INTRODUCTION

There is increasing emphasis in pedagogical research on encouraging critical thinking in the classroom. The specific mental processes and behaviors involved require the individual to engage in reflective and purposeful thinking. Critical thinking encompasses the ability to examine ideas, make decisions, and solve problems (1, 2). The skills necessary to think critically are essential for learners to evaluate multiple perspectives and solve novel problems in the classroom and throughout life. Career success in the 21st century requires a complex set of workforce skills. Current labor market assessments indicate that by the year 2020, the majority of occupations will require workers to display cognitive skills such as active listening, critical thinking, and decision making (3, 4). In particular, current studies show that the US economy is impacted by a deficit of skilled workers able to solve problems and transfer learning to any unique situation (3).

Both research and practical experience in education support the use of case studies in the classroom to engage students and develop critical thinking skills. In particular, working through case studies in scientific disciplines encourages students to incorporate knowledge from a variety of backgrounds and apply a breadth of information. While it is recognized that critical thinking is important for student success in professional school and future careers, a specific strategy to tackle a novel problem is lacking in student training. We have developed a four-step systematic approach to solving case studies that improves student confidence and provides them with a definitive road map that is useful when solving any novel problem, both in and out of the classroom. This approach encourages students to define unfamiliar terms, create a timeline, describe the systems involved, and identify any unique features. This method allows students to solve complex problems by organizing and applying information in a logical progression. We have incorporated case studies in anatomy and neuroanatomy courses and are confident that this systematic approach will translate well to courses in various scientific disciplines.
that which students learn through the related course taken for professional school and careers in the sciences. The learning process, which we believe will better prepare them, encourages critical thinking and engages students in the process. This activity can easily be expanded to any discipline. This approach to solving case studies has been applied to implement this process in a course that runs in different classroom settings only requires that students have a basic understanding of the material needed to solve the case study. As such, the case study problem and questions should be built around current topics being studied in the classroom.

Using unfamiliar words teaches students to identify important information. This encourages integration of information and terminology, which can be critical for understanding anatomy. Simple terms, like superficial or deep, guide discussions about anatomical relationships. While students may be able to recite the definitions of these concepts, applying that information to a case study requires integrating the basic definition with an understanding of the relevant anatomy. Specific prerequisite knowledge for the sample case study is detailed in Appendix 1.

Learning time

This process needs to be learned and practiced over the course of a semester to ensure long-term retention. With structured and guided attempts, students will be able to implement this approach to solving case studies in one 50-minute class period (Table 1). The course described in this study is a capstone course that meets once weekly. Each 50-minute class period centers around working through a case study. As some class sessions are reserved for other activities, students complete approximately 10 case studies during the semester. Students begin to show increased confidence with this method within a few weeks and ultimately are able to integrate this approach into their critical thinking skillset by the end of the semester. Presentation of the case study, individual or small group work, and class discussion are all achieved in one standard class session (Table 1). The current model does not require student work prior to the class meeting. However, because this course is taken concurrently with a related, content-heavy lecture component, students are expected to be up to date on relevant material. Presenting the case study in class to their peers encourages students to work through the systematic approach we describe here. Each case study is designed to correlate with current topics from the lecture-based course. Following the class period, students are expected to complete a written summary of the discussed case study. The written summary should include a detailed explanation of the approach they utilized to solve the problem, as well as a definitive solution. Written summaries are to be completed two days after the original class period.

| Activity                      | Approximate Time | Anticipated |
|-------------------------------|------------------|-------------|
| Presentation of the case study| 5 minutes        |             |
| Individual or small group work| 15 minutes       |             |
| Class discussion              | 30 minutes       |             |

This approach to solving case studies has been applied in undergraduate courses, specifically in the sciences. This curriculum is currently utilized in both human gross anatomy and functional neuroanatomy capstone courses. While it is ideal to implement this process in a course that runs in parallel with a lecture-heavy course, it can also be utilized with case studies in a typical lecture class.

Anatomy-based case studies lend themselves well to this problem-solving approach due to the complexities of clinical problems. However, we believe with an appropriately designed case study, this model of teaching critical thinking can easily be expanded to any discipline. This activity encourages critical thinking and engages students in the learning process, which we believe will better prepare them for professional school and careers in the sciences.

Prerequisite student knowledge

Required previous student knowledge only extends to that which students learn through the related course taken previously or concurrently. Application of this approach in different classroom settings only requires that students have a basic understanding of the material needed to solve the case study. As such, the case study problem and questions should be built around current topics being studied in the classroom.
Learning objectives

This model for teaching a systematic approach to solving case studies provides a framework to teach students how to think critically and how to become engaged learners when given a novel problem. By mastering this technique, students will be able to:

1. Recognize words and concepts that need to be defined before solving a novel problem
2. Recall, interpret, and apply previous knowledge as it relates to larger anatomical concepts
3. Construct questions that guide them through which systems are affected, the timeline of the pathologies, and what is unique about the case
4. Formulate and justify a hypothesis both verbally and in writing

PROCEDURE

As a faculty member, it can be challenging to create appropriate case studies when developing this model for use in a specific classroom. There are resources that provide case studies and examples that can be tailored to specific classroom needs. The National Center for Case Study Teaching in Science (University at Buffalo) can be a useful tool. The ultimate goal of this model is to teach an approach to problem solving, and a properly designed case study is crucial to success. To build an effective case study, faculty must include sufficient information to provide students with enough base knowledge to begin to tackle the problem. This model is ideal in a course that pairs with a lecture-heavy component, utilized in either a supplementary course or during a recitation. The case study should be complex and not quickly solved. An example of a simplified case study utilized in Human Gross Anatomy is detailed in Appendix 1.

This particular case study encourages students to think through the anatomy of the lateral knee, relevant structures in this area, and which muscle compartments may be affected based on movement disabilities within the case. While more complex case studies can certainly be developed for the Neuroanatomy course through Clinical Case Studies, this case study provides a good example of a problem to which students cannot immediately provide the answer. They must think critically through the four-step process to identify the “diagnosis” for this patient.

Materials

This approach to solving case studies can be integrated into the classroom with no special materials. However, we use a PowerPoint presentation and personal whiteboards (2.5’ x 2’) to both improve delivery of the case study and facilitate small group discussion, respectively. The PowerPoint presentation is utilized by faculty to assist in leading the classroom discussion, prompting student responses and projecting relevant images. As the faculty member is presenting the case study during the first five minutes of class (Table 1), the wording of the case study can be displayed on the PowerPoint slide as a reference while students take notes.

Faculty instructions

It is helpful to first present an overview of the approach and to solve a case study together as a class. We recommend giving students a lecture describing the benefits of a systematic approach to case studies and emphasizing the four-step approach outlined in this paper. Following this lecture, it is imperative that faculty walk the students through the first case study. This helps to familiarize students with the approach and lays out expectations on how to break down the individual components of the case. During the initial case study, faculty must heavily moderate the discussion, leading students through each step of the approach using the provided Case Study Handout (Appendix 2). In subsequent weeks, students can be expected to show increasing independence.

Following initial presentation of the case study in class, students begin work that is largely independent or done in small groups. This discussion has no grades assigned. However, following the in-class discussion and small group work, students are asked to detail their approach to solving the case study and their efforts are graded according to a set rubric (Appendix 3). This written report should document each step of their thought process and detail the questions they asked to reach the final answer, providing students with a chance for continual self-evaluation on their mastery of the method.

Implementing this model in the classroom should focus not only on the individual student approach, but also on creating an encouraging classroom environment and promoting student participation. Student questions may prompt other student questions, leading to an engaging discussion-based presentation of the case study, which is crucial to increasing confidence among students, as has been seen with the data represented in this paper. When moderating the discussion, it is important that faculty emphasize to students that the most critical goal of the exercise is to learn how to ask the next most appropriate question. The questions should begin with broad concepts and evolve to discussing specific details. Efforts to quickly arrive at the answer should be discouraged.

Students should be randomly assigned to groups of two to three individuals as faculty members moderate small group discussion during class. Randomly assigning students to different groups each week encourages interaction between all students in the class and promotes a collaborative environment. Within their small groups, students should work through the systematic four-step process for solving a novel problem. Students are not assigned specific roles within the group. However, all group members are expected to contribute equally. During this process, it can be beneficial to provide students with a template to follow (Appendix 2). This template guides their discussion and encourages them to use the four-step process. Additionally, each small
group is given a white board that they can use to facilitate their small group discussions. Specifically, asking students to write down details of each of the four facets of the problem (definitions, timeline, systems involved, unique features) and how they arrived at these encourages them to commit to their answers. This also ensures they have concrete evidence to support their “diagnosis” and that they have confidence in presenting it to the class. Two or three small groups are chosen randomly each week to present their hypothesis to the class using their whiteboard.

Suggestions for determining student learning

The cadence of the in-class discussion can provide an informal gauge of how students are progressing with their ability to apply the systematic approach. The discussion for the initial case studies should be largely faculty led. Then, as the semester progresses, faculty should step back into a facilitator role, allowing the dialogue to be carried by the students.

Additionally, requiring students to write a detailed summary of their approach to the problem provides a strong measure of student learning. While it is important for students to document their final “diagnosis” or solution to the problem, the focus of this assignment is primarily on the process and the series of relevant questions the student used to arrive at the answer. These assignments are graded according to a set rubric (Appendix 3).

Sample data

The following excerpt is from a student who showed marked improvement over the course of the semester in implementing this approach to solving case studies. The initial submission for the case study write-up was rudimentary, did not document the thought process through appropriate questions, and lacked an in-depth explanation to demonstrate any critical thinking. By the end of the semester, this student documented a logical thought progression through this four-step approach to solving the case study. This student, additionally, detailed the questions that led each stage of critical thinking until a “diagnosis” was reached (complete sample data are available in Appendix 4).

Initial sample: “Given loss of sensory and motor input to left lower limb, right anterior cerebral artery ischemia caused the sensory and motor cortices of the contralateral (left) lower limb to be without blood flow for a short amount of time (last night). The lack of flow led to a fast onset of motor and sensory paresis to limb.”

Final sample: “…the left vestibular nuclei which explains the nystagmus, and the left cerebellar peduncles which carry information that aids in coordinating intention movements. My next question was where in the brainstem are all of these components located together? I narrowed this to the left caudal pons. Finally, I asked which artery supplies the area that was damaged by the lesion? This would be the left anterior inferior cerebellar artery.”

Safety issues

There are no known safety issues associated with implementing this approach to solving case studies.

DISCUSSION

The primary goal of the model discussed here is to give students a method that uses critical reasoning and helps them incorporate facts into a complete story to solve case studies. We believe that this model addresses the need for teaching the specific skill set necessary to develop critical thinking and engage students in the learning process. By encouraging critical thinking, we begin to redirect the tendency to simply recite a memorized answer. This four-step approach to solving case studies is ideal for the college classroom, as it is easily implemented, requires minimal resources, and is simple enough that students demonstrate mastery within one semester. While it was designed to be used in anatomy and neuroanatomy courses, this platform can be used across scientific disciplines. Outside of the classroom, in professional school and future careers, this approach can help students to break down the details, ask appropriate questions, and ultimately solve any complex, novel problem.

Field testing

This model has been implemented in several courses in both undergraduate and graduate settings. The data and approach detailed here are specific to an undergraduate senior capstone course with approximately 25 students. The lecture-based course, which is required to be taken concurrently or as a prerequisite, provides a strong base of information from which faculty can develop complex case studies.

Evidence of student learning

Student performance on written case study summaries improved over approximately ten weeks of practicing the systematic four-step approach (Fig. 1). As indicated by the data, scores improve and begin to plateau around five weeks, indicating a mastery of the approach. In the spring 2016 semester, a marked drop in scores was observed at week 8. We believe that this reflects a particularly difficult case study that was assigned that week. After observing the overall trend in scores, instructional format was adjusted to provide students with more guidance as they worked through this particular case study.

After the class session, students were asked to provide a written summary of their findings. A set rubric (Appendix 3) was used to assess students on their ability to apply basic anatomical knowledge as it relates to the timeline, systems
involved, and what is unique in each case study. Students were also asked to describe the questions that they had asked in order to reach a diagnosis for the case study. The questions formulated by students indicate their ability to bring together previous knowledge to larger anatomical concepts. In this written summary, students were also required to justify the answer they arrived at in each step of the process. In addition to these four steps, students were assessed on the organization of their paper and whether their diagnosis is well supported.

Although class participation was not formally assessed, the improvements demonstrated in the written assignments were mirrored in student discussions in the classroom. While it is difficult to accurately assess how well students think critically, students demonstrated success in learning this module, which provides the necessary framework for approaching and solving a novel problem.

Student perceptions

Students were asked to answer the open response question, “Describe the process you use to figure out a novel problem or case study.” Responses were anonymized, then coded based on frequency of responses. Responses were collected at the start of the semester, prior to any instruction in the described systematic approach, and again at the end of the semester (Figs. 2 and 3). Overall, student comments indicated that mastering this four-step approach greatly increased their confidence in tackling a novel problem. Below are some sample student responses.

“Rather than being intimidated with a set of symptoms I can’t explain, I’m now able to break them down into simpler questions that will lead me down a path of understanding and accurate explanation.”

“I now know how to address an exam question or life problem by considering what is needed to solve it. This knowledge will help me to address each problem efficiently and calmly. As a future nurse, I will benefit from developing a logical and stereotypical approach to solving problems. I have learned to assess my thinking and questioning and modify my approach to problem-solving. While the problems may be different in the future, I am confident that I will be able to efficiently learn from my successes and setbacks and continually improve.”

“I’m sure I’ll use this approach when I’m faced with any other novel problem, whether it’s scientific or not. Stepping back and establishing what I know and what I need to find out makes difficult problems a lot more approachable.”

“Before, I would look at all the information presented and try to find things that I recognized. Then I would simply ask myself if I knew the answer. Even if I did actually know the answer, I had no formula to make the information understandable, cohesive, or approachable. I now feel far more confident when dealing with novel problems and do not become immediately overwhelmed.”

This approach encourages students to quickly sort through a large amount of information and think critically. Although students can find the novel nature of this method
cumbersome in the initial implementation in the classroom, once they become familiar with the approach, it provides a valuable platform for attacking any novel problem in the future. The ability to apply this approach to critical thinking in any discipline was also demonstrated, as is evidenced by the two following student responses.

“When I first thought about this question and when solving case studies I tried to find the answer immediately. I’m good at memorizing information and spitting it back out but not working through an issue and having a method. I definitely have a more successful way to think through complex problems and being patient and coming up with an answer.”

“I already use it in many of my other classes and life cases. When I take an exam that is asking a complicated question or is in a long format, I work to break it down like I did in this class and try to find the base question and what the answer may be. It has actually helped significantly.”

Possible modifications

Currently, students are randomly assigned to groups each week. In future semesters, we could improve small group work by utilizing software that helps to identify individual student strengths and assign groups accordingly. Additionally, while students are given flexibility within their small groups, if groups struggle with equality of workload we could assign specific roles and tasks.

We are also using this model in a large class (100 students) and assessing understanding of the case study through instant student response questions (ICLICKER). While this
model does not allow for the valuable in-depth classroom discussions, it still presents the approach to students and allows them to begin to implement it in solving complex problems. Preliminary data from these large classes indicate that students initially find the method difficult and cumbersome. Further development and testing of this model in a large classroom will improve its use for future semesters.

SUPPLEMENTAL MATERIALS

Appendix 1: Sample case study
Appendix 2: Case study handout
Appendix 3: Case study grading rubric
Appendix 4: Student writing sample

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REFERENCES

1. Sternberg RJ. 1986. Critical thinking: its nature, measurement, and improvement. National Institute of Education, New Haven, CT.
2. Facione PA. 2000. The disposition toward critical thinking: its character, measurement, and relationship to critical thinking skill. Inform Logic 20:61–84.
3. Altstadt D. 2010. Building opportunity: how states can leverage capital and infrastructure investments to put working families on a path to good jobs. The Working Poor Families Project, East Dummerston, VT.
4. Business-Higher Education Forum & American Council on Education. 2003. Building a nation of learners: the need for changes in teaching and learning to meet global challenges. Washington, DC.
5. Association of American Colleges and Universities. 2005. Liberal education outcomes: a preliminary report on student achievement in college. AACU, Washington, DC.
6. American Association for the Advancement of Science. 2011. Vision and change in undergraduate biology education: a call to action: a summary of recommendations made at a national conference organized by the American Association for the Advancement of Science, July 15–17, 2009. Washington, DC.
7. Bloom BS. 1956. Taxonomy of educational objectives: the classification of educational goals by a committee of college and university examiners. Handbook 1: cognitive domains. Longman, Green, New York, NY.
8. Abrami PC, Bernard RM, Borokhovski E, Wade A, Surkes MA, Tamim R, Zhang D. 2008. Instructional interventions affecting critical thinking skills and dispositions: a stage 1 meta-analysis. Rev of Educ Res 78(4):1102–1134.
9. Paul RW. 1992. Critical thinking: what, why, and how? New Dir Commun Coll 77:3–24.
10. Willingham DT. 2008. Critical thinking: why is it so hard to teach? Arts Educ Pol Rev 109:21–32.
11. Quitadamo IJ, Kurtz MJ. 2007. Learning to improve: using writing to increase critical thinking performance in general education biology. CBE Life Sci Educ 6:140–154.
12. Herreid CF. 1994. Case studies in science—a novel method of science education. J Coll Sci Teach 23(4):221–229.