CASE STUDY
Locate the Lesion: A Project-Based Learning Case that Stimulates Comprehension and Application of Neuroanatomy

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A fictitious patient, Mr. Challenge, is admitted to the emergency room and displays symptoms consistent with damage to the central nervous system. In this problem-based learning case, students are challenged to determine the location of a lesion that is consistent with Mr. Challenge's symptoms. Students discover details about Mr. Challenge's symptoms while exploring three anatomical pathways: corticospinal tract, spinothalamic tract and medial lemniscal pathway. Students make predictions as to which of these pathways may be damaged in Mr. Challenge and defend their predictions based on their research of the function and anatomical location of these tracts. This ultimately leads the student to identifying a single lesion site that can account for Mr. Challenge's symptoms. This case is executed in an undergraduate neuroscience course and would be useful in anatomy and physiology course, as well as other courses that serve students interested in health science related careers.

Key words: case study, problem based learning (PBL), anatomical tracts, corticospinal tract, spinothalamic tract, medial lemniscal pathway, active learning, generation-based learning, flipped classroom

CONTEXT

Case studies promote active learning by capturing student interest and motivating students to apply concepts to a novel situation. The case described here, called Locate the Lesion, challenges undergraduates to apply key concepts of neuroanatomy to determine a single lesion site that accounts for all the symptoms of an imaginary patient, Mr. Challenge. This case is designed to promote generative learning; an effective form of learning where students attempt to solve a problem prior to being shown the answer (Brown et al., 2014). Generative learning, which admittedly can be frustrating for the learners, has been shown to be a valuable method for long term retrieval (Brown et al., 2014), provided corrective feedback is given, as done here.

This case is implemented in an upper level, undergraduate Principles of Neuroscience course at a small liberal arts college. This course typically enrolls twenty-four students and is as a required Capstone course for Biology Majors with a Neuroscience and Behavior Concentration, and Psychology Majors with a Brain Science Concentration. This course also serves as an elective for Biology Majors and Human Services and Rehabilitation Studies majors, some of whom are Physical Therapy or Occupational Therapy Concentrators. This case would be useful in an anatomy and physiology course, and other courses that serve undergraduates preparing for entry into graduate programs in health science professions.

Locate the Lesion has been implemented three times, consistently in the first third of the semester while we are covering the topic of neuroanatomy in lecture and in lab. Typically, the lecture session meets three times each week for fifty minutes each class. However, when possible, this course is taught twice per week for eighty minutes per session. The latter schedule works better for this case, however, the former schedule is also successful. The lab meets once each week for three hours, however, we do not *directly* devote lab time to this case study. In lab, we do *indirectly* contribute to the case study by identifying anatomical structures through the use of fixed sheep brains, plastic human brain and vertebral column models, brain atlases, stained spinal cord sections (observed under the microscope) and human brain MRI images.

This case is a narrative about an undergraduate who is shadowing a medical student in the emergency room. The undergraduate witnesses conversations between the medical student and a doctor, who is examining an imaginary patient Mr. Challenge, who has symptoms suggestive of injury to the central nervous system. The medical student and the undergraduate student work together to identify a lesion area that could account for Mr. Challenge's symptoms. This story tends to be relatable to our students, as many of them volunteer or work in local hospitals or clinics, and are interested in careers within the health sciences, such as a physician assistant, nurse, physical therapist, and medical doctor.

Students are assigned to work in groups of 3-4 (preferably 4) by their instructor. Groups are selected by the instructor in a manner to ensure representation of various academic backgrounds in each group, when possible. For example, one group may have two Biology majors, a psychology major, and a Human Services and Rehabilitation Major. The rationale for this selection is explained to the class to promote transparency of this design. Students serve as "experts" from their field/major and work together with their colleagues to solve the case.

This case is divided into four assignments/scenes. Each assignment includes a short passage and several questions generated from the passage. One assignment is given per class period for four consecutive sessions. Working in groups, students complete assigned work

outside of class. Work is collected and assessed as a "low stakes" assignment, meaning that students are rewarded for evidence of good effort but not penalized heavily for incorrect answers. Grades for each of these four group assignments are placed in a category entitled, "assignments and discussions" in the syllabus, that is collectively worth 5% of the overall course grade. The intention is to promote investigation and curiosity, without significant penalty for mistakes during initial exposure to the case-based approach. After practicing additional cases, students are challenged to solve case-based questions on exams that have a greater impact on their overall course grade.

At the start of each class, time is devoted to reviewing material relevant to each recently completed assignment. For the final assignment, an entire lecture period (or sometimes 1.5 lecture periods) is devoted to reviewing the case as a whole as well as practicing other imaginary patient scenarios. Student comprehension and acquired skills are ultimately assessed by similar-style questions on an exam. The Classroom Implementation notes, full case narrative, and additional practice cases with answer key are available upon request from the corresponding author or from cases.at.june@gmail.com.

Learning Objectives

Content Objectives:
At the end of the case, students will be able to:

- Identify anatomical structures in the brain including: precentral gyrus, postcentral gyrus, central sulcus, pyramidal decussation, thalamus, homunculus, as well as structures in the spinal cord, including: substantia gelatinosa, dorsal column nuclei, ventral horn, dorsal horn, ventral column, dorsal column and lateral column.
- Describe known functions of anatomical structures.
- Describe major anatomical landmarks of three pathways: corticospinal tract, spinothalamic tract, and medial lemniscal pathway.
- Trace the physical pathways of each of the three tracts listed above with special attention to when the pathways cross (or decussate) to the contralateral side.
- Explain information that is conveyed or perceived by signals traveling along these pathways (e.g., sensory or motor).
- Identify select blood vessels that feed the brain and spinal cord (anterior cerebral artery, middle cerebral artery, posterior cerebral artery, anterior spinal artery, posterior spinal artery).
- Describe the anatomical regions that these blood vessels feed.
- Compare patterns of symptoms of a brain lesion to spinal cord lesion.

Skill/Process Objectives
At the end of the case, students will be able to:

- Properly use terms such as superior, inferior, anterior, posterior, dorsal, ventral, contralateral, ipsilateral while accurately describing an anatomical location.
- Harness understanding of anatomical tracts to deduce a single lesion site that accounts for all symptoms of an imaginary patient.
- Resolve the most likely vessel in which a stroke may have occurred that can account for imaginary patient's symptoms.
- Articulate reasons that support one possible lesion site and exclude other possible lesion sites.
- Effectively communicate with peers to defend a position or present evidence to dissuade peers of a position.

CLASSROOM MANAGEMENT OVERVIEW

Each group of 3-4 students is assigned to work collaboratively to complete four assignments/scenes. For each assignment, students must select a "role" for each group member. Roles are defined as: 1) Recorder- person who takes notes and distributes notes to group members, keeps attendance for each group meeting, and also keeps record of each group member's contribution to this work, 2) Leader- person who keeps group on-task, helps focus discussion to relevant points in the case, the leader reviews group work and determines if edits are needed prior to sending final product to instructor, 3) Manager- person who keeps track of time during class and at out-of-class meetings, makes certain group is being productive with their time and assigns tasks to other group members between meetings/class and 4) Planner- person who organizes group meeting outside of class, sets start time, end time and location for meeting, makes certain everyone can make the meeting, keeps line of communication open and clear, documents all instances of communication, ensures that work can be completed in a timely manner. Students must change their role for each of the four assignments, thus serving each of the four roles at least once. If there are only three members in a group, then students take turns serving as two roles for each assignment. The purpose of selected "roles" is to encourage all students to participate and contribute in a multiple ways for these assignments. It also helps decrease confusion regarding which students are responsible for specific tasks (such as submission of work to instructor).

Questions associated with each scene lead students to generate "Learning Issues" (LIs), as described previously (Roesch and Frenzel, 2016). Examples of LIs for this case include: What is meant by the phrase, "voluntary motor function"? What is "proprioception" and how would a doctor test for this? Why is the phrase "sudden onset" an important detail to describe the patient? Students are prompted to investigate terms they do not know and answer questions that are generated after reading the passage. Students use their required textbook (Bear et al., 2016) and the internet to solve these questions, and each group submits answers to these questions to the instructor for assessment. At the start of the next lecture period, the class reviews the main points of the case and the instructor helps clarify unresolved points.

Students are asked if certain tracts may be damaged in Mr. Challenge, based on his symptoms. Students make a prediction or hypothesis (for example, the corticospinal tract is likely to be damaged, or the corticospinal tract is *not*

likely to be damaged) and then defend their position based on their investigative work. Students receive feedback after each scene to ensure that their prediction is accurate and sound before proceeding to the next assignment. While students sometimes feel uncomfortable with investigating topics that are not yet fully known to them, the process of trying to solve a problem before knowing the solution is an effective learning strategy, even if the initial guess/answer was incorrect (Brown et al., 2014).

CASE EVALUATION

Assessment

Students' comprehension of material and acquired skills are primarily assessed via questions on an exam. Here, we report student performance on the final, cumulative exam. The final exam was worth 20% of the overall course grade. As done previously (Brielmaier, 2016), scores (n=23) for questions focused on "case-relevant" material were compared to scores from "control" questions with similar Bloom's taxonomy, but focused on material not relevant to this case. Sample score comparisons are as follows (case-relevant versus control): 23/23 correct (100%) versus 13/26 correct (57%) for multiple choice questions, and 17/23 correct (74%) versus 15/23 correct (65%) for fill in the blank questions. On average, students earned 6.3/9 points (70%) collectively for short answer questions about imaginary patients, similar to the Mr. Challenge case. These questions were the most challenging on the exam (as perceived by the instructor) and it is challenging to find appropriate questions to compare. However, the set of questions that came the closest to this goal included a set of neurophysiology questions. Students earned 5.9/8 points (74%) on neurophysiology questions that were also application-based (and not related to case material). Questions and answers are reported in the implementation notes. While this limited data set is not sufficient for statistical analyses, the overall trend is encouraging and suggests that this case may promote enduring learning, as revealed on the final exam.

Student Feedback

At the end of the case, student feedback was informally and anonymously collected. Comments from students were very positive, particularly about the challenge of trying to solve a medical case. Students wrote, "this [case] was more engaging than listening to a lecture" and, "I felt I learned more through this assignment…it was fun to think about anatomy like a puzzle." Another student wrote, "I thought the locate the lesion was a useful assignment and I personally really enjoyed the assignment because of the way it relates to medicine." However, some students did express frustration with the case and wondered if it would be "easier if the instructor just told us the answer." This frustration is understandable, however, the sense of struggle while tackling new material has been correlated with a stronger, longer-lasting understanding (Brown et al., 2014). Perhaps students would better receive this case if this point (a stronger, longer-lasting understanding can be achieved by struggling with material and even by making mistakes) was made more clear by the instructor, as mentioned in future directions.

At the end of the semester, students were asked to complete a brief survey regarding their experience with this case. Eleven students (out of twenty-three enrolled) responded to this survey. The results (Table 1) were positive overall. A four-point scale was used where 1= very useful, 2=somewhat useful, 3=not very useful and 4= not useful at all. Data from such a limited number of students precludes us from drawing firm conclusions, however, we will describe our findings here. Students reported that the case was a very useful or somewhat useful approach to learning anatomical tracts compared to a traditional lecture (1.7 = average score). Students felt that exploring these tracts through the locate the lesion case of Mr. Challenge was very/somewhat useful (1.5= average score). These scores are very encouraging and suggest students enjoyed investigating the case of Mr. Challenge while learning anatomical pathways. However, students reported that working in groups outside of class while tackling new material was somewhat useful or not very useful (2.6 = average) and students felt that exploring

Survey Statement	Average Rating (Mean $\pm$ SD)
In general, how useful did you find the locate the lesion assignments in learning anatomical tracts?	1.7 $\pm$ 0.65
How useful did you find working on the locate the lesion assignments outside of class in small groups?	2.6 $\pm$ 0.81
How useful did you find learning neuroanatomy in the context of solving the case of an imaginary patient, Mr. Challenge, compared to a traditional lecture?	1.5 $\pm$ 0.52
Did you find it useful to explore unknown material first, followed by a summary given by the instructor?	2.2 $\pm$ 0.87

Table 1. Students rated the case study as useful. A four-point scale was used to gauge their impressions, where 1=very useful, 2=somewhat useful, 3=not very useful and 4=not useful at all. Eleven out of twenty-three students completed survey.

new material first, followed by an instructor summary was somewhat useful or not very useful (2.2= average). These scores seemed to reflect frustration by some students while exploring novel material outside of class and with their peers. Modifications of this case are proposed under "future directions" aim to address these points.

Lastly, students offered additional feedback on this survey and wrote, "I loved this assignment and portion of the class. I found it so interesting" and "…I feel I am more engaged and absorb material better when it can be applied to clinical cases and real scenarios." We plan to build on these positive student perceptions as we continue to improve this case implementation (see future directions).

SUMMARY AND FUTURE DIRECTIONS

This case continues to be a work in progress. Overall, it has been well received by students and it is also enjoyable from the perspective as the instructor. While most students enjoy a break from traditional lecture, it remains a challenge for this instructor to refrain from transitioning into lecture where the instructor is the "source" of information, rather than the students. However, the benefits of student-centered inquiry are numerous and well worth the effort.

In the future, this case may be further developed to explore relevant aspects of a neurological exam. This would further tap into the students' reported enthusiasm for covering life-like medical scenarios. There are numerous, reliable websites that explain components of a neurological exam and include videos. One such website is from the University of Utah (http://library.med.utah.edu/neurologicexam/html/sensory_normal.html). Students could investigate *how* Mr. Challenge's proprioception or fine touch was tested and in some cases, students can practice the exam on their peers, further enhancing the student experience with the material through elaborative learning.

Noting that some students reported discontent with group work outside of the lecture period, it may be worthwhile to designate time in class to begin each scene. For example, students could select their roles during class time and begin to plan their assigned work and group meetings. This may help initiate a stronger start to the group work that is required with this case. Alternatively, the entire lecture time can be devoted to group work to allow for completion of each scene during class time, provided students have access to the internet and textbooks. Additionally, time in lab can be designated to this case.

Students reported dissatisfaction and sometimes aggravation while exploring novel material prior to lecture. As mentioned earlier, student frustration with this challenge can be common and understandable. However, the struggle of solving a problem prior to "knowing the right answer" is ultimately beneficial to learning and is supported by several studies that are summarized in *Make it stick, The Science of Successful Learning* (Brown et al., 2014). In the future, the benefits of generation-based learning will be discussed with students prior to this case. It should be noted that even when attempted solutions are wrong, this leads to longer-lasting learning, provided that corrective feedback is given (as done in class by the instructor). If students were made aware of these studies, this could help students understand the benefits of this case study.

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