leveling is key: limiting novel elements while scaffolding task complexity reduces cognitive load and promotes the development of problem-solving schema (Sweller et al., 2011).

Figure 2
Example text of a short case vignette. During class students would work through a series of questions like these

A basketball player experiences a valgus force when she is hit on the lateral aspect of her knee. She immediately falls to the ground in pain. As an athletic trainer, what structures are you most concerned about as a result of this force? Explain how you came to this conclusion?

Figure 3
Example of a longer case vignette

Patient presentation:

You are a student physician assistant on sports medicine rotation. A 22 y.o. female is in the assessment room complaining of chest pain. She throws discus, hammer, and shot, for the local college track and field team so a skeletomuscular injury is always a possibility. During the initial assessment the athlete complains of an hx of chest pain, a progressive hoarse cough, and a deep burning sensation near her sternum. You palpate the region, but there is no superficial tenderness. She explains that it hurts more at night. At night she also tends to feel nauseous and has hiccups, along with the hoarse cough which seems to get worse as she is trying to fall asleep. You ask her to point to the specific location of the pain, but she can't identify it. Most of the time it is near her sternum, but it can also be diffuse, near the u.l.q. of her abdomen and lower left side of her rib cage.

The cases developed for the undergraduate anatomy course present only anatomically-related dysfunctions or pathologies. This substantially limits cognitive load because students are only required to work with anatomical knowledge rather than attempt to integrate knowledge from multiple disciplines. The cases are presented as a series of short vignettes or complex longer vignettes. Shorter vignettes concentrate on one structure or discreet body region (i.e., the knee) and a direct mode of injury (Figure 2).

Longer vignettes present a patient with a more complex set of non-specific symptoms, or clinical cues. The case is structured as a simplified version of a patient history a practitioner might encounter in a typical electronic health record in a clinical setting (Figure 3). Both types of cases, whether done as a series of smaller vignettes or one to two longer case vignettes, typically take 15-20 minutes of class time. The cases, referred to as Collaborative Questions, are distributed throughout a lecture period. This format, referred to as active lecture, is discussed later in this article.

Region-based course organization. For the most part, the curricula of conventional basic science courses, like anatomy, are organized around body systems (Arslan, 2014). However, the cases used in clinical instruction should reflect "the way a patient presents at a clinician's office" (ten Cate, 2018, p.10). The clinical cases developed for the undergraduate anatomy course are designed to reflect how practitioners need to integrate anatomical knowledge during clinical problem solving; namely, to visualize the geography of the human body and analyze relationships and dependencies of structures from multiple systems at the same time. In light of this, course content was organized into body region-based units of instruction: a) introduction to anatomy (includes tissues); b) thorax, abdomen, and pelvis; c) head and neck; and d) upper and lower extremities. This is a rather novel approach in an undergraduate anatomy course. In fact, after an extensive search, the authors found only one reference to an undergraduate anatomy course employing a region-based curriculum (Spudich & Stanford, 2013).

Active Lecture. A substantial amount of in-class instructional time in the undergraduate anatomy course is dedicated to case-based clinical problem-solving. This required a shift from a traditional lecture format to an active lecture format. Active lectures are characterized by cycle of short periods of teacher-centered content delivery, punctuated by student-centered learning activities that give students facilitated time to process, manipulate, and apply new material (Pickering & Roberts, 2018). There are different types of activities that make up the active portion of a class period in the undergraduate anatomy course, including collaborative diagramming and interactive demonstrations. However, case-based instruction, or Collaborative Questions, makes up the bulk of the student-centered activities. During Collaborative Questions, students work with a small group of peers to

Figure 4

Excerpt from an instructor Think-aloud protocol. This case featured a patient with a spleen laceration.

INSTRUCTOR SCRIPT: Lacerated spleen case.

I. **“***Let’s try this question using our clinical reasoning process. Go ahead and take out your card.”*

II. **How would you summarize the patient’s chief complaint?**”

A. *“Our first step is to consider the patient’s situation. This case is already pretty short, but take a moment and try to visualize what is happening, and create a mental clinical picture.*

III. *“Let’s move on to Considering Clinical Cues”*

A*. “Talk with the people around you again and try:*

1. Pick-out or discriminate the most relevant clinical cues

2. Note the gaps. What do you wish you knew about this case?

3. Explain to each other what the relevant cues might indicate?”

B. Point our which clinical cues you find pertinent and explain what they might indicate.

1. “There are major gaps in the information. We don’t know her vitals like temperature, heart rate, ox levels. But there are some very important clinical cues to pay attention to.”

“a. Location is critical. Tells us what structures may have sustained damage.

b. The fact her condition is deteriorating might indicate whatever damage was sustained is causing symptoms to become worse

c. The most alarming symptom, most likely the chief complaint, is that she is slipping in and out of consciousness. Think about it. What types of damage in the abdominal area might result in loss of consciousness? She didn’t get kicked in the head.”

Protocol Continues

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work through the case, using the undergraduate anatomy clinical reasoning model. Instructors and teaching assistants circulate, coaching the students through the process and answering questions.

While the pacing is different and needs to be planned intentionally, the active lecture approach has been successfully implemented in both 50- and 75-minute undergraduate anatomy lecture times frames, with 50-minute lectures offered three times a week, and 75 twice a week.

Supplemental Blended Course Structure. The active lecture format in the “Thinking like a Clinician” pedagogy is contingent on two preconditions: 1) some didactic content needs to be removed from in-class instruction to accommodate case-based instruction and student-centered activities; and 2) students still need exposure to the didactic material to meet curricular expectations and fully participate in the Collaborative Question activities. Adopting a supplemental blended structure allowed the instructional team to build a course format that met those preconditions.

A supplemental blended structure preserves the general face-to-face course schedule while supplementing instruction with technology mediated content delivery (Twigg, 2003). Technology mediated content delivery in the undergraduate anatomy course takes the form of online modules that students are required to complete prior to coming to class. Students access these modules through the course site within the campus learning management system. Online modules consist of assigned textbook readings and instructor created video mini-lectures that feature functional anatomy demonstrations, and virtual anatomy tours via Visible Body, a 3-D anatomy atlas application. Students complete an online comprehension quiz at the end of each module. To receive credit, students must complete the online module and quiz prior to each in-class section. This policy helps ensure students are well-prepared to participate during in-class case-based instruction.

Worked Examples

Students are not expected to inherently know how to apply the Undergraduate Clinical Reasoning Model during case-based instruction. Therefore, along with in-class facilitated practice, worked examples play a critical role in the “Thinking like a Clinician” pedagogical approach. Worked examples, or problems worked by instructors in front of students to exemplify a process, significantly reduce cognitive load and improve novice students' initial skill acquisition during problem solving tasks (Kirschner et al., 2006; Likourezos & Kalyuga, 2017). This outcome, known as the "worked example effect", has been demonstrated repeatedly across a spectrum of disciplines and age ranges (Chen, Kalyuga, & Sweller, 2015; Sentz & Stefaniak, 2019). Worked examples can take a number of forms, but generally "provide learners with full guidance that contain key steps needed to solve a problem" (Chen et al., 2015, p. 689). Like an advance organizer, worked examples also provide novice students with an initial cognitive model, and reinforce development of their own problem-solving schema (Stark, Kopp, & Fischer, 2011). Worked examples in the undergraduate anatomy course take the form of Think-alouds and annotated exemplars.

Think-alouds. Worked examples via the Think-aloud method involve an instructor making their implicit thought processes explicit by deconstructing their thinking process, verbalizing both "what I am doing" as well as "why I am doing" while working through a problem-solving procedure (Hodges, 2014; Nilson, 2013). This instructional method of has a long history in K-12 pedagogy and is emerging as an accepted practice in clinical reasoning instruction (Pinnock, Young, Spence, Henning, & Hazell, 2015).

In the "Thinking like a Clinician" pedagogy, Think-alouds are a key feature of both in-class and online instruction. Instructors use Think-alouds to introduce and teach students how to work with the Undergraduate Clinical Reasoning Model. Figure 4 shows a portion of a Think-aloud protocol, or script. This script includes what the instructor plans to say (in italics). The scripts also include cues (in bold) reminding the instructors to explain their thinking processes. Instructors don't necessarily read from the script. Rather, in the process of developing detailed the scripts, the instructors practice deconstructing their own clinical reasoning processes and map them to the language used in the Undergraduate Clinical Reasoning Model.

In-class CR instruction is supplemented with online instructional videos featuring Think-aloud case walk throughs, similar to the instructor Think-aloud protocols used during in-class instruction. The online video modality provides additional instructional affordances. The videos are tightly scripted and concise, which ensures the Undergraduate Clinical Reasoning Model is explained in a consistent manner, reducing the reliance on instructor fidelity or experience with the Think-aloud method, and the constraints imposed by in-person instruction, like time. Additionally, the medium itself allows for an ancillary layer of visual and auditory signals that can further emphasize salient aspects of the clinical reasoning process (Brame, 2015).

Annotated Exemplars. We adopted annotated exemplars as a second worked example modality. Annotated exemplars provide model answers with written commentary. These have been shown to improve student learning outcomes. Typically, annotations explain how an example answer meets the parameters of the assignment. Annotations can be done by the student as a reflective practice or by the instructor to elucidate the internal logic of the answers construction (Carter, Salamonson, Ramjan, & Halcomb, 2019; Handley & Williams, 2011).

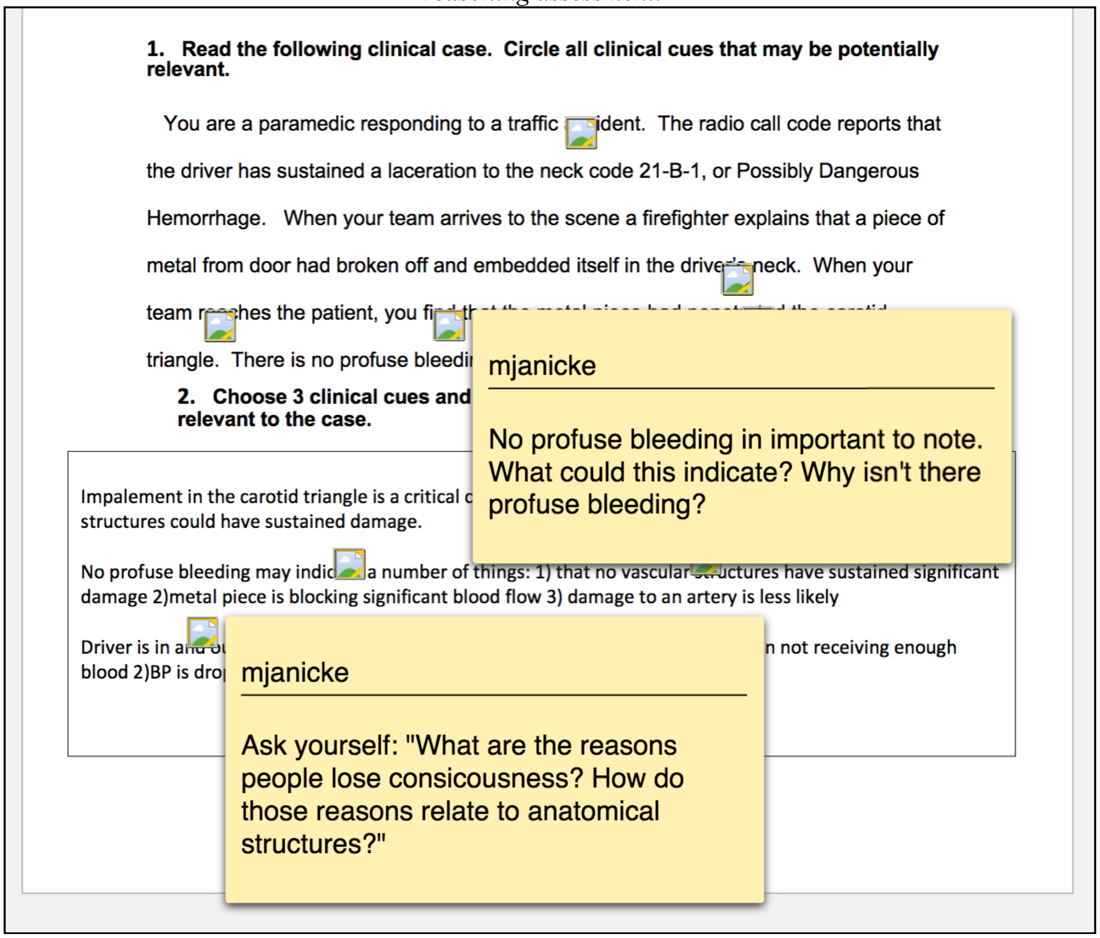
In the undergraduate anatomy course, students are provided with annotated exemplars after the first two clinical reasoning assessments (these assessments will be discussed later in this paper). The exemplars provide model answers that serve as an "answer key" of sorts, satisfying the students desire to know the "right" answer. The annotations also illustrate the syntax of each answer, sometimes down to specific sentence composition. However, the intention is not to have the students mimic, but to synthesize their own answers. Therefore, annotations also function as a written version of a Think-aloud, explicating the instructor's internal thought processes. The annotations are done using the Comments tool in Adobe Acrobat Pro and posted online in the course site within the campus learning management system. A segment from an annotated exemplar is provided in Figure 5.

After the third clinical reasoning assessment, students are again provided with an instructor developed exemplar. However, unlike the first two exemplars, the third exemplar is not annotated. Rather, students are asked, via an online short-answer quiz, to reflect on the model answers, decode the how the answers are structured, and compare the model answers to their own work. After completing this activity, students pre-plan a strategy for completing the final fourth written clinical reasoning assessment.

Assessing Foundational Clinical Reasoning Skill Development

Pre-clinical novice students should be evaluated on the expression of their analytic clinical reasoning process, the reasonableness, not necessarily accuracy, of their conclusions, and semantic quality and internal logic of their answers (ten Cate, 2018). Oermann (2018) suggests using clinical cases as the most appropriate method for assessing emerging analytic skills. ten Cate (2018) and Dory et al. (2016) also contend that a written case-based format is the most appropriate and practical method for measuring initial clinical reasoning skills in a pre-clinical setting. Dory et al. (2016) explain that written answers provide insights into students' reasoning processes, including how they gather, interpret, and rationalize their conclusions.

Figure 5
Segment from an annotated exemplar. Student would have access to an annotated exemplar after each clinical reasoning assessment.



Developing a Clinical Reasoning Assessment

Following these recommendations, the instructional team developed a case-based written clinical reasoning assessment and rating rubric. As the assessment was under development, instructors from professional level health-science programs were consulted, including a physical therapist, graduate level gross anatomy instructors, an occupational therapist, Doctors of Nursing practice, a Physician Assistant, and athletic trainers. A final version of the assessment was piloted during a summer session of the undergraduate anatomy course prior to implementing the assessment at scale.

The written assessments are administered four times per semester, during class, once per unit of instruction. Each written assessment takes approximately 12-15 minutes to complete. The format of each assessment is the same. First, students read a clinical case similar to the longer, more complex, vignettes used for in-class clinical reasoning practice. Following the case presentation, students are asked to complete four tasks that mirror the four steps in the Undergraduate Clinical Reasoning Model:

1) Read the following clinical case. Circle all clinical cues that may be potentially relevant.
2) Choose three clinical cues and explain how you determined each to be potentially relevant to the case.
3) List any potentially relevant anatomical structures that could be involved.
4) For each of the anatomical structures found most relevant, please describe why they may be related to the clinical cues you identified.

The written assessments are rated via a scoring rubric. Students can achieve a rating of 0 to 4 on each of the 4 tasks for a maximum of 16 points. Following the parameters described by ten Cate (2018), the rubric criteria evaluate the analytic cognitive operations

Table 1
Alignment of the Undergraduate Clinical Reasoning Model, Written Assessment, and Rubric

Steps in the Clinical Reasoning Model	Task on Written Assessment	Top-Level Criterion Description
1. Consider the patient's situation: Identify Chief Complaint; Differentiate relevant cues.	1. Read the following clinical case. Circle all clinical cues that may be potentially relevant**.**	1. *Comprehensive:* Identifies almost all clinical cues *Discriminative:* Avoids identifying irrelevant cues; precise
2. Connect: Determine most relevant cues.	2. Choose 3 clinical cues and explain how you determined each to be potentially relevant to the case.	2. *Discriminative:* Identifies 3 of the most relevant cues *Connective*: Complete logic pattern: Cue→ Indication→ Justification
3. Comprehend: regional or global Differentiate: Multiple systems that could be involved	3. List any potentially relevant anatomical structures that could be involved.	3. *Comprehensive:* Considers all relevant systems; *Discriminative:* Specific anatomical structures identified in detail
4. Connect: Explain how anatomical structure is related to clinical cues. Explain why that relationship is relevant to the c.c**.**	4. For each of the anatomical structures found most relevant, please describe why they may be related to the clinical cues you identified. Why might you have ruled other out?	4. *Discriminative:* Identifies all relevant anatomical structures from list. *Connective:* Complete logic pattern: Cue→ Indication→ Specific structure → Justification

embedded within the Undergraduate Clinical Reasoning Model, Comprehend, Differentiate, Connect, by assessing the semantic quality and internal logic of their written answers. Table 1 illustrates the alignment the of the Undergraduate Clinical Reasoning Model, the tasks on the written assessment, and the top-level rating criteria on the rubric. Note, that *Discriminative* is used instead of *Differentiate. Differentiate* was used for the students because it is a term more directly related to health care (i.e. differential diagnosis.)

Conclusion

It is possible and potentially necessary to foster the development initial clinical reasoning schema before novice students enter professional health science programs. Introducing clinical reasoning instruction in pre-professional undergraduate anatomy courses may be one way to accomplish this goal. This article presents the details of a pedagogical approach for teaching clinical reasoning skills in an undergraduate anatomy course built on these essential concepts: a) introduce students to an initial clinical reasoning model; b) ensure the model is aligned with their basic skills and knowledge level; c) use the model to scaffold clinical reasoning instruction; d) which in turn increases the efficacy of case-based instruction; (e) while at the reducing the inherent cognitive load of clinical reasoning tasks.

An initial evaluation of this approach has shown demonstrably positive results. Over the course of the 2018-2019 school year, the efficacy of the "Thinking Like a Clinician" pedagogical approach was evaluated via a quasi-experimental study. The intervention section (*n*=210) received direct clinical reasoning instruction. This group had access to the undergraduate clinical reasoning model advance organizer, the in-person and online Think-alouds, and the annotated exemplars. The comparison group (*n*=251) participated in the same curriculum, with the same case-based instruction, and clinical reasoning assessments. However, this group did not have access to the undergraduate clinical reasoning model advance organizer, nor Think-alouds or annotated exemplars. The initial result from the study showed that the intervention group significantly outperformed the comparison group on the clinical reasoning assessments. The groups did not differ significantly on more traditional multiple-choice exams that generally assessed retention of anatomical knowledge (Anderson et al., 2020). The most salient difference between the two groups was that it appeared that more students in the intervention group seem better equipped to organize their thoughts and articulate their reasoning process. One area for further research is to investigate if gains in CR skills as a result of the instructional intervention described in this article persist into professional programs when students are asked to approach more complex clinical cases.

Although undergraduate anatomy became the vehicle for this pedagogical approach in this instance, the underlying high-level pedagogical concepts that are the foundation of this pedagogical approach are context agnostic and could be adapted to many disciplines. This may be especially true for other prerequisite basic biology and life science courses for pre-health care students. For example, the initial clinical reasoning model and subsequent advance organizer could be modified to focus on concepts from introductory physiology, presenting cases with physiological pathologies rather than anatomical pathologies. Similarly, the pedagogical approach presented here could be modified for microbiology, toxicology, and aspects of kinesiology and sports science. Ultimately, our intention is not only to share the pedagogical methods we found promising but also to encourage educators to consider how undergraduate basic science courses, in this case anatomy, can contribute to the preparation of students matriculating into professional health sciences programs.

References

Anderson, M., Stamm, J.M., Hills-Meyer, P., & Brown, K. R. (2020). Integrating clinical reasoning skills in an undergraduate anatomy course. *The FASEB Journal(34)*1_Supplement

Arslan, O. E. (2014). Region vs. system-based anatomy: Efficacy and implementation. *American International Journal of Biology, 2*(3&4), 01-23. doi: 10.15640/aijb.v2.n3-4a1

Benner, P., Sutphen, M., Leonard, V., & Day, L. (2010). *Educating nurses: A call for radical transformation*. San Francisco, CA: Jossey-Bass.

Brame, C. J. (2015). *Effective educational videos.* Center for Teaching, Nashville, TN: Vanderbilt University. https://cft.vanderbilt.edu/guides-sub-pages/effective-educational-videos/

Brown, E. (2018). Clinical reasoning: An important aspect of clinical skills. *Clinician Today*. https://cliniciantoday.com/clinical-reasoning-an-important-aspect-of-clinical-skills/

Carter, R., Salamonson, Y., Ramjan, L. M., & Halcomb, E. (2018). Students use of exemplars to support academic writing in higher education: An integrative review. *Nurse Education Today*, *65*, 87-93. doi: 10.1016/j.nedt.2018.02.038

Chen, O., Kalyuga, S., & Sweller, J. (2015). The worked example effect, the generation effect, and element interactivity. *Journal of Educational Psychology, 107*(3), 689-704. doi: 10.1037/edu0000018

Christensen, L. S. (2016). The academic performance of students: Legal and ethical issues. In D. M. Billings & J. A. Halstead (Eds.), *Teaching in nursing: A guide for faculty* (5th ed., pp 35-54). Amsterdam, Netherlands: Elsevier.

Croskerry, P. (2009). A universal model of diagnostic reasoning. *Academic Medicine, 84*(8), 1022-1028. doi: 10.1097/ACM.

Custers, E. J. F. M. (2013). Medical education and cognitive continuum theory: An alternative perspective on medical problem solving and clinical reasoning. *Academic Medicine, 88*(8), 1074-1080. doi: 10.1097/ACM.0b013e31829a3b10

Custers, E. J. F. M. (2018). Training clinical reasoning: Historical and theoretical background. In O. ten Cate, E. J. F. M. Custers, & S. J. Durning (Eds.), *Principles and practices of case-based clinical reasoning education: A method for pre-clinical students* (pp. 21-33). New York, NY: Springer International Publishing.

Dory, V., Gagnon, R., Charlin, B., Vanpee, D., Leconte, S., Duyver, C., Young, M., & Loye, N. (2016). In brief: Validity of case summaries in written examinations of clinical reasoning. *Teaching and Learning in Medicine, 28*(4), 375-384. doi: 10.1080/10401334.2016.1190730.

Drake, R. L., McBride, J. M., & Pawlina., W. (2014) An update on the status of anatomical sciences education in united states medical schools. *Anatomical Sciences Education, 7*(4), 321-325. doi: 10.1002/ase.1468

Elizondo-Omaña, R. E., Morales-Goméz, J. A., Morquecho-Espinoza, O., Hinojosa-Amaya, J. M., Villareeal-Silva, E. E., Garcia-Rodriguez, M. D. L. A., & Guzmán-López, S.. (2010). Teaching skills to promote clinical reasoning in early basic science courses. *Anatomical Sciences Education, 3*(5), 267-271. doi: 10.1002/ase.178

Ericsson, K. A. (2015). Acquisition and maintenance of medical expertise: A perspective from the expert-performance approach with deliberate practice. *Academic Medicine 90*(11), 1471-1486. doi: 10.1097/ACM000000000000939

Gilland, S. (2014). Clinical reasoning in first- and third-year physical therapist students. *Journal of Physical Therapy Education, 28*(3), 64-80. doi: 10.1097/00001416-201407000-00009

Gurlitt, J., Dummel, S., Schuster, S., & Nückles, M. (2012). Differently structured advance organizers lead to different initial schemata and learning outcomes. *Instructional Sciences, 40*(2), 351-369. doi: 10.1007/s11251-011-9180-7

Handley, K., & Williams, L. (2011). From copying to learning: Using exemplars to engage students with assessment criteria and feedback. *Assessment &*

Evaluation in Higher Education, 36(1), 95-108. doi:10.1080/02602930903201669

Hodges, L. (2014). *Teaching undergraduate science: A guide to overcoming obstacles to student learning.* Sterling, VA: Stylus Publishing.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychology, 41*(2), 75-86. doi: 10.1207/s15326985ep4102_1

Kuklak, V., & Newton, G. (2015). An investigation of the pedagogical impact of using case-based learning in an undergraduate biochemistry course. *International Journal of Higher Education, 4*(4), 13-25.

Lazarus, M. D., Chinchilli, V. M., Leong, S. L., & Kauffman G. L. Jr. (2012). Perceptions of anatomy: Critical components in the clinical setting. *Anatomical Sciences Education, 5*(4),187-199. doi: 10.1002/ase.1281

Levett-Jones, T., Hoffman, K., Dempsey, J., Jeong, S .Y., Noble, D., Norton, C. A., Roche, J., & Hickey, N. (2010). The 'five rights' of clinical reasoning: An educational model to enhance nursing students' ability to identify and manage clinically 'at-risk' patients. *Nurse Education Today, 30,* 515-520. doi: 10.1016/j.nedt.2009.10.020

Likourezos, V., & Kalyuga, S. (2017). Instruction-first and problem-solving-first approaches: Alternative pathways to learning complex task. *Instructional Science, 45*(2), 195-219. doi: 10.1007/s11251-016-9399-4

Liou, S., Liu, H., Tsai, H., Tsai., Y., Lin, Y., Chang, C., & Cheng, C. (2016). The development of psychometric testing of a theory-based instrument to evaluate nurses' perception of clinical reasoning competence. *Journal of Advanced Nursing, 73*(3), 707-171. doi: 10.1111/jan.12831

Margulieux, L. E., & Catrambone, R. (2016). Improving problem solving with subgoal labels in expository text and worked examples. *Learning and Instruction, 42*(1), 58–71. doi: 10.1016/j.learninstruc.2015.12.002

Nilson, L. B. (2013). *Creating self-regulated learners: Strategies to strengthen learners' self-awareness and learning skills.* Sterling, VA: Stylus Publishing.

Norman, G. R., Monteiro, D. S., Sherbino, S. J., Ilgen, G. J., Schmidt, G. H., & Mamade, G. S. (2017). The causes of error in clinical reasoning: Cognitive biases, knowledge deficits, and dual process thinking. *Academic Medicine, 92*(1), 23-30. doi: 10.1097/ACM.0000000000001421

Oermann, M. H. (2018) Assessment method. In M. H. Oermann, J. C. De Gagne, B. C. Phillips (Eds). *Teaching in nursing and role of the educator: The complete guide to best practice in teaching, evaluation, and curriculum development* (2nd ed. pp. 233-258). New York, NY: Springer Publishing Company.

Pickering, J. D., & Roberts, D. J. H. (2018). Flipped classroom or an active lecture? *Clinical Anatomy, 31*(1), 118-121. doi: 10.1002/ca.22983

Pinnock, R., Young, L., Spence, F., Henning, M.,& Hazell, W. (2015). Can think-aloud be used to teaching and assess clinical reasoning in graduate medical education. *Journal of Graduate Medical Education, 15,* 334-337. doi: 10.4300/JGME-D14-00601.1

Richard, D. C, Felix, T. M., Zimmerman, J. A., Adams, N. E., Knehans, A. M., & Faber, F. S. (2017). Individualized patient-centered care: A physician assistant curriculum in information mastery, clinical reasoning, and shared decision making. *The Journal of Physician Assistant Education, 28*(3), 158-163. doi: 10.1097/JPA.0000000000000139

Sentz, J., & Stefaniak, J. (2019). Instructional heuristics for the use of worked examples to manage instructional designers' cognitive load while problem solving. *Tech Trends, 63,* 209-225. doi: 10.1007/s11528-018-0348-8

Stark, R., Kopp, V., & Fischer, M. R. (2011). Cased-based learning with worked examples in complex domains: Two experimental studies in undergraduate medical education. *Learning and Instruction, 21*(1), 22-33. doi: 10;1016/j.learninstruc.2009.10.001.

Supdich, E. A., & Stanford, J. S. (2013). Teaching regional anatomy to undergrads: Too much or more relevant preparation for post graduate clinical education. *The FASEB Journal, 21*(1-supplement).

Sweller, J., Ayres, P., & alyuga, S. (2011) *Cognitive Load Theory.* New York, NY: Springer.

ten Cate, O. (2018). Introduction. In O. ten Cate, E. J. F. M. Custers, & S. J. During (Eds.), *Principles and practices of clinical reasoning education: A method for pre-clinical students.* New York, NY: Springer International.

ten Cate, O., & Durning, S. J. (2018). Understanding clinical reasoning from multiple perspectives: A conceptual and theoretical overview. In O. ten Cate, E. J. F. M. Custers, & S. J. During (Eds.), *Principles and practices of clinical reasoning education: A method for pre-clinical students.* New York, NY: Springer International.

ten Cate, O., Custers, E. J. F. M., & Durning, S. J., (2018) *Principles and practices of clinical reasoning education: A method for pre-clinical students.* New York, NY: Springer International.

Tennyson, R. D., V& olk, A. (2015). Learning theories and educational paradigms. In J. D. Wright (Ed.) *International encyclopedia of the social and behavioral sciences* (2nd ed., pp. 699-711). Amsterdam, Netherlands: Elsivier.

Twigg, C.A. (2003, September/October) Improving learning and reducing costs: New models for online learning. *Educause Review,* 28-38.

van Merriënboer, J. J. G. (2019). The four-component instructional design model: An overview of its main design principles. Retrieved from https://www.4cid.org/publications/

Young, J., van Merriënboer, J. J. G., During, S., & ten Cate, O. (2014). Cognitive Load Theory: Implications for medical education. *Medical Teacher, 36*(5), 381-384. doi: 10.3109/0142159X.2014.889290

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