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Lesson

Doctor in the House: Improving Undergraduate Critical Thinking Skills Through Diagnosing Medical Case Studies

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Abstract

Students in undergraduate anatomy and physiology courses are not often exposed to clinical examples of homeostatic imbalances, particularly ones that provide an opportunity to diagnose a medical case. We designed a set of medical cases that require students to integrate their content knowledge of multiple organ systems, practice critical thinking related to diagnostic processes, and communicate effectively. In this multi-week lesson, students used deductive reasoning to diagnose the primary and underlying condition of their patient and prepare a formal report on their patient's condition and their recommended treatment. In addition to requiring students to apply their prior knowledge, this lesson introduces homeostatic imbalances in a unique way, and also has the potential to be revised to ask students to consider common cognitive biases that occur during medical diagnosis.

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Supporting Materials: Supporting Files S1. Medical Case Study - Instructions; S2. Medical Case Study - Test Requests Template; S3. Medical Case Study - Case 1 Medical History Form; S4. Medical Case Study - Case 1 Kidney Stones Information; S5. Medical Case Study - Case 1 Example Student Work; S6. Medical Case Study - Case 2 Medical History Form; S7. Medical Case Study - Case 2 Esophageal Ulcer Information; S8. Medical Case Study - Case 2 Example Student Work; S9. Medical Case Study - Case 3 Medical History Form; S10. Medical Case Study - Case 3 Mitral Valve Regurgitation Information; S11. Medical Case Study - Case 3 Example Student Work; S12. Medical Case Study - Case 4 Medical History Form; S13. Medical Case Study - Case 4 Diverticulitis Information; S14. Medical Case Study - Case 4 Example Student Work; S15. Medical Case Study - Case 5 Medical History Form; S16. Medical Case Study - Case 5 Hyperprolactinemia Information; and S17. Medical Case Study - Case 5 Example Student Work.

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Learning Goal(s)

- Integrate prior knowledge of anatomy and physiology, deductive reasoning, and research skills to diagnose a medical case and propose an appropriate treatment plan.
- Communicate medical information effectively.
- Gain clinical decision-making skills.

Learning Objective(s)

- Students will be able to evaluate medical information and ask appropriate questions to form a diagnosis.
- Students will be able to identify a specific homeostatic imbalance of the human body and explain how it's addressed in the medical field.
- Students will be able to prepare and present a formal report on a medical diagnosis and treatment.
- Students will be able to apply their prior knowledge to solve an unfamiliar problem and investigate multiple avenues for a potential solution.
- Students will achieve the Human Anatomy and Physiology Society (HAPS) learning outcome: given a disruption in the structure or function of a system, predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes) (1).

INTRODUCTION

The development of this case study arose from a desire to introduce students to medical cases of homeostatic imbalance, integrate their knowledge of multiple organ systems, and practice deductive reasoning. Although case studies are common in medical education (2), students spend more time learning normal physiology in many undergraduate anatomy and physiology courses. Indeed, while most Human Anatomy and Physiology textbooks include sections that incorporate clinical cases or homeostatic imbalances (e.g., McGraw Hill, Pearson), these are not the focus of these courses. Futhermore, the cases that do exist often use extensive medical terminology, making them less accessible to undergraduate students. However, there has been increased evidence and support for the use of active learning strategies (3,4), and specifically, case studies of various types and formats (5) at the undergraduate level. Indeed, case studies have been shown to improve student learning both for undergraduates (6) and medical students (2).

The goal of this lesson was to incorporate homeostatic dysfunction (i.e., disease or disorder) along with the process of medical diagnosis at the undergraduate level. This lesson was the second of two larger "homeostatic imbalance" assignments

during the second semester of an anatomy and physiology course. For the first, students were asked to identify one homeostatic imbalance that applied to the content they had learned and prepare a short presentation on this topic. The second assignment, presented here, was a medical case study in which the imbalance was unknown to the students, who were then tasked with figuring it out. This aligns with the Human Anatomy and Physiology Society (HAPS) learning outcomes that target "predictions related to disruption of homeostasis," and specifically, "given a disruption in _____, predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict the possible causes)" (1).

In this case study assignment, students are given a patient's symptoms and medical record, and are asked to determine the patient's illness, its cause, and a treatment approach. Table 1 describes each case, the intended difficulty level, and the background information that is useful for students. We designed cases that targeted different organ systems that would require students to consider multiple causes (Figure 1). Specifically, the cases we designed include:

1. Kidney stone formation caused by unmedicated hyperparathyroidism
2. Esophageal ulcer caused by bulimia nervosa
3. Chronic mitral valve regurgitation that was exacerbated by rheumatic fever
4. Idiopathic diverticulitis
5. Erectile dysfunction caused by hyperprolactinemia

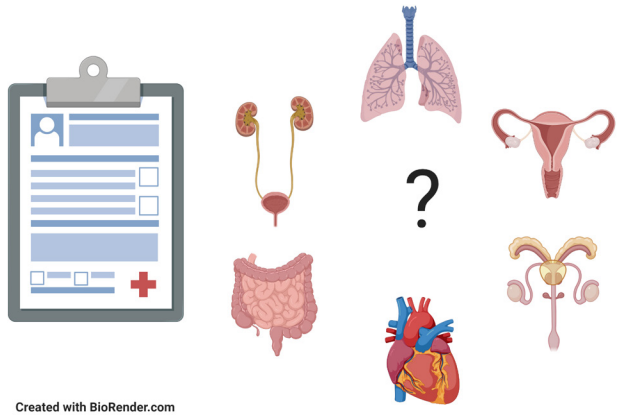

Figure 1. Overview of case studies. This figure was created with Biorender.com and exported under a paid subscription.

To ensure that students think carefully about their patients' symptoms and medical history, each case also includes several symptoms/past issues in the patient's medical history that were unrelated to the current complaint. We have noted these in the information document for each case (Supporting Files S4. Medical Case Study - Case 1 Kidney Stones Information, S7. Medical Case Study - Case 2 Esophageal Ulcer Information, S10. Medical Case Study - Case 3 Mitral Valve Regurgitation Information, S13. Medical Case Study - Case 4 Diverticulitis Information, S16. Medical Case Study - Case 5 Hyperprolactinemia Information), and an instructor could choose to modify the distractors. Please note that these documents were reviewed by medical professionals, but instructors should check them for accuracy, as well as updated medical information (e.g., changes to normal laboratory values or newly developed drugs).

After reviewing the patient's symptoms, researching illnesses that present similar symptoms, and looking for connections to information provided in the medical record, students develop a list of possible illnesses their patient could have, then run tests and ask questions that help them efficiently deduce their patient's illness(s). In a similar fashion, students then determine the root cause of the patient's problem. That is, students are expected to use the hypothetico-deductive process (7). To summarize their work, students write an initial group report and if their diagnosis is correct, they then determine the best treatment approach for their patient and create a final group report that details their efforts in solving the case and preparing a treatment approach. Lastly, students answer follow-up questions regarding their approach towards solving the case and peer review final reports of two other case studies to further expose them to this analytical style of thinking. For a visual representation of how students will work through the problem, see Figure 2.

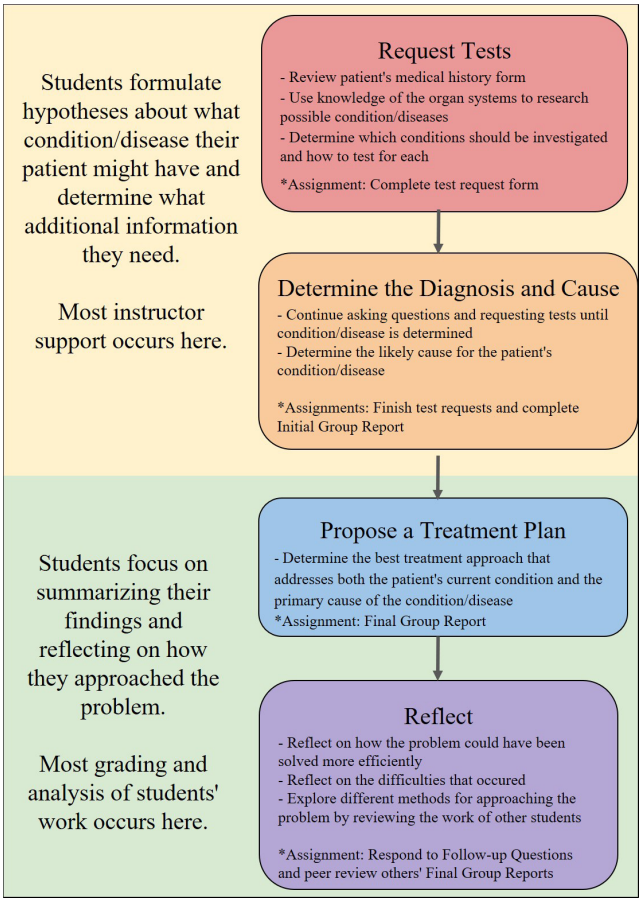

Figure 2. Flowchart of Students' Thinking. Pictorial representation of how students will work through the problem and when each part of the project is to be completed.

This assignment addressed several aspects of learner-centered teaching approaches, including active learning with feedback, application of knowledge to enduring and relevant problems, and integrating content knowledge with general skills (8). The focus of this assignment was not on a particular organ or organ system but how to approach an unknown problem, come up

with diagnostic hypotheses, and frame the collection of new data with prior information. Therefore, this assignment provides students with an opportunity to practice the process of science, work collaboratively, and tap into the interdisciplinary nature of science (9).

Scientific case studies are diverse in format and are an effective way to teach scientific content and the scientific process (5). Furthermore, case studies allow pre-health professional students to gain valuable clinical reasoning and decision-making skills. Diagnostic errors are frequent in the medical field, and it is thought that the majority of errors are not related to content error, but to data collection and integration (7). Indeed, it has been suggested that training in the diagnostic process is critical and should begin at the undergraduate level (7). Furthermore, although we did not design this lesson to explicitly address cognitive biases, we will discuss how they are applicable and how this lesson could be extended to increase reflection and incorporate metacognitive skills.

This assignment is distinct from most other case studies we found. Hundreds of valuable case studies are available from publishers such as McGraw Hill and Pearson, as well as on sites such as the National Center for Case Study Teaching in Science (NCCST) and the Life Science Teaching Resource Community. Many of these focus more on answering questions about a specific homeostatic imbalance and less on diagnosing medical cases; that is, "given a cause, state a possible effect" questions. For example, a case on the CNS provides diagnoses (brain surgery, tumor) and asks students to use their prior knowledge to answer questions regarding medical cases with a diagnosis provided, similar to many other cases in anatomy and physiology (10). Another endocrine case walks students through different symptoms and hormone levels throughout an individual's life, requiring students to use "given a cause, state a possible effect" over developmental time and integrate of multiple organs systems. Other cases require students to interpret physiological measures in response to environmental changes, such as fluid and salt intake during distance running.

While we have also used these types of cases and found them valuable, these cases did not require students to work through a medical problem and use the hypothetico-deductive process. Specifically, we require students to figure out what further information they need and ask appropriate questions, similar to a real-world situation. Our cases focus on "given a disruption in _____, predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict the possible causes)" and are similar to what is done in a "detective" case using a rodent model (11). While our cases are medicine-based, the medical jargon is kept at a minimum, thus making the material accessible to undergraduate students. Given the different style of learning and thinking involved in our case study compared to existing case studies, we believe the cases presented here provide a unique and valuable learning opportunity for undergraduate biology students.

Intended Audience

This assignment was implemented in an upper division anatomy and physiology course (Bio 312) at a 4-year undergraduate liberal arts institution. The majority (~66%) of the students were biology, chemistry-biology, or psychobiology majors. The remaining students were exercise science majors. Twenty-seven students were in this course, which allowed for nine groups. It would be possible to implement this in a larger class, although assessment time would increase. Therefore, it may be difficult to implement this lesson in a large introductory anatomy and physiology course.

Required Learning Time

This assignment was implemented online over approximately a six-week time period. A detailed schedule is included in Table 2 and possible modifications that could affect the timing are included in Table 3.

Prerequisite Student Knowledge

Students are required to work at higher Bloom's Taxonomy levels in this lesson. Specifically, this assignment requires that they be able to apply their knowledge, as well as analyze, evaluate, and synthesize information. Furthermore, they should be able to search for medical information, differentiate between reliable and unreliable sources of medical information, work independently from the instructor, cite formally, and write clearly and concisely. Our upper division students typically have these skills and we also attempted to make groups of students with different skills. Adaptations or further scaffolding may be required to implement this in a lower division course.

Each case included here addresses different organ and organ systems, and it may be helpful for students to have had some background on the structures involved for some of the cases. We determined that each case had a different difficulty level and therefore gave the harder cases to students who had expressed interest in the medical field or we felt could benefit and handle the challenge. Table 1 describes each case, the intended difficulty level, and the background information that is useful for students. Simple modifications could be made to meet individual course/student background (for example, removing the unrelated patient medical history). However, our students were generally able to determine what tests to run (e.g., which imaging techniques) with minimal prior knowledge and proper searching for reliable information.

Prerequisite Teacher Knowledge

Although a medical background is helpful, it is not necessary for implementing these cases, given the supporting information available in this article and the internet. Most importantly, the instructor must be able to facilitate group work and successful collaboration, and provide constructive feedback.

SCIENTIFIC TEACHING THEMES

Active Learning

This assignment involves extensive student engagement, both in groups or individually. Much of the learning occurs outside of class. Students conduct independent research, group research, and synthesize the information in order to diagnose their patient and create a report or presentation. Student groups then either present to the class or prepare a report that is shared with the class. Finally, individual students peer review the reports of other students and reflect on their learning.

Assessment

We designed this assignment to include formative assessments. Formative assessment is a student-centered teaching approach that is particularly effective because it engages students by

providing timely feedback to both instructors and students about learning (8,12). As part of the formative assessment, students needed to submit requests for additional medical tests and design questions for the patient, while providing the rationales for the tests and questions. The rationales were extremely informative for determining whether students were thinking carefully about their patient's history and symptoms, or just requesting a plethora of tests in order to get more information. The initial group report also provided a valuable opportunity to ensure students had the correct diagnosis before preparing their final report.

Summative assessments included the final group report (students could choose to do either a presentation or a written report) and the individual responses to the follow-up questions. We found the individual responses to follow-up questions extremely useful for determining each student's understanding. Rubrics for both the presentation and written final report are included in Supporting File S1. Medical Case Study - Instructions. No rubric was used for the individual responses, but the responses were expected to be thorough and include citations.

Lastly, we asked each student to reflect on whether the learning goals as listed at the beginning of the lesson were met and whether they preferred this diagnostic case study or the earlier homeostatic imbalance assignment for which they chose their own topic to investigate.

Inclusive Teaching

This engaging, multiple week lesson allows students to identify and diagnose their own "patient." We deliberately included patients with different backgrounds, ethnicities, and characteristics.

The ability to integrate medical history and test results is an important scientific process skill that does not just benefit pre-health students. This diagnostic case study allows for multiple paths/thought processes to get to the correct answer. Lastly, we gave the students an option to write a report or do an oral presentation for their final project.

LESSON PLAN

The information below is also summarized in Table 2.

Pre-class Preparation

Before introducing this activity, the instructor should read the background information on the case(s) used (Supporting Files S4. Medical Case Study - Case 1 Kidney Stones Information, S7. Medical Case Study - Case 2 Esophageal Ulcer Information, S10. Medical Case Study - Case 3 Mitral Valve Regurgitation Information, S13. Medical Case Study - Case 4 Diverticulitis Information S16. Medical Case Study - Case 5 Hyperprolactinemia Information). For any case an instructor uses, note that they must adjust the patient's birth date (and any operation dates, if applicable) forward by one year for each year past the original date that the assignment was devised (2020). We used all five cases, divided among nine lab groups of three students that made up two different lab sections. In other words, each group of three students got one case and each lab section had 4-5 of the cases (one lab section was smaller than the other).

We also spent approximately one hour designing the student groups ahead of time. To the best of our ability, we formed groups that included students of similar work styles (e.g., students that liked to start on projects right away were grouped together) but different skill levels and strengths, particularly different medical backgrounds (e.g., there were several CNAs and EMTs). If students had a particular interest in medicine, we did our best to have them work on one of the potentially more complicated cases. While not done here, an instructor could potentially group students of similar skill level together to push students to work on parts of the project that don't necessarily play to their strengths.

The instructor can print or make available the following Supporting File documents: Supporting Files S1. Medical Case Study - Instructions, S2. Medical Case Study - Test Requests Template, and the Medical History Files needed (Supporting Files S3 Medical Case Study - Case 1 Medical History Form, S6. Medical Case Study - Case 2 Medical History Form, S9. Medical Case Study - Case 3 Medical History Form, S12. Medical Case Study - Case 4 Medical History Form, S15. Medical Case Study - Case 5 Medical History Form). Note that if desired, an instructor can add specific due dates to the Supporting File S1. Medical Case Study - Instructions document.

Assignment Introduction

We originally structured the assignment to be completed on campus with some time set aside in the lab to work on the project and check in with students. However, circumstances (coronavirus pandemic in spring 2020) required us to shift to a completely online format. Therefore, the lesson plan below is described as an exclusively online activity after the initial case introduction. We introduced the assignment during lab before the conversion to online learning. The instructor should introduce the assignment by providing and walking through the instruction document (Supporting File S1. Medical Case Study - Instructions). The groups then received their patient's medical history form and looked over their case. The goal of this first meeting was for students to get to know their patient and establish a plan for communicating and meeting outside of class time.

While we emphasized that the assignment requires extensive independent work and that students would need to take initiative to ask questions, the students did not have many questions at this point. Therefore, it might be beneficial for an instructor to ask each group to introduce their patient to the class and state their initial thoughts on the case. If time allowed, students could also turn in a list of possible conditions, as done in Appendix 2 of Supporting File S5. Medical Case Study - 1 Example Student Work. This could be something they refer back to as they obtain information from the test requests. It also could be beneficial to provide a designated time for students to ask their "patient" questions before requesting tests, as they would during an office visit. In this case, the instructor could act as the patient or ask other students to role-play.

Scaffolded Weekly Assignments

Students added their requests for medical tests and questions for the patient to Supporting File S2. Medical Case Study - Test Requests Template and submitted the completed document via Google Classroom, where instructors then responded with test "results." Students should be made aware that they are to provide rationale for requesting each test and asking each question, as well as sources for any factual information used in their rationale. Not only does requiring a rationale encourage students

to consider why each test is necessary, but having rationales makes it easier for the instructor to follow the student's train of thought during the project. Instructors should emphasize that students need to follow-up with further tests and questions until they have enough information to make a correct diagnosis, as determined by the instructor. Students can also submit a list of tests to run with stipulations like "only run the next test on this list if the previous one had the following result: __."

As students submit their questions and test requests, the instructor will give the students their test results, as well as feedback on how to move forward (or, that they have all the information they need to correctly diagnose the patient). A list of tests and the respective results that students might request are included in Supporting Files S4. Medical Case Study - Case 1 Kidney Stones Information, S7. Medical Case Study - Case 2 Esophageal Ulcer Information, S10. Medical Case Study - Case 3 Mitral Valve Regurgitation Information, S13. Medical Case Study - Case 4 Diverticulitis Information, and S16. Medical Case Study - Case 5 Hyperprolactinemia Information. Note that we did not give the students the normal laboratory values and there were some inconsistencies between the different sources on the normal ranges. To avoid any miscommunication regarding the interpretation of test results, we recommend instructors provide students with normal laboratory ranges or a common website with laboratory values, as provided in Supporting File S1. Medical Case Study - Instructions. If students requested tests with insufficient rationale, we recommend the instructor send the test requests back and ask for further justification. If an inappropriate test was requested (i.e., either the incorrect test completely or an expensive option, such as a MRI instead of an ultrasound) we stated "insurance company denied this request." Some groups may need a hint to help push them in the right direction or to understand that they have not yet found the cause of the patient's illness, so instructors will likely need to use some judgement about how to answer questions and what hints to give. We found that groups varied in the number of test request submissions needed before they had enough information to write their initial report. We therefore recommend that instructors set a due date for the first round of test requests, then simply respond for further test requests and questions from students as they come in. Examples of actual student test requests and our responses are included in Supporting Files S8. Medical Case Study - Case 2 Example Student Work, S11. Medical Case Study - Case 3 Example Student Work, S14. Medical Case Study - Case 4 Example Student Work, and S17. Medical Case Study - Case 5 Example Student Work. Example student work was chosen if we felt that the students met the learning goals for the assignment and provided a useful example for future instructors. Scores on the Final Group Reports ranged from 27/30 to 30/30. Student work is included with consent.

Once students believe they have figured out the patient's illness(s) and its cause and have evidence (i.e., test results and question responses) to support their hypothesis, the students write an initial group report. The initial group report should be a brief discussion regarding how the group determined their patient's illness(s) and its underlying cause, as well as what test results/question responses led them to their diagnosis. The goal of having students complete an initial report is to ensure that students have correctly figured out the case, not necessarily to determine how well they thought through the problem. While the initial group report is not a necessary component of the assignment, requiring an initial report can be an effective formative assessment used to check in on students' progress. For the initial report, we gave feedback on writing style, possible treatment elements, and comments clarifying their thought processes; however, most of our feedback was given on the test requests and final report.

Final Report and Follow-up Assignments

Next, students will turn in their final group report, which is meant to be a complete summary of their work while solving the case and devising a treatment plan for their patient. Students should detail their thinking process while solving the case enough so that the instructor can understand why they took each step they did to solve the case and how each test result/question response influenced their course of action. When doing this assignment online, we gave students the option to record a presentation or write out their final report, but most students chose to submit a written report. Rubrics for grading written reports and presentations are included in Supporting File S1. Medical Case Study - Instructions.

After reading through or watching each report, we devised a list of approximately 5-10 follow-up questions to ask each student individually. Note that while we spent extensive time reviewing the final reports and creating follow-up questions, we found the student responses to these questions to be incredibly informative regarding the thoroughness of the students' thinking process throughout the project. For instructors choosing to have live presentations as the final report, they will have less time to develop follow-up questions based on the final project report and should instead ask follow-up questions throughout the entire project. Table 4 provides advice for types of follow-up questions and the example student follow-up questions with responses are provided in Supporting Files S8. Medical Case Study - Case 2 Example Student Work, S11. Medical Case Study - Case 3 Example Student Work, S14. Medical Case Study - Case 4 Example Student Work, and S17. Medical Case Study - Case 5 Example Student Work. Student responses were expected to be thorough and include citations.

Finally, all of the students' final reports were shared with the entire class. To give students exposure to the other cases, the last part of the assignment required students to read or view the final reports of two different cases and write a summary about what they learned. For instructors of in-person courses, one option to give students exposure to other cases would be to have the final reports be live presentations to each group's respective lab section.

TEACHING DISCUSSION

Overall, we felt that this assignment was a success. Here we discuss student feedback, notes on individual cases, potential revisions, and possible extensions.

The majority of our students reported that they felt the learning goals were met. Specific student comments included:

- *I felt that this activity worked well to allow us to apply what we have learned in the classroom to a real life scenario, especially since many of the patients were experiencing problems that affected several body systems, allowing us to integrate our knowledge.*

- *It challenged me to apply myself in ways that courses usually don't require me to. It wasn't an answer I could find in my head or in my notes. I also really liked the interaction of having to request tests.*

Importantly, although several students noted that it was more difficult, the majority of students, particularly those interested in the medical field, preferred this unknown (diagnostic) case to the known homeostatic imbalance topic that they presented on earlier in the semester. For example, students said:

- *In the case study where a specific disorder was chosen to present, prior knowledge of anatomy and physiology was required, however, less deduction was necessary because there were no unknown causes in the case study.*

- *I preferred the unknown case study as you can google on your own any disease/disorder and learn about in five minutes. However, in real life patients do not have clear cut symptoms of disorders and doctors often have to pick apart what is pertinent to the case and what is not.*

- *I very much preferred the unknown case study to the one where a disease/disorder was simply chosen because it was more satisfying to generate a hypothesis and run tests to successfully determine what was ailing the patient. Even after having to switch to online classes, this project still worked out well as it took the form of a written project.*

Through their test requests, initial and final reports, and responses to follow-up questions, students demonstrated the ability to evaluate medical information and ask appropriate questions to form a diagnosis, identify a specific homeostatic imbalance of the human body and explain how it's addressed in the medical field, prepare and present a formal report on a medical diagnosis and treatment, apply their prior knowledge to solve an unfamiliar problem and investigate multiple avenues for a potential solution (given an effect, predict possible causes).

Summary of Individual Cases

Kidney Stones

The kidney stone case (Supporting Files S3. Medical Case Study - Case 1 Medical History Form, S4. Medical Case Study - Case 1 Kidney Stones Information, S5. Medical Case Study - Case 1 Example Student Work) was perceived to be of low difficulty because the organ system involved seemed readily apparent from the patient's symptoms. Student comments on the case after the fact suggested that our preliminary assessment of the case difficulty was accurate. However, we also found that students ran the risk of getting stuck at diagnosing the UTI and not investigating the cause of the UTI (kidney stone and cessation of hyperparathyroidism medication) any further. Finally, while not applied here, future instructors could add bone pain after exercise and indigestion to the list of patient symptoms to make the case study more integrative.

Esophageal Ulcer

The esophageal ulcer case (Supporting Files S6. Medical Case Study - Case 2 Medical History Form, S7. Medical Case Study - Case 2 Esophageal Ulcer Information, and S8. Medical Case Study - Case 2 Example Student Work) was also thought to not be very difficult to diagnose because the symptom of "pain when swallowing" seemed highly indicative of an issue concerning the esophagus. At most, we thought the students would need to rule out pulmonary issues before getting to the correct diagnosis. However, the case is made more complicated by the fact that students must realize that the patient has bulimia nervosa and is not being straightforward with them. When we ran this case, we found that some of the students had training in spotting psychological disorders and they were immediately in tune to the possibility of bulimia nervosa. If an instructor wished to mitigate this in the future, they could revise the patient's medical history and mother's report slightly to make the psychological disorder less obvious (e.g., by removing the patient's medication and psychiatric care from Supporting File S6. Medical Case Study - Case 2 Medical History Form). Alternatively, an instructor could make the patient's condition more severe by giving the patient black stool, bloody emesis, and/or low hematocrit and hemoglobin levels. Along with making the diagnosis less obvious, including these symptoms would make students aware that ulcers often bleed and are often found by endoscopy after first discovering anemia and/or blood in the stool.

Mitral valve regurgitation

The mitral valve regurgitation case (Supporting Files S9. Medical Case Study - Case 3 Medical History Form, S10. Medical Case Study - Case 3 Mitral Valve Regurgitation Information, and S11. Medical Case Study - Case 3 Example Student Work) was perceived to be of medium difficulty because while heart damage would not be obvious at the start, the students would likely understand that something was wrong with the patient's circulatory system. Given that rheumatic fever by itself produces symptoms similar to what the patient is experiencing, we thought that the most difficult part of the case would be figuring out that the patient had preexisting heart abnormalities as well. After the final report was turned in, we found that students were able to determine that the patient likely had a preexisting problem but could not narrow it down any further than that. We recommend that an instructor running this case should ensure that the students ask questions to learn that the patient has a family history of heart conditions and that their EKG had an elevated QRS amplitude, as these pieces should be enough to suggest preexisting heart damage and point students in the right direction.

Diverticulitis

The diverticulitis case (Supporting Files S12. Medical Case Study - Case 4 Medical History Form, S13. Medical Case Study - Case 4 Diverticulitis Information, and S14. Medical Case Study - Case 4 Example Student Work) was perceived to be difficult because the list of conditions that could cause abdominal pain and signs of infection is expansive. Furthermore, in most populations, diverticulitis is more commonly associated with pain on the lower left quadrant. Our patient was of Asian descent, which more commonly presents as right side pain with diverticulitis. That is, although left side pain is more common in diverticulitis, individuals of Asian descent are more likely to have right side pain. We found this to be the case during the activity but after the students reasoned that a CT scan might be appropriate to help them narrow down the illness quickly, the case became much easier to figure out. We also noticed that when requesting the CT scan, the students did not suspect diverticulitis, so perhaps students assigned to this case should be advised to greatly expand their list of possible illnesses before requesting any tests. This could be done by asking students to

turn in a list of possible conditions, as done in Appendix 2 of Supporting File S5. Medical Case Study - Case 1 Example Student Work.

It should be noted that the presence of the perforation makes this case quite urgent. Since the goal of this assignment is to have students carefully think through all possibilities before they make a diagnosis, not handle emergency situations, an instructor may want to make this case less urgent by having less intense pain symptoms and no bowel perforation. Instead, the infection could be caused by a microperforation or simply a blocked diverticulum, thereby making immediate surgery less necessary.

Hyperprolactinemia

The hyperprolactinemia case (Supporting Files S15. Medical Case Study - Case 5 Medical History Form, S16. Medical Case Study - Case 5 Hyperprolactinemia Information, and S17. Medical Case Study - Case 5 Example Student Work) was perceived to be difficult because prolactin levels do not seem immediately related to erectile dysfunction (ED). Moreover, since hormone levels are far from the most common cause of ED, we believed that it would take students a while to arrive at the correct diagnosis. While we were correct in that students would not immediately connect prolactin to ED, most students quickly determined some hormonal imbalance as the cause. We suspect that the students unintentionally applied the availability heuristic because our class material heavily focused on the role of hormones in various organ systems, thus priming students to think about hormonal imbalances.

Considerations for Future Implementations

As noted previously, we recommend that instructors prompt students to start thinking about the assignment more carefully as soon as they receive their cases, for example by asking each group to introduce their patient to the class and state their initial thoughts on the case. Students also had trouble determining what tests to request, both in terms of how to get started on diagnosing their patient and how specific to be with their requests. Most student groups missed opportunities to ask questions in order to learn more about their patient's symptoms, prior history, and to rule out illnesses. For example, students investigating Elan, who had hyperprolactinemia, requested to test for allergy to levothyroxine because there was a medical history of hives. If they had asked Elan about his medical history, they would have learned that these were pet allergies, and likely unrelated to his current erectile dysfunction. To encourage students to ask questions, it could be beneficial to provide a time for students to ask their "patient" questions before requesting tests, as they would during an office visit. Depending on the background of the class, this time period for asking questions could happen the same day they receive their case (e.g., in lab) or a future class period (or a virtual session). Again, the instructor or another student could play the role of the patient. Students should also be reminded that more than one round of testing is likely necessary, as their first requests may be denied or not give them all of the necessary information. Instructors should be sure to further emphasize that students are expected to request specific tests (e.g., not a "blood panel").

Because a large portion of this assignment requires independent work, we believe this lesson could be implemented successfully either in-person, in a hybrid course, or in an all online course. As stated previously, we originally structured the assignment to be completed in person with some time set aside in the lab to work on the project and check in with students. However, circumstances (coronavirus pandemic in spring 2020) required us to shift to a completely online format. It is worth mentioning that this component of the course was the smoothest transition to online of all the course components, as evidenced by student feedback and performance. For example, students gave higher ratings of this lesson compared to other online lab activities.

We determined three important structural factors to consider when implementing this assignment, particularly when considering whether to conduct the assignment online vs. in person. These factors (degree of scaffolding/frequency of formative assessments, final project format, and forming student groups) and how they might influence the student's learning experience and the time required are comprehensively summarized in Table 3.

Modifications and Extensions

The case studies do not have to be presented to the students in the same format as seen here (i.e., assigning all five cases to different groups at the same time). Instead, an instructor could assign the same case to the entire class, or could have students complete multiple case studies over the course of the semester (potentially so that the topic of the case aligns with the subject being discussed in the class). Alternatively, instead of having students solve all of the cases, students could improve their reasoning skills by reviewing cognitive biases in medical diagnoses, then going through one or more of the sample final reports included here and writing a critique detailing how the author of the sample report could have better approached the case. While students would experience more passive exposure to clinical decision making via this last style of case presentation, this method requires less time for both the instructor and the students.

Another modification option for instructors is to extend the scope of the cases by taking the basic format laid out in this assignment and creating their own case study. For example, in this class, we had several students who wanted to go into physical therapy who had a difficult time seeing how this assignment would be useful for their future profession. To help these students connect more with the material, it might have been beneficial to give them a case that required comprehension of the material taught in our class and that had a patient with an injury treatable by a physical therapist.

Finally, walking students through various logical fallacies (e.g., anchor bias, in which one relies too much on one initial piece of information, or sunk costs fallacy, in which one continues to investigate something because they have already invested time and energy into it) seen in clinical diagnoses (7) would be an extremely valuable extension to this lesson, as doing so would improve their ability to spot and overcome such fallacies in their own logic. For example, an instructor could describe the fallacies and provide real examples of these fallacies before giving out the case studies. Discussing the fallacies beforehand would prime students to think about the fallacies while doing the assignment and may help them avoid making such errors. After they have completed their report, students would look through their own work and write a reflection about areas where they could have improved their thinking. There has been increasing evidence for the value of reflective practices in medicine (13). While doing the case study implicitly introduces students to cognitive biases, having a more explicit conversation about

biases and encouraging students to take note of their own biases could help students solidify their ability to deductively reason through the diagnostic process.

SUPPORTING MATERIALS

- S1. Medical Case Study - Instructions
- S2. Medical Case Study - Test Requests Template
- S3. Medical Case Study - Case 1 Medical History Form
- S4. Medical Case Study - Case 1 Kidney Stones Information
- S5. Medical Case Study - Case 1 Example Student Work
- S6. Medical Case Study - Case 2 Medical History Form
- S7. Medical Case Study - Case 2 Esophageal Ulcer Information
- S8. Medical Case Study - Case 2 Example Student Work
- S9. Medical Case Study - Case 3 Medical History Form
- S10. Medical Case Study - Case 3 Mitral Valve Regurgitation Information
- S11. Medical Case Study - Case 3 Example Student Work
- S12. Medical Case Study - Case 4 Medical History Form
- S13. Medical Case Study - Case 4 Diverticulitis Information
- S14. Medical Case Study - Case 4 Example Student Work
- S15. Medical Case Study - Case 5 Medical History Form
- S16. Medical Case Study - Case 5 Hyperprolactinemia Information
- S17. Medical Case Study - Case 5 Example Student Work

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Table 1. Case overviews. Summary of the five cases we designed. For each case we have stated the disease, our estimate of case difficulty, recommended (not required) background information, the Human Anatomy and Physiology Society (HAPS) learning objectives addressed, and the Supporting Files relevant to the case.

Difficulty	Background info useful	HAPS learning objective	Supporting Files needed
Case 1: Kidney stones (hyperparathyroidism)			
Low	Urinary anatomy Parathyroid function Urinalysis results	MODULE P: Urinary System Identify and describe the gross anatomy and location of the ureters, urinary bladder, and urethra. Describe the composition of normal urine. Given a disruption in the structure or function of the urinary system (e.g., blood in the urine), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).	S1. Instructions S2. Request forms S3. Medical History S4. Disease Information S5. Student example
Case 2: Esophageal ulcers (principal) and Bulimia (underlying)			
Principal diagnosis-low Underlying diagnosis-moderate	Digestive anatomy and basic physiology	MODULE N: Digestive system Describe the compositions, locations, and functions of the inferior esophageal (cardiac, lower esophageal) sphincter and the pyloric sphincter. Given a disruption in the structure or function of the digestive system (e.g., diarrhea), predict the possible factors or situations that might have created that disruption (i.e., given an effect, predict possible causes).	S1. Instructions S2. Request forms S6. Medical History S7. Disease Information S8. Student example
Case 3: Mitral valve regurgitation			
Moderate	Heart anatomy and function (inc. EKG)	MODULE K: Cardiovascular System Identify and describe the structure and function of the primary internal structures of the heart, including chambers, septa, valves, papillary muscles, chordae tendineae, fibrous skeleton, and venous and arterial openings. Name the waveforms in a normal electrocardiogram (ECG or EKG) and explain the electrical events represented by each waveform. Relate the electrical events represented on an electrocardiogram (ECG or EKG) to the normal mechanical events of the cardiac cycle. Relate the opening and closing of specific heart valves in each phase of the cardiac cycle to pressure changes in the heart chambers and the great vessels (i.e., blood vessels entering and leaving the heart). Given a disruption in the structure or function of the cardiovascular system (e.g., pulmonary edema), predict the possible factors or situations that might have created that disruption (i.e., given an effect, predict possible causes).	S1. Instructions S2. Request forms S9. Medical History S10. Disease Information S11. Student example
Case 4: Diverticulitis			
Moderately difficult	Digestive anatomy (intestines) General infections	MODULE N: Digestive system Given a disruption in the structure or function of the digestive system (e.g., diarrhea), predict the possible factors or situations that might have created that disruption (i.e., given an effect, predict possible causes).	S1. Instructions S2. Request forms S12. Medical History S13. Disease Information S14. Student example
Case 5: Hyperprolactinemia			
Difficult	Anatomy and physiology of anterior pituitary	MODULE J: Endocrine System Describe the major functions of the endocrine system. Describe major hormones secreted by the anterior pituitary, their control pathways, and their primary target(s) and effects. Given a disruption in the structure or function of the endocrine system (e.g., hypothyroidism), predict the possible factors or situations that might have caused that disruption (i.e., given an effect, predict possible causes).	S1. Instructions S2. Request forms S15. Medical History S16. Disease Information S17. Student example

Table 2. Timeline. Overview of the timeline we used this semester, with a brief description and notes for each activity.

Activity	Description	Estimated Time	Notes
Introduction of assignment	1. Describe the lesson, the goals, the instructions. 2. Provide a copy of the Instructions. 3. Give students time to "meet" their patient and discuss in groups.	30 minutes	Refer to: Supporting File S1. Medical Case Study Instructions and Medical History Forms (Supporting Files S3, S6, S9, S12, S16).
Test Requests	Proposed tests and rationales, and follow-up tests as necessary.	1-2 weeks	Students need to follow-up with further tests and questions until we let them know they have reached a correct diagnosis. We found that each group required a different number of rounds of testing before they could write their initial report.
Initial Group Report	Final diagnosis of your patient, referencing test results.	1 week following completion of test requests	While the initial group report is not a necessary component of the assignment, if an instructor is doing this assignment in an online course, requiring an initial report can be an effective formative assessment used to check in on students' progress.
Final group report	This report should be a clear and concise description which includes: • The patient's symptoms. • The diagnosis and what test results led to this diagnosis. • The cause of the illness and what test results led to this.	1-2 weeks after completion of the initial group report	Format of this (e.g., live presentation, recorded presentation, written report) may depend on the format of the course (online, hybrid, or in-person). Live presentations require less outside work for the instructor. Recorded presentations and papers afford the instructor more time to think of in-depth discussion questions to ask the students.
Follow-up questions	5-10 questions answered individually by students	~1 week after completion of the final group report	See Table 4 for advice on types of follow-up questions and the Supporting File S8, S11, S14, S17 for example student follow-up questions and responses.
Reflection	Write a summary about what they learned from two other cases. Reflect: what did you learn from this? Did this assignment meet learning goals?	~2 weeks after completion of the final group report	Could be extended by discussing/reflecting on cognitive biases (see discussion section).

Table 3. Design considerations. Summary of three factors that could be considered by instructors and how they would impact 1) student learning and 2) the teaching and timeline of the lesson. Which approach one uses may depend on the format of the course (online, hybrid or in-person).

Factor	Approaches	Effect on Student Learning	Effect on Timetable/Teaching
Degree of Scaffolding/ Formative Assessments	Extensive scaffolding/ frequent formative assessments	Having several small assignments and check-in times ensures that students are continuously working on the project. As frequent formative classroom assessments are a hallmark of student-centered and inclusive classrooms (8,12), we recommend this approach. Additionally, this is preferred for an online or hybrid course, where informal check-ins are infrequent.	Extensive scaffolding may increase the timeline of the entire lesson. Instructor will spend more time on assessment.
	Less scaffolding, fewer formative assessments, more flexibility	Less scaffolding (e.g., not having designated test request times or removing the initial project report) allows for flexibility and more independent work.	Instructor will spend less time on assessment.
Final Project Format	Oral presentations (recorded if online, live if "in-person"	Oral presentations have value in terms of practicing science communication skills. Oral presentations given to the whole class (live) results in all students getting some exposure 1) science communication skills, 2) to all cases. This may work best for an in-person course.	Live presentations require less outside work for the instructor. Recorded presentations (and papers) provide the instructor with more time to think of in-depth discussion questions to ask the students.
	Written Report	Written papers also have value in terms of practicing science communication skills. Written reports may be easier to implement for an online course, where students are collaborating electronically.	Written work (and recorded presentations) provides the instructor with more time to think of in-depth discussion questions to ask the students.
	Choice	Giving students the option to give an oral presentation and paper final reports.	Similar workload to the two scenarios above (all written report or all oral presentation).
Individuals vs. Groups (Note, an extensive discussion of the various ways to form groups is discussed elsewhere (5)).	Groups	Students working in groups gain the opportunity to practice communication and collaboration skills, and may find the case more manageable in terms of the amount of work.	Most efficient for assessment. More difficult to monitor groups to ensure that all members are actively involved.
	Individuals or Individuals an option	Students working alone will be more challenged more in terms of their individual knowledge, research, and skill. Most feasible for the instructor in small online courses. Useful for pre-health professional students. Solo work may be appropriate in an online format, as 1) the instructor cannot easily monitor groups to ensure that all members are actively involved and 2) some students had difficulties communicating with their groups online.	More time spent assessing work. Instructor could consider reducing the amount of follow-up questions and/ or scaffolding assignment in order to compensate for the increased time assessment of individual work. Most feasible for instructors of small online courses.

Table 4. Advice for posing follow-up questions. Overview of the types of follow-up questions we asked the student groups and the purpose of each type of question.

Question Type	Reason for Asking Question	Example Questions
Related to Patient's Chart	Instructor can determine whether students are continuously thinking about and drawing from this important information.	"Assuming medications were appropriate for this patient, could Aarav take indapamide as a diuretic? Explain." *Aarav's chart says he is allergic to sulfonamides, like indapamide.*
Hypothetical Scenario	Asking students to revisit an earlier problem with new information can help an instructor determine how well students could have dealt with setbacks and if they had any thought through any back-up plans. Students can also be further challenged with questions that ask them to expand on their treatment approach.	"Suppose the testosterone results came back normal. What would you have done next and why?" "What advice would you give to the mother to help her daughter through her bulimia nervosa treatment?"
Clarification	Instructor can determine exactly what a student is trying to express. A student's decision during the case may not always make sense, so asking clarification questions can help an instructor determine if the student had a good reason for taking the action they did.	"Can you clarify/provide rationale for running the WBC and electrolyte tests?" "Why did you continue asking questions pertaining to kidney disease when the test results did not suggest that the patient had any kidney problems?"
Conviction in Diagnosis/ Treatment	Instructor can determine if the student has thought through the material enough to be confident in their answer, as students often think questions like this are meant to be taken as a hint from the instructor that they made an error somewhere.	"Ebony said she had been on her medication for a couple years but did not think it was working. Are you sure you want to continue prescribing this medication?"
Reflection	Asking students to reflect on how they could have approached a problem differently can help students make fewer mistakes in the future.	"Do you think it would have been appropriate to run the CT scan earlier than it was? Explain." "In retrospect, what questions could you have asked the patient to rule out any conditions?"
Probe Decision Making Process	Asking students to further explain how they arrived at their diagnosis and inquiring about whether they considered different possibilities can help make any cognitive errors or biases more obvious.	"When considering whether the UTI or prostatitis came first, what made you rule out the UTI as the cause of the prostatitis?"