ARTICLE
Effective Use of Student-Created Case Studies as Assessment in an Undergraduate Neuroscience Course

Dianna M. Bindelli[1*], **Shannon A.M. Kafura**[1*], **Alyssa Laci**[1*], **Nicole A. Losurdo**[1*], **Denise R. Cook-Snyder**[1,2]

**These authors have contributed equally to this work; [1]Neuroscience Department, Carthage College, Kenosha, WI 53140; [2]Department of Physiology, Medical College of Wisconsin, Milwaukee WI 53226.*

Case studies and student-led learning activities are both effective active learning methods for increasing student engagement, promoting student learning, and improving student performance. Here, we describe combining these instructional methods to use student-created case studies as assessment for an online neurovirology module in a neuroanatomy and physiology course. First, students learned about neurovirology in a flipped classroom format using free, open-access virology resources. Then, students used iterative writing practices to write an interrupted case study incorporating a patient narrative and primary literature data on the neurovirulent virus of their choice, which was graded as a writing assessment. Finally, students exchanged case studies with their peers, and both taught and completed the case studies as low-stakes assessment. Student performance and evaluations support the efficacy of case studies as assessment, where iterative writing improved student performance, and students reported increased knowledge and confidence in the corresponding learning objectives. Overall, we believe that using student-created case studies as assessment is a valuable, student-led extension of effective case study pedagogy, and has wide applicability to a variety of undergraduate courses.

Key words: case study; primary literature; active learning; cooperative learning; collaborative learning; neurovirology

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It is well established that active learning increases student engagement, promotes student learning, and improves student performance compared to traditional lecture (Armbruster et al., 2009; Haak et al., 2011; Freeman et al., 2014). Moreover, active learning is a critical component of inclusive pedagogy that is effective for all students, and decreases the achievement gap for persons excluded because of their ethnicity or race (PEERs; Haak et al., 2011; Ballen et al., 2017; Penner, 2018; Theobald et al., 2020; Asai, 2020). Frequent student-led learning activities are an important component of an active learning classroom, where students engage with course content and work collaboratively with their peers to increase their own and each other's learning. Student-led learning techniques range from short, cooperative activities like think-pair-share and the jigsaw method (Faust and Paulson, 1998; Lom, 2012; Lang, 2016), to full collaborative learning courses where students prepare and lead most classes (Casteel and Bridges, 2007; Davidson and Major, 2014; Kurczek and Johnson, 2014). Case studies are also an effective active learning method that uses narratives to engage students in higher-level learning objectives within Bloom's Taxonomy (Anderson and Krathwohl, 2001; Handelsman et al., 2004; Herreid et al., 2012; Wiertelak et al., 2016). As one example, case studies have been incorporated into introductory and upper-level neuroscience courses to promote student analysis and evaluation of primary literature (Cook-Snyder, 2017; Sawyer and Frenzel, 2018; Rollins, 2020). Typically, student-led learning activities and case studies are both used as in-class practice before a separate, larger assessment, like an exam testing similar content (Freeman et al., 2014; Cook-Snyder, 2017; Sawyer and Frenzel, 2018). Here, we describe using the case study itself as the assessment, where students work collaboratively to write a case study that demonstrates and applies their neurovirology knowledge and requires analysis and evaluation of the primary literature. In turn, students lead their peers in discussion of their case to promote their own and each other's learning.

As described here, we used student-created case studies as assessment in a four-week, online neurovirology module in an upper-level neuroanatomy and physiology course. Neurovirology is the interdisciplinary study of viruses that affect the central nervous system (Nath and Berger, 2020) and students voted to learn more about neurovirology during the SARS-CoV-2 (COVID-19) pandemic in the spring 2020 semester. Accordingly, student-created case studies focused on neurovirulent viruses, or viruses that can cause disease of nervous tissue (Racaniello, 2020a). Students used iterative writing practices to write their case studies, which were graded as writing assignments. Then, students exchanged case studies with their peers, and both taught and completed the cases in small groups as low-stakes assessment. Student performance data and self-reported evaluations support the success of the neurovirology module and case study assignment in meeting the content and skills learning objectives listed below. Case studies are highly effective tools in undergraduate education (Handelsman et al., 2004; Herreid et al., 2012; Wiertelak et al., 2016), and we believe that using student-created case studies as assessment is a valuable extension of established case study pedagogy.

Learning Objectives

Content Objectives:

After this module, students should be able to:

- Understand and explain basic virology principles, including:
  - Viral properties and classification
  - Viral pathogenesis, including infection and immune response
- Understand and explain neuroscience principles relevant for viral pathogenesis, including:
  - CNS barriers, including the blood-brain barrier
  - Mechanisms of neurotoxicity and neuronal death

Skills Objectives:

Additionally, students will increase their skills in:

- Applying virology and neuroscience principles to neurovirulent viruses and neurologic disorders
- Using resources from the neurovirology module to learn more about virology
- Analyzing and evaluating primary literature
- Collaborating to write original case studies
- Leading peers in analysis and evaluation of case studies

MATERIALS AND METHODS

Neurovirology Module

The neurovirology module was developed for a one-semester, neuroanatomy and physiology lecture and laboratory course for junior and senior neuroscience majors at a small liberal arts college (Neuroscience 4100, Carthage College). Enrollment for the course is typically 25-30 students, with greater than 60% of students reporting clinically focused health care career goals. The most common career goals are physician (M.D. or D.O.), physician assistant, physical or occupational therapist, and clinical psychologist, consistent with the hypothesis that students believe a neuroscience major will better prepare them for health care careers (Prichard, 2015; Ramos et al., 2016a, 2016b).

The neurovirology module was developed as a substitution for in-person labs when remote instruction was implemented in the spring 2020 semester due to the COVID-19 pandemic. Student survey data was collected using Google Forms at the beginning of remote instruction, and 96% of students voted in favor of using lab time to learn more about virology and infectious disease, with an emphasis on neurovirology (n = 26 enrolled students; 24/26 students for, 0/26 students against, 2/26 students abstained). Accordingly, the neurovirology module was administered over Zoom (https://zoom.us/) during weekly 3-hour lab periods for a total of four weeks (Week 1 to Week 4; 12 hours total; see Supplementary Material Appendix A, Appendix B). Students received instruction in using Zoom prior to the neurovirology module, including joining a Zoom class, providing verbal and non-verbal feedback to the instructor, and joining breakout rooms to work with peers.

The neurovirology module followed a flipped classroom format, in which students gained familiarity with neurovirology content before class, and used class time for active learning strategies (Mazur, 2009; Brame, 2013). Appendix A provides details on before class readings, videos, and assignments, and in-class activites for the neurovirology module. Briefly, in Week 1, students learned basic principles of virology using recorded lectures and readings from a free, online, open-access virology course (https://www.virology.ws/course/) and blog (https://www.virology.ws/virology-101/) courtesy of Vincent Racaniello at Columbia University (Racaniello, 2004; Racaniello, 2009a, 2009b, 2009c, 2009d, 2009e, 2009f, 2009g; Racaniello, 2020a, 2020b, 2020c). These materials were supplemented with textbook readings on the immune system (Widmaier et al., 2014). Week 1 materials were chosen to provide students with enough background on viral properties, classification, and pathogenesis that they could apply their knowledge to neurovirulent viruses and neurologic disorders in Week 2. Accordingly, in Week 2, students read about central nervous system barriers in the course textbook (Kandel et al., 2013), and watched a brief, recorded lecture summarizing major mechanisms of neurotoxicity and neuronal death (Appendix A; Fink and Cookson, 2005; Jellinger, 2010; Fan et al., 2017; full lecture available from the corresponding author by request). After completing these additional background readings, students read a neurovirology review article describing mechanisms of invasion and disease for specific neurovirulent viruses (Swanson and McGavern, 2015).

Before class assignments for Week 1 and Week 2 included short, online comprehension quizzes, and collaborative "neurovirology dictionary" assignments, where students were responsible for adding new terms and definitions to create a shared "neurovirology dictionary" from the before class readings and videos (Appendix A). Both of these graded assignments incentivized student preparation before class and provided checks of student understanding, which are key elements of a flipped classroom (Brame, 2013).

Week 1 and Week 2 class time used cooperative, student-led learning, where students worked together to complete questions based on the before class content (Davidson and Major, 2014). Specifically, students were randomly assigned to groups of 3-4 using the breakout room function in Zoom. Each group was assigned a different set of instructor-created questions to discuss and complete in a shared Google Slides document, and the instructor circulated between groups to check understanding. Then, each group presented their answers to the full class. This format provided structure for students to create their own study guide summarizing neurovirology content, and provided additional practice in cooperative, student-led learning (Davidson and Major, 2014).

Case Study Assignment

Weeks 3-4 of the neurovirology module were used for the case study assignment. Broadly defined, case studies use narratives to engage students and meet learning objectives (Herreid, 2007). The case study assignment was worth 6% of the final course grade, and Appendix B provides details on assignment requirements and a grading rubric. Briefly, students worked in self-selected groups of 2-3 to write their case study on any neurovirulent virus of their choosing. Case studies were required to follow an interrupted, literature-based format (Herreid et al., 2012; Prud'homme-Généreux, 2016; Cook-Snyder, 2017), where the first part of the case study used a patient narrative or primary literature data and asked questions on the epidemiology and/or symptoms and diagnosis of the virus. The second part of the case study was required to use primary literature data and ask questions on the pathogenesis and/or treatment of the virus. Students included answers to their own questions, and the answers were required to be clearly supported by the course materials and by their case study. Supplementary Material Appendices C and D provide example student-created case studies on rabies virus and enterovirus 71, respectively.

Students followed an iterative writing practice to create their case studies, which sought to couple goal-directed practice with targeted feedback (Ambrose et al., 2010). Specifically, students submitted the first draft of their co-authored case study in Week 3, which was graded by the instructor using a holistic rubric that included a grading scale, comments, and specific examples from the students' draft (Appendix B; Allen and Tanner, 2006). The first draft was worth 10% of the students' final grade on the assignment, which incentivized student performance on the draft while still serving as a low-stakes assesement and providing formative feedback (Birol et al., 2013; Brownell et al., 2013; Cotner and Ballen, 2017; Cyr, 2017). Then, students revised and submitted the final draft of their case study in Week 4, which was graded by the instructor using the same rubric as the first draft to provide summative feedback, and was worth 90% of the students' final grade. Students were asked to write new or edited text on the final draft in a different color, so the instructor could more easily identify the students' improvements from the first draft and incorporation of first draft feedback.

Students also shared their case study final draft with one other student group, and the case study authors led their peers through their case studies following a previously described classroom management strategy (Cook-Snyder, 2017). This classroom management strategy is consistent with effective student-led discussion practices, including students working in teams to create and disseminate discussion questions before leading class discussion (Casteel and Bridges, 2007; Kurczek and Johnson, 2014). Briefly, in Week 4, peers completed the student authors' case study questions as homework before class, and class time was used to discuss their answers. Discussion was facilitated by the student authors, and emphasized that there can be multiple "correct" answers where the best answers are accurate and well-supported. Well-supported answers cited the case study itself, the neurovirology module, previous course content, and/or the primary literature as needed. This approach encourages students to apply course knowledge and conduct targeted literature searches to increase their knowledge. Peers edited their answers based on the discussion, and these edits were factored into a pass/fail grade from the instructor. Each case study was allotted 30 minutes for discussion; at the end of 30 minutes, the peers and students authors switched roles and discussed the peers' case study. Appendix B provides a table illustrating this format for a three-hour class period. Overall, each student received three grades on the case study assignment: a grade on the first draft and a grade on the final draft of the case study they wrote, and a pass/fail grade on the case study they completed (Appendix B). Additionally, each student had the opportunity to teach their case study to their peers as a student-led learning activity. By implementing the case study assignment workflow outlined here, students both created original work and led their peers in analysis and evaluation of their work, consistent with higher-level learning objectives from Bloom's Taxonomy (Anderson and Krathwohl, 2001).

Assessment of Learning Objectives

Learning objectives for the neurovirology module and case study assignment were assessed directly and indirectly using student performance data and self-reported evaluations, respectively (Muir, 2015). Data and evaluations were collected in accordance with federal guidelines for research in education settings, and with approval from the Institutional Review Board at Carthage College. All statistical analyses were performed in GraphPad Prism 8 for macOS (San Diego, CA) with a significance level of $p<0.05$.

Analyzed student performance data included student grades on the first draft and final draft of the case study assignment (Figure 1). Comparison of first draft and final draft case study grades was analyzed using a parametric paired t-test.

De-identified student self-reported evaluations were collected using Google Forms after Week 4 of the neurovirology module and case study assignment. Quantitative evaluations used a Likert scale with the following responses: 5-Strongly Agree; 4- Agree; 3- Neutral; 2- Disagree; 1- Strongly Disagree (Figures 2-4). All questions included a "prefer not to respond" option for student response, although no students chose this option for the questions reported here. Student responses were analyzed using a nonparametric one-sample Wilcoxon signed-rank test, with a hypothetical median of 3- Neutral. If

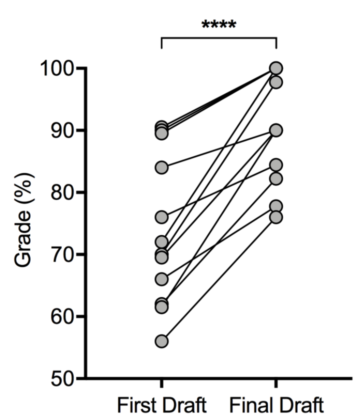

Figure 1. Student performance improved with iterative writing practice and low-stakes assessment. Student group grades for the first draft and final draft of the case study are shown as a percentage of the total possible points for the draft (grey circles). Lines connect the first draft and final draft grades from the same student group (n = 12 student groups; paired t-test, ****p<0.001).

the responses were significantly different from 3- Neutral, we concluded that the students agreed/strongly agreed (4-5) or disagreed/strongly disagreed (1-2) with the question. This analysis method is consistent with previous research analyzing student-led learning activities (Stavnezer and Lom, 2019).

De-identified qualitative evaluations included three open-ended questions: (1) What will you take away from the neurovirology module?; (2) What aspects of the neurovirology module were most valuable?; (3) What suggestions do you have for how Dr. Cook-Snyder (i.e., instructor and corresponding author) can improve the neurovirology module? The corresponding author categorized student responses to align with the content and skills learning objectives, or with the neurovirology module materials (Appendix A) and case study assignment (Appendix B; Figure 5). Some student responses contained module/case study assignment category. Additionally, some student responses (31.03% of responses) did not contain a suggestion for improvement, and were omitted from analysis. Accordingly, qualitative evaluation sample sizes vary from course enrollment because one response can contain zero or multiple categories, consistent with analysis methods from previous studies (Stavnezer and Lom, 2019).

RESULTS

Student Performance

Student learning in the neurovirology module (Supplementary Material Appendix A) was primarily assessed with the case study assignment (Supplementary Material Appendix B). As examples, two student-created case studies on neurovirulent viruses are included in Supplementary Material Appendices C and D. Student authors (DMB, SAMK, AL, NAL) had substantial familiarity with interrupted, literature-based case studies before writing their own case study in this format. Indeed, almost all students who wrote case studies (25 out of 26 students) had previously completed 13 interrupted, literature-based case studies over two semesters in the corresponding author's courses (Cook-Snyder, 2017). In Appendix C, the student-created case study on rabies virus applies content from the neurovirology module with detailed analysis of primary literature data on rabies virus, blood-brain barrier permeability, and vaccine efficacy (Long et al., 2020). In Appendix D, the student-created case study on enterovirus 71 also applies neurovirology content to investigate vaccine efficacy (Li et al., 2008; Zhang et al., 2012). Additionally, this case study reviews cerebellar and pontine structure and function, which were previously discussed in the course, in relation to viral pathogenesis (Huang et al., 1999; Shen et al.,1999; Jain et al., 2014). In both case studies, student authors successfully met the skills learning objectives of the neurovirology module and case study assignment by applying their knowledge of neurovirology and analyzing and evaluating primary literature.

The case study assignment used an iterative writing process and low-stakes assessment, where the first draft of the case study was worth 10% of the students' final grade on the assignment, and the final draft was worth 90%.

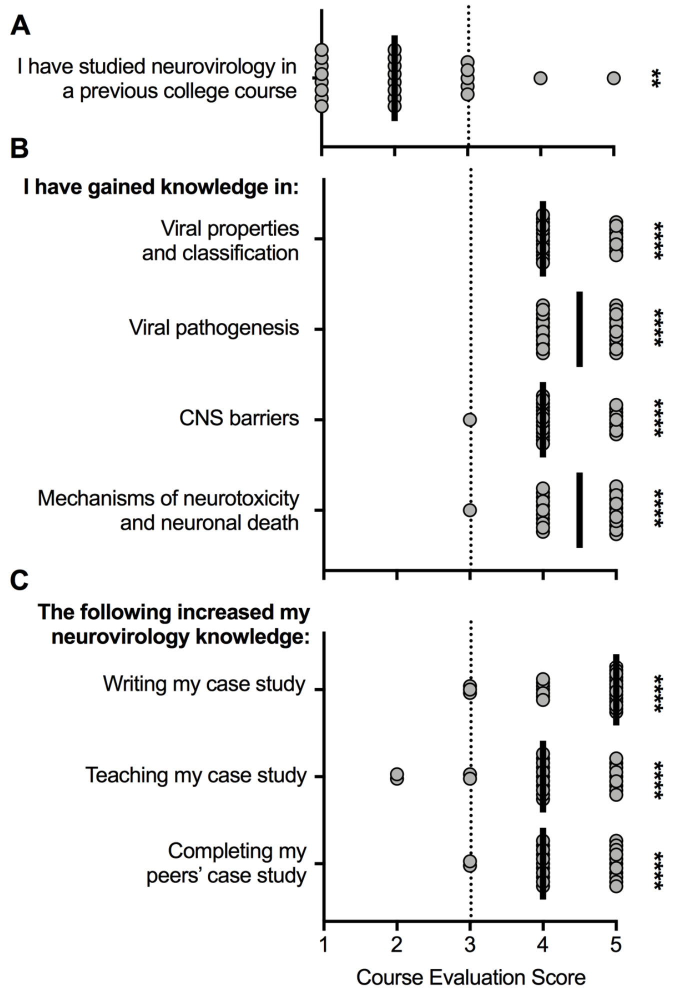

Figure 2. Students self-reported familiarity with neurovirology (*A*), increased knowledge in content learning objectives (*B*), and activities contributing to knowledge (*C*). Evaluations used a Likert scale: 5-Strongly Agree; 4- Agree; 3- Neutral; 2- Disagree; 1- Strongly Disagree. Scatter plots show individual student responses (grey circles) and the median response (black bar) for each question (n = 23-24 students; one-sample Wilcoxon signed rank test to a hypothesized median of 3- Neutral (dotted line); $^{**}p<0.01$, $^{****}p<0.0001$).

Iterative writing practices and low-stakes assessment have been shown to improve student performance and confidence within a course (Freestone, 2009; Brownell et al., 2013; Cyr, 2017). Therefore, we compared student grades on the first draft and final draft of the case study, and consistent with previous literature, our results show that every student group increased their grade from the first draft to the final draft (Figure 1). These results further support that iterative writing practices and low-stakes assessment can improve student performance.

Student Evaluations

For quantitative evaluations, students used a Likert scale to self-report their knowledge of content learning objectives and confidence in skills learning objectives after completion of the neurovirology module and case study assignment. Our results show that the majority of students had not studied neurovirology in a previous college course, and that they reported increased knowledge of content learning objectives after completing the neurovirology module and case study assignment (Figure 2A, 2B). Moreover, students reported that writing, teaching, and completing a neurovirology case study all increased their neurovirology knowledge, with writing (median = 5- Strongly Agree) ranking higher than teaching or completing (median = 4- Agree; Figure 2C). Additionally, students reported increased confidence in skills learning objectives (Figure 3), and agreed that if they took the course again, they would want the neurovirology module included, and to write more case studies (Figure 4). Taken together, these data suggest that the neurovirology module and case study assignment were largely successful in meeting content and skills learning objectives and student satisfaction.

For qualitative evaluations, students answered open-ended questions on takeaways, strengths, and areas for improvement after completion of the neurovirology module and case study assignment. When asked what they will take away from the neurovirology module, student responses spanned the module's learning objectives but reported more content than skills takeaways (Figure 5A; 55.3% of responses for content learning objectives; 44.7% of response for skills learning objectives). Additionally, students emphasized the importance of the module as a foundation for further exploration, as exemplified by the following responses:

"I will take away how much I loved learning about neurovirology. I was always interested in infectious diseases and loved neuroscience so tying them together has been fantastic… I am definitely more confident in reading primary literature on the topic due to this section and that will hopefully carry me through any future education."

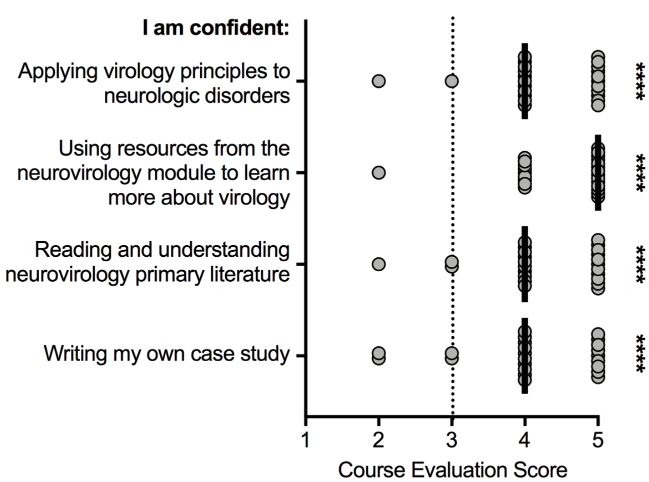

Figure 3. Students self-reported increased confidence in skills learning objectives. Evaluations used a Likert scale: 5-Strongly Agree; 4- Agree; 3- Neutral; 2- Disagree; 1- Strongly Disagree. Scatter plots show individual student responses (grey circles) and the median response (black bar) for each question (n = 23-24 students; one-sample Wilcoxon signed rank test to a hypothesized median of 3- Neutral (dotted line); ****p<0.0001).

"I thought the material was interesting and relevant and I appreciated that I could take the information and neurovirology definitions we were learning about and begin to apply them to literature being published now about COVID-19…."

When asked about the most valuable aspects of the neurovirology module, students identified before class readings and videos, and in-class active learning strategies in Weeks 1-2 of the module (Appendix A), and writing and teaching their case studies in Weeks 3-4 of the case study assignment (Appendix B; Figure 5B; 56.4% of responses for the neurovirology module, 43.6% of responses for the case study assignment). Writing the case study was the most commonly identified valuable aspect of the class (33% of responses; Figure 5B), as exemplified by the following responses:

"I found the case study we created to be most helpful. It pushed me to go through the neurovirology material learned in the lectures, readings, and videos and truly understand the topic I had to eventually write and teach about. I felt that it allowed for more active learning in which I had to think about the topic from multiple angles- researching a virus, creating the prompt, writing questions and answers..."

"I really enjoyed having the challenge of writing our case study. It made me think more like a scientist and a physician regarding viruses and how they can affect the nervous system. It is very interesting to apply the theory to what we could see in real life on a patient undergoing a viral infection."

"I think the aspect that was most valuable was the creation of the case study. I thought it was beyond inspiring to have crafted our very own case study that seemed so professional and to teach it to our peers was very meaningful."

When asked for suggestions for improving the neurovirology module, student feedback spanned the module and the case study assignment (Figure 5C; 55% of responses for the neurovirology module, 45% of responses for the case study assignment). The most common areas for improvement were adding more content, especially clinical symptoms and diagnosis (30% of responses) and completing more case studies (30% of responses). Interestingly, adding more content was also the most common area for improvement for students that reported neutral or disagree with knowledge of content learning objectives (Figure 2B) or confidence in skills learning objectives (Figure 3; 57% of responses from these students). As two students wrote:

"Discussing more symptoms and how you would classify a disease based on the symptoms presented [is an area of improvement]…learning how to diagnose/differentiate these types of diseases would be helpful."

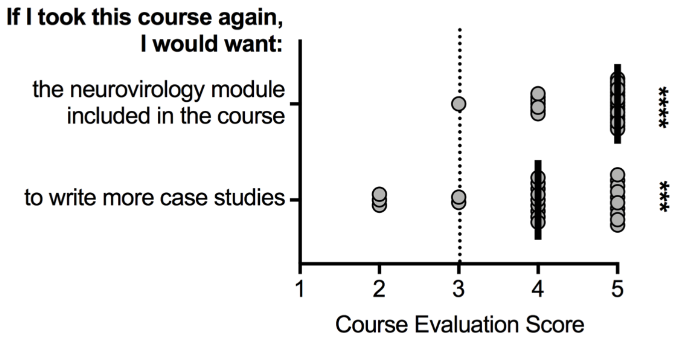

Figure 4. Students self-reported satisfaction with the neurovirology module and case study assignment. Evaluations used a Likert scale: 5-Strongly Agree; 4- Agree; 3- Neutral; 2- Disagree; 1- Strongly Disagree. Scatter plots show individual student responses (grey circles) and the median response (black bar) for each question (n = 24 students; one-sample Wilcoxon signed rank test to a hypothesized median of 3- Neutral (dotted line); ***p<0.001, ****p<0.0001).

"…I think it would be interesting if we all got to do or at least listen in on everyone's case study. This would allow us to learn about different neuroviruses."

Interestingly, some students also identified providing more instruction on teaching the case study as an area for improvement (Figure 5C; 15% of responses). As one student wrote:

"While I did think that creating our own case study was very valuable, I did think that some of the expectations on how it was going to be presented were unclear. I wish there was a little more format to that portion of the project. Other than that I really did enjoy this module and I hope that you can find a way to integrate it into the class material in the future."

Taken together, qualitative student evaluations suggest that student takeaways aligned with content and skills learning objectives, and that students valued the structure of the neurovirology module and case study assignment, although important improvements to content and instruction are needed.

DISCUSSION

In this article, we describe using student-created case studies as assessment for a neurovirology module. Our results suggest that the neurovirology module and the case study assignment met their intended content and skills learning objectives by improving student performance and increasing students' self-reported knowledge and confidence. We believe our approach is a valuable extension of case study pedagogy with broad applicability to a variety of undergraduate courses.

As described in this article, students followed iterative writing practices to create their case studies, which have been shown to improve student performance and confidence within a course (Freestone, 2009; Brownell et al., 2013; Cyr, 2017). Our data was consistent with the previous literature, showing improved student grades from the first draft to the final draft of the case study assignment (Figure 1). Previous studies also suggest that iterative writing practice coupled with calibrated peer review may be particularly effective in improving performance for the lowest-performing students (Birol et al., 2013). Future version of the case study assignment could repeat the iterative writing practices described here and included calibrated peer review for the first draft, then measure improvement from the first draft to the final draft for high- and low-performing students. Moreover, additional studies suggest that iterative writing practices may not improve student writing performance across all domains or in subsequent courses (Rayner et al., 2014; Holstein et al., 2015). Further analysis would be necessary to determine if students show longitudinal improvements in writing performance across multiple writing assignments and courses after completion of the case study assignment described here.

Quantitative and qualitative student self-report evaluations support that the neurovirology module and case study assignment promoted content and skills learning objectives in understanding, applying, analyzing, evaluating, and creating (Anderson and Krathwohl, 2001), and that students valued the structure of the neurovirology module and case study assignment (Figures 2 - 5). Importantly, student self-report evaluations of active learning may underestimate the amount of actual student learning (Deslauriers et al., 2019), so the high student evaluations of learning objectives are notable. However, students also offered important areas for improvement, including adding more content on clinical symptoms and diagnosis on neurovirulent disorders (Figure 5C). To address this, future iterations of the neurovirology module should include clinical textbook readings and primary literature (Bookstaver et al., 2017; Nath and Berger, 2020) coupled with public health resources on symptoms and diagnosis (Centers for Disease Control and Prevention, 2020; National Institute of Allergy and Infectious Disease, 2020; National Institute of Neurological Disorders and Stroke, 2020). Encouraging students to read scientific articles written for the general public prior to or concurrent with reading primary literature on the same topic improves student understand of complex or unfamiliar literature (Gottesman and Hoskins, 2013; Bodnar et al., 2016; Kararo and McCartney, 2019). Additionally, students suggested providing more instruction on teaching case studies and completing more case studies (Figure 5C). This area for improvement is consistent with quantitative evaluations, where students reported that writing, teaching, and completing a neurovirology case study all increased their neurovirology knowledge, but writing ranked higher than teaching or completing (Figure 2C). To address this, future iterations of the case study assignment will include teaching guidelines in the assignment requirements (Appendix B) based on nine facilitator strategies for student-led discussion (Rees, 1998; Soranno, 2010). Students will be asked to reflect on these strategies and write a short paragraph at the end of their first draft on how they will work as a team to teach their case study using these strategies.

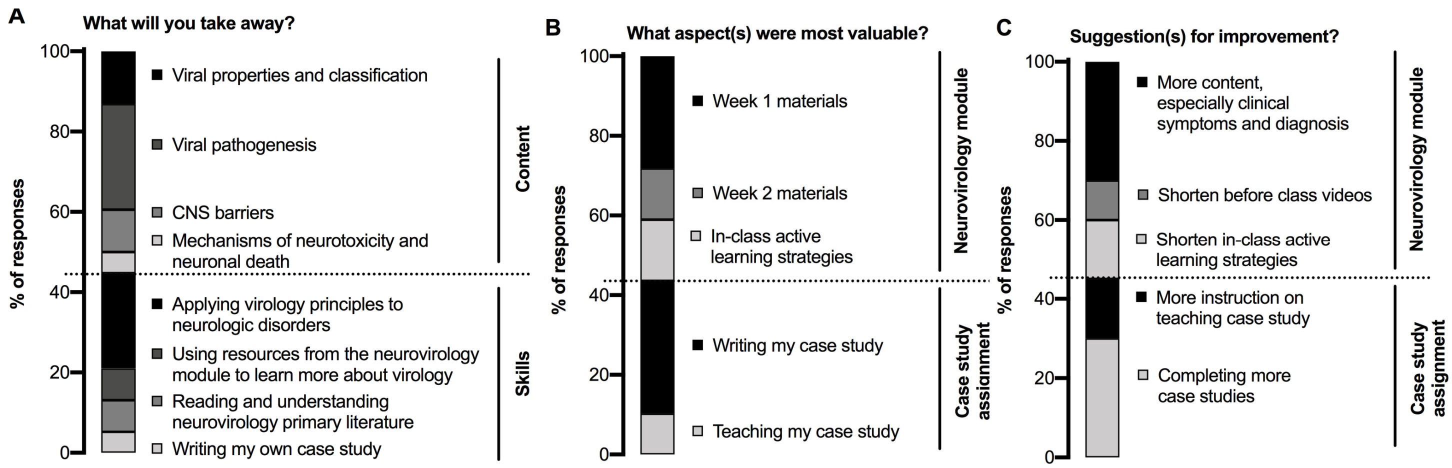

Figure 5. Students self-reported content and skills learning objective takeaways, and provided strengths and areas for improvement for the neurovirology module and case study assignment. Qualitative evaluations used open-ended questions to assess takeaways (*A*), strengths (*B*), and areas for improvement (*C*). (*A*) Students responses on takeaways were aligned with content learning objectives (above dotted line) or skills learning objectives (below dotted line), and the percentage of total responses for each learning objective is shown (n = 38 responses). (*B, C*) Student responses on strengths (*B*) and areas for improvement (*C*) were aligned with neurovirology module materials (above dotted line) or the case study assignment (below dotted line), and the percentage of total responses for each category is shown (*B*: n = 39 responses; *C*: n = 20 responses)

Additionally, students will share their case study final draft with at least two other student groups to increase the number of case studies each student completes. Quantitative and qualitative evaluations should be repeated to determine if these interventions address students' areas for improvement.

Students had considerable familiarity with interrupted, literature-based case studies before writing their own cases. Indeed, almost all students who wrote case studies (25 out of 26 students) had previously completed 13 interrupted, literature-based case studies over two semesters in the corresponding author's courses (Cook-Snyder, 2017). This is consistent with active learning pedagogy, which emphasizes students practicing the skills necessary to succeed in assessment before they are assessed (Armbruster et al., 2009; Haak et al., 2011; Freeman et al., 2014). However, previous research suggests that more limited practice with case studies prior to writing a case study may still be effective. For example, research on collaborative learning courses describe instructor modeling of good discussion practices "several" times before students prepared and led classroom discussions (Casteel and Bridges, 2007; Kurczek and Johnson, 2014). Therefore, we suggest that students complete several (two to four) instructor-provided and -taught case studies following the structure and classroom management of the case study assignment before writing and leading their own case.

Active learning is a critical component of inclusive pedagogy that is effective for all students, and decreases the achievement gap for PEERs (Haak et al., 2011; Ballen et al., 2017; Penner, 2018; Theobald et al., 2020; Asai, 2020). Studies suggest that active learning may be particularly effective for PEERs because active learning helps students identify as scientists, and science identity is critical for persistence in STEM (Graham et al., 2013; Trujillo and Tanner, 2014; Theobald et al., 2020). Case studies are important components of active learning (Handelsman et al., 2004; Herreid et al., 2012; Wiertelak et al., 2016), and some qualitative student evaluations suggest that the case study assignment promoted scientific identity, where students described thinking "more like a scientist and a physician," and that writing a case study "seemed so professional." However, direct questions on students' science identities are needed for future iterations of the case study assignment to determine if the assignment promoted science identity (Trujillo and Tanner, 2014). Likewise, further studies are needed to determine if the case study assignment promoted persistence in STEM. In this article, the case study assignment was used in a spring semester course for junior and senior neuroscience majors at Carthage College, where nearly 100% of junior and senior neuroscience majors graduate from Carthage with a neuroscience degree (data not shown). This is consistent with previous research, which estimates that STEM attrition rates peak in students' first and second academic year, and plateau in third and fourth year (Aulck et al., 2017; Chen et al., 2018). However, if the case study assignment was used in first or second year neuroscience courses, when STEM attrition rates are higher, measuring subsequent retention of students in a STEM major could be particularly valuable metric.

We believe that using student-created case studies as assessment has wide applicability to undergraduate education because case studies themselves have wide applicability. Case studies have been used effectively in introductory and advanced neuroscience courses with small and large student enrollments to address a variety of content and skills learning objectives (Herreid et al., 2012; Brielmaier, 2016; Ogilvie and Ribbens, 2016; Roesch and Frenzel, 2016; Wiertelak et al., 2016; Lemons, 2017; Nagel and Nicholas, 2017; Sawyer and Frenzel, 2018; Mitrano, 2019; Ogilvie, 2019; Watson, 2019; Rollins, 2020). Case studies are also effective active learning methods for synchronous and asynchronous online and hybrid teaching (Brooke, 2006; Schiano and Anderson, 2014). Accordingly, we believe that the case study assignment described here could be adapted to follow any of these existing methods of case study writing and teaching. Additionally, we encourage instructors to adapt our neurovirology module to their students' needs and interests, taking advantage of the free virology resources available online (https://www.virology.ws/course/; https://www.virology.ws/virology-101/). Moreover, we believe the module format and case study assignment described here could be duplicated for other important neuroscience topics that are highly relevant to students but not always discussed in the neuroscience curriculum, like social neuroscience or neuroethics (Flint and Dorr, 2010; Abu-Odeh et al., 2015; Wiertelak et al., 2018). Overall, we believe that using student-created case studies as assessment is a valuable, student-led extension of effective case study pedagogy, and has wide applicability to a variety of undergraduate courses.

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Address correspondence to: Dr. Denise Cook-Snyder, Carthage College, Neuroscience Department, 2001 Alford Park Dr., Kenosha, WI, 53140. Email: dcooksnyder@carthage.edu

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APPENDIX 1:
NEUROVIROLOGY MODULE MATERIALS

WEEK 1

Before Class Readings and Videos:

Instructions for students: Please read and watch the following *in order.* Note that most of these are short readings and videos, but Infection Basics is an hour-long lecture.

- Introduction to viruses:
    - What is a virus?: https://www.virology.ws/2004/07/28/what-is-a-virus/
    - How viruses are classified: https://www.virology.ws/2009/08/07/how-viruses-are-classified/
    - Simplifying virus classification: The Baltimore system: https://www.virology.ws/2009/08/12/simplifying-virus-classification-the-baltimore-system/
- Viral pathogenesis and immunity
    - Infection Basics:
        - Recorded lecture: https://www.youtube.com/watch?v=fBJ0vcOIS7I&feature=youtu.be
        - Slides: https://virology2020.s3.amazonaws.com/012_4310_20.pdf
        - Please watch the entire lecture
    - Immunology:
        - Vander's Human Physiology Ch.18: The Immune System
            - pg. 652 - 656
            - pg. 662- adaptive immune responses overview
            - These pages define immune cell types and cytokines, and give overviews of the innate immune response and adaptive immune response
            - The rest of the chapter is for your reference
        - Innate immune defenses: https://www.virology.ws/2009/06/03/innate-immune-defenses/
        - The inflammatory response: https://www.virology.ws/2009/07/01/the-inflammatory-response/
        - Adaptive immune defenses: https://www.virology.ws/2009/07/03/adaptive-immune-defenses/
        - Adaptive immune defenses: Antibodies: https://www.virology.ws/2009/07/22/adaptive-immune-defenses-antibodies/
        - Immunopathology: Too much of a good thing: https://www.virology.ws/2009/01/23/immunopathology-too-much-of-a-good-thing/
    - Acute infections:
        - Recorded lecture: https://www.youtube.com/watch?v=TQkg0mID-w8&feature=youtu.be
        - Slides: https://virology2020.s3.amazonaws.com/016_4310_20.pdf
        - Please watch until 8:00 (slide 7) of this lecture. The rest of the lecture is posted for your reference.
    - Persistent infections:
        - Recorded lecture: https://www.youtube.com/watch?v=oWRynTL8NI4&feature=youtu.be
        - Slides: https://virology2020.s3.amazonaws.com/017_4310_20.pdf
        - Please watch until 5:30 (slide 6) of this video. The rest of the lecture is posted for your reference

Before Class Assignments:

Instructions for students:

- Quiz (*Instructor note: Figure A1 provides sample quiz questions*).
- Neurovirology dictionary (*Instructor note: Figure A2 provides example neurovirology dictionary entries*). Neurovirology has so many terms that we're going to create our own neurovirology dictionary. You are responsible for adding two new definitions to the dictionary this week. Your two definitions should be unique- they should not have already been defined by your classmates. I've included a few definitions to get us started. Your neurovirology dictionary definitions are worth 5 points, and you will receive full credit for being thoughtful, thorough, and on time.

In Class: Zoom lecture

Instructions for students:

- Study questions will be distributed at the beginning of class. You'll have the first part of class to work on the study questions in groups, and we'll discuss the answers to the study questions during the second part of class.
- At the end the end of class, please submit your study questions to the assignment posted below (*Instructor note: this course uses Schoology as learning management software*). Your study questions are worth 5 points, and you will receive full credit for being thoughtful, thorough, and on time.

<u>WEEK 2</u>

Before Class Readings and Videos:

Instructions for students: Please read and watch the following *in order.*

- Kandel, Appendix D, The Blood-Brain Barrier, Choroid Plexus, and Cerebrospinal Fluid: pgs. 1565-1575.
- Mechanism of neurotoxicity and neuronal death (*Instructor note: this is a brief, recorded lecture focusing on key definitions, including apoptosis, autophagy, necrosis, inflammation, excitotoxicity, trophic factor withdrawal, oxidative stress, mitochondrial dysfunction, protein misfolding and aggregation, and axonal transport dysfunction*).
- Swanson and McGavern, 2015- Viral Diseases of the Central Nervous System (*Instructor note: key concepts from this review include viral spread, CNS entry, viral cytopathology, and immunopathology*).

Before Class Assignments:

Instructions for students:

- Quiz (*Instructor note: Figure A3 provides sample quiz questions*).
- Neurovirology dictionary (*Instructor note: Figure A2 provides example neurovirology dictionary entries*). Neurovirology has so many terms that we're going to create our own neurovirology dictionary. You are responsible for adding two new definitions to the dictionary this week. Your two definitions should be unique- they should not have already been defined by your classmates. I've included a few definitions to get us started. Your neurovirology dictionary definitions are worth 5 points, and you will receive full credit for being thoughtful, thorough, and on time.

In Class: Zoom lecture

Instructions for students:

- Study questions will be distributed at the beginning of class. You'll have the first part of class to work on the study questions in groups, and we'll discuss the answers to the study questions during the second part of class.
- At the end of class, please submit your study questions to the assignment posted below (*Instructor note: this course uses Schoology as learning management software*). Your study questions are worth 5 points, and you will receive full credit for being thoughtful, thorough, and on time.

Match the following definitions with the correct terms (1 point each):

Viruses that can cause disease of nervous tissue — 1 point

- ○ Neuroinvasive
- ○ Neurotropic
- ○ Neurovirulent

Viruses that can infect neural cells; infection may occur by neural or hematogenous spread from a peripheral site — 1 point

- ○ Neuroinvasive
- ○ Neurotropic
- ○ Neurovirulent

Viruses that can enter the CNS after infection of a peripheral site — 1 point

- ○ Neuroinvasive
- ○ Neurotropic
- ○ Neurovirulent

Figure A1. Sample quiz questions for Week 1 neurovirology module.

Term	Definition	Source	Added by:
Acute infection	infection with a rapid onset of viral reproduction, disease period, and resolution	Virology Lectures 2020 #16: Acute Infections	(Student)
Adaptive Immune response	A secondary response to foreign viruses should they continue to multiply after an innate response. This response is unique to the specific virus, and is maintained in our immune memory. Consists of the humoral response and cell-mediated response.	Adaptive Immune Defenses: https://www.virology.ws/2009/07/03/adaptive-immune-defenses/	(Student)
Alphavirus (Infection)	A type of ssRNA(+) viruses that can induce apoptosis within neurons; may indirectly cause neuronal death through the release of pro-inflammatory cytokines and excitatory amino acids (excitotoxicity)	Swanson and McGavern, 2015- Viral Diseases of the Central Nervous System, https://viralzone.expasy.org/625?outline=all_by_species	(Student)
Antigen	any molecule, regardless of its location or function, that can induce a specific immune response against itself	Vanders Ch. 18	(Student)

Figure A2. Example student-created neurovirology dictionary entries for Week 1 and Week 2 neurovirology module. Student names have been redacted.

Match the following definitions with the correct terms (1 point each):

Description (optional)

Inflammation in the meninges or ventricular lining (ependymal cells)

- Encephalitis
- Meningitis
- Myelitis

Inflammation in the spinal cord

- Encephalitis
- Meningitis
- Myelitis

Inflammation in the brain parenchyma

- Encephalitis
- Meningitis
- Myelitis

Figure A3. Sample quiz questions for Week 2 neurovirology module.

APPENDIX 2:
CASE STUDY ASSIGNMENT REQUIREMENTS AND RUBRIC

Instructions for students:

<u>What is a neurovirology case study?</u> We've used case studies to practice applying our knowledge from lecture to solve biomedically-relevant problems. By now, you all are experts in answering case studies questions- now it's your turn to work in groups to write your own case study, similar to the case studies we've completed in class, and teach it to your peers.

<u>What should you include in your neurovirology case study?</u> You should work with your lab group to write a neurovirology case study on any neurovirulent virus of your choosing. Your virus can also be neurotropic and/or neuroinvasive, but this is not required. (*Instructor note: neurovirulent viruses cause disease of nervous tissue. Neurotropic viruses infect neural cells; infection may occur by neural or hematogenous spread from a peripheral site. Neuroinvasive viruses enter the CNS after infection of a peripheral site*).

Your neurovirology case study should have two parts:

1. **Part #1:**
    a. Part #1 of your case study should investigate your neurovirulent virus using a patient narrative and/or primary literature data. You are encouraged to refer back to our previous case studies as examples.
    b. Based on your patient narrative and/or primary literature data, you should write a minimum of two questions, with answers, which address the epidemiology and/or symptoms and diagnosis of your virus.
2. **Part #2:**
    a. Part #2 of your case study should continue to investigate your neurovirulent virus using primary literature data. You are encouraged to refer back to our previous case studies as examples- nearly all of our case studies include questions based on primary literature data.
    b. Based on your primary literature data, you should write a minimum of three questions, with answers, which address the pathogenesis and/or treatment of your virus.
3. **For both Part #1 and Part #2:**
    a. Answers to your questions should be clearly supported by previous readings, videos, and lectures from class, and by the case study itself. You are encouraged to use any material from class as needed- you are not limited to just our neurovirology readings, videos and lectures.
    b. Remember, your peers are going to read your case study and answer your questions. So, your peers should be able to answer your questions based on material from class, plus any additional information you provide for them in the case study. Your peers should have to do minimal additional research to answer your questions correctly.

Your neurovirology case study should also have two versions:

1. **Answer Key:**
    a. This is the version you will submit to Schoology for grading (*Instructor note: this course uses Schoology as learning management software*). Your Answer Key should include Part #1 and Part #2, as described above, plus
        i. The answers to your questions
        ii. In-text citations for all parts of your case study, especially your patient narrative/primary literature data and the answers to your questions.
        iii. A list of references on the last page.
    b. You will write a 1st draft and a final draft of your Answer Key- see the Submission requirements and Grading and Feedback sections below for details
2. **Without Answers**
    a. This is the version you will share with your peers, so they can read your case study and answer your questions. This version should be identical to your Answer Key final draft, but not include the answers to your questions, in-text citations, or your list of references at the end.

<u>How will you teach your neurovirology case study to your peers?</u> During Week 4, you will be leading your peers in a discussion of your case study, similar to our class discussions of case studies (*Instructor note: see Cook-Snyder, 2017 for a detailed classroom management strategy for case studies*).

- You will share your Neurovirology Case Study- Without Answer with your peers
- Your peers will read your case study, answer the questions, and submit their answers to Schoology before class.
- Then, in class, you will lead your peers in a discussion of your case study, and your peers will submit their original answers plus annotations to Schoology after class
- You will have one hour to discuss your case studies- 30 minutes for your case, then 30 minutes for your peer's case- following this format:

Timeslot	**Case Study Authors**	**Peers**
8:00-8:30am	Group A	Group B
8:30-9:00am	Group B	Group A
9:00-9:30am	Group C	Group D
9:30-10:00am	Group D	Group C
10:00-10:30am	Group E	Group F
10:30-11:00am	Group F	Group E

<u>Submission requirements:</u>

- Your **Neurovirology Case Study- Answer Key** should be submitted to Schoology:
    - **Your 1st draft is due Tuesday, May 5th, before your lab section starts** *(Instructor note: this is Week 3).*
    - **Your final draft is due Monday, May 11th, 10:30am** *(Instructor note: this is Week 4).*
    - Even though you're writing one case study per lab group, all group members should submit the case study to Schoology. This will ensure that all group members receive their case study grades.
- Your **Neurovirology Case Study- Without Answers should be emailed to your peers by Monday, May 11th, 10:30am** *(Instructor note: this is Week 4).*

<u>Grading and Feedback:</u>

You will be graded according to the Neurovirology Case Study Grading Rubric posted below. Note that 10% of your case study grade will be earned on your 1st draft, and 90% will be earned on your final draft.

I will provide feedback electronically on all drafts (1st and final). My feedback will summarize the strengths, areas for improvement, and specific actions you can take to improve. **IMPORTANT: I will provide a maximum of two comments per rubric section. This doesn't mean that there aren't any additional areas for improvement, or that if you only address these comments that you will get a 100%.** But, I believe targeting your attention and effort to these top areas will make the most improvement.

Neurovirology Case Study Grading Rubric

***On your final draft, please write your new or edited text in red, so I can more easily identify the changes you've made**

1st draft: ##/5 **Final draft: ##/45** **Grade: ##/50**				
Criteria	**Grading Scale**			
Writing and Mechanics Concise scientific writing ● Objective and precise language ● Correct spelling, punctuation, and grammar Versions and reference requirements met	Excellent writing and mechanics **1st draft: 1 point** **Final draft: 9 points** **Total: 10 points**	Good writing and mechanics **0.8 points** **7.2 points** **8 points**	Adequate writing and mechanics **0.6 points** **5.4 points** **6 points**	Poor writing and mechanics **0.4 points** **3.6 points** **4 points**
Comment	**Example**		**Strengths or areas of improvement for example**	
Part #1 ● Investigates a neurovirulent virus using a patient narrative and/or primary literature data. ● Minimum two questions on epidemiology and/or symptoms and diagnosis. ● Answers are clearly supported by course materials and the case study itself.	Excellent content and structure **1st draft: 2 points** **Final draft: 18 points** **Total: 20 points**	Good content and structure **1.5 points** **13.5 points** **15 points**	Adequate content and structure **1 point** **9 points** **10 points**	Poor content and structure **0.5 points** **4.5 points** **5 points**
Comment	**Example**		**Strengths or areas of improvement for example**	
Part #2 ● Continues to investigate a neurovirulent virus using primary literature data. ● Minimum three questions on pathogenesis and/or treatment. ● Answers are clearly supported by course materials and the case study itself.	Excellent content and structure **1st draft: 2 points** **Final draft: 18 points** **Total: 20 points**	Good content and structure **1.5 points** **13.5 points** **15 points**	Adequate content and structure **1 point** **9 points** **10 points**	Poor content and structure **0.5 points** **4.5 points** **5 points**
Comment	**Example**		**Strengths or areas of improvement for example**	

APPENDIX 3:
STUDENT-CREATED CASE STUDY- RABIES VIRUS

Instructor note: This case was written by Alyssa Laci and Nicole A. Losurdo, undergraduate students in Neuroscience 4100, Spring 2020 semester, Carthage College. In-text citations and references are in blue font. The answer key version of this case is available via request to cases.at.june@gmail.com. The corresponding author (DRCS) has edited the case for formatting and clarity and has indicated whether each answer is supported by the case study in the neurovirology module, previous course content, and/or the primary literature in blue font.

Part I:

Brian was engaging in yard work when he heard his wife yell to him.

"Brian! There is a stray dog in the yard that is acting rather strange. He is staggering and having a hard time standing upright. I think I also saw a foamy discharge coming from his eyes and mouth. I noticed him while I was in the garden because he was making this weird high-pitched noise" (Taylor and Nel, 2015).

Brian walked over to his wife.

She looked concerned and asked him, "What do you think we should do about him?"

Brian replied with a similar concerned tone, "Well we better make sure he is okay and consider calling animal control. In the meantime, I'll go take a closer look at him."

Brian slowly moved closer to the dog, trying not to disturb or frighten him. He reached toward the dog, trying to comfort his fear. Instead, the dog lunged at his hand and bit him.

Brian pulled his hand away in pain. He glanced down at his fingers and found blood oozing from them. He stepped away from the dog and went inside to wash his hands off from the bite.

As he was washing his hands, the area around the bite tingled and itched (CDC, 2019). He continued to scrub until the blood was gone, applied a bandaid and grabbed the phone to call animal control.

A week passed, and the area of Brian's bite began to itch more excessively and he just couldn't drum up the motivation to leave his bed because he felt so sleepy (CDC, 2019). His wife entered into his bedroom, "Honey, please quit itching. You're just going to make it worse." She reached for his forehead, it felt warm.

Extremely irritated by her suggestion, Brian tried to keep his response low, but raised his voice at her (CDC, 2019). "Don't tell me what to do! I am a grown man! And stop coming in here to turn my light on. It's so bright and hurts my eyes!" Shocked, his wife turned down the light and left the room, giving him time to rest.

Several more days passed. As he laid in bed, Brian began to lose feeling in his hand. He glanced down at it, noticing that it was twitching (CDC, 2019). He looked up at the bedroom doorway. "Where am I?" He thought. "My mouth is so full of spit and I can hardly swallow because my throat feels so tight. Almost like its spasming." He got out of bed and walked toward the hallway to splash his face with water. While he walked through the hallway, he noticed a creepy figure standing above him. Thinking that he may be hallucinating, Brian called to his wife. "Sweetie, please call 911."

Part I Questions:

1. What are Brian's signs and symptoms? (Answer based on case study)
2. Brian was brought to the hospital after his wife called him an ambulance. Based on his symptoms, what do you think he will be diagnosed with? What diagnostic tests do you think physicians will use to achieve this diagnosis? (Answer based on case study and requires primary literature search)

Part II:

After being taken to the hospital, Brian was diagnosed with rabies virus. Rabies virus enters peripheral nerves directly, and then can migrate to the central nervous system and up to the brain (Rupprecht, 1996). One mechanism of entry into the peripheral nerves is through the neuromuscular junction (Rupprecht, 1996). Once symptoms begin to appear, both general symptoms of fever or fatigue and neurological symptoms like hydrophobia, the disease cannot be reversed or cured (Rupprecht, 1996). If the rabies vaccine is administered before the onset of symptoms, it can generally prevent or destroy the disease and the inevitable death that follows (Long et al., 2020). Since Brian has already developed neurological symptoms, it is unlikely that the current rabies vaccine will be able to cure him (Long et al., 2020).

The efficacy of the vaccine is reliant upon a permeable blood brain barrier (BBB) to allow immune cells to reach the virus in the brain and destroy it (Kandel et al., 2013; Long et al., 2020). A study looked at the role of the phosphoprotein gene of the rabies virus on the permeability of the BBB (Long et al., 2020). The study inoculated mice with either a wild-type (GD-SH-01), an attenuated rabies virus (HEP-Flury), or a chimeric virus that had the phosphoprotein gene of the wild-type inserted into the genome of the attenuated version (rHEP-SH-P). The rHEP-SH-P phosphoprotein gene is silenced by the placement in the attenuated genome. GD-SH-01 generally produced mild inflammation with eventual complete breakdown of the BBB, while the HEP-Flury produces high inflammation, but a more transiently permeable BBB. Figure 1 shows the data on BBB permeability (modified from Figure 1 in Long et al., 2020).

Part II Questions

1. Is the rabies spread by hematogenous spread or neural spread? (Answer based on neurovirology module)

2. Does the phosphoprotein cause a relative increase or decrease in BBB permeability? Use Figure 1 to explain your answer. (Answer based on case study)

3. Would the incorporation of a phosphoprotein antagonist improve vaccine efficacy in the attenuated virus? Use Figure 1 to explain your answer. (Answer based on case study and neurovirology module)

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APPENDIX 4:
STUDENT-CREATED CASE STUDY- ENTEROVIRUS 71

Instructor note: This case was written by Dianna M. Bindelli and Shannon A.M. Kafura, undergraduate students in Neuroscience 4100, Spring 2020 semester, Carthage College. In-text citation and references are in blue font. The answer key version of this case is available via request to cases.at.june@gmail.com. The corresponding author (DRCS) has edited the case for formatting and clarity and has indicated if each answer is supported by the case study the neurovirology module, previous course content, and/or the primary literature in blue font.

Part I:

It was the summer of 1998 in China when Finley Chang, a 10-year-old boy, went to the orthodontist to get his braces. It was mid-July, so Finley was extremely warm on his way to the orthodontist, also he was nervous. His mom, Mrs. Chang waited for him in the waiting room and was delighted to see her little boy growing up with his new braces.

The orthodontist, Dr. Wung had noticed that Finley was visibly sweating. He asked Finley if he was feeling fine. Finley said, "just nervous". Dr. Wung had informed Mrs. Chang that the braces were all in place and his mouth had looked good! He warned that he may have pain in his mouth for a few days while adjusting to the braces.

One morning he woke up and he complained of a stomachache. He decided that he must just be hungry and proceeded to go downstairs for breakfast. On his way down the stairs, he began to feel woozy. He felt like the room was spinning, so he hurried down the stairs to sit down.

His mom had made pancakes and had orange juice for him.

"Good morning! What's the rush? How did you sleep?" asked his mom.

"Fine." responded Finley.

Mrs. Chang knew something was wrong when Finley did not dive into his sugary pancakes and was sitting there with his eyes closed.

Finley really did not feel like eating. He did not want to tell his mom about his stomachache. So, he decided to stick with the juice for now. After a couple sips of juice, he got a sour face.

"What happened?" asked his mom.

Finley began to feel the inside of his mouth and responded, "I have weird cuts in my mouth". His mom looked and saw cuts on his gums and mouth and thought it may be from the braces (Huang et al., 1999). However, it has been over a month since he had them, so she decided to call the orthodontist and have the alignment checked out.

While Finley was getting ready to leave for the orthodontist, he began vomiting. Mrs. Chang thought he had the flu bug and canceled the appointment, for now.

The next morning Mrs. Chang thought Finley would be better. However, Finley woke up with sweating and vomiting, and with even more sores in his mouth (Huang et al., 1999). He sat up in bed and felt even more dizzy than yesterday and had to lie down. Mrs. Chang felt his head and thought his fever was even higher (Huang et al., 1999). At this point she decided to take Finley to the pediatrician.

Dr. Hu looked at Finley's mouth sores and brought him some water. She decided to run a few tests. She set up Finley with some anti-nausea medication and ordered an IV. In the meantime, she was analyzing the tests she ran.

Part I Questions:

1. What are Finley's signs and symptoms? (Answer based on case study)

2. What tests would you run based on Finley's signs and symptoms? Hypothesize the expected results. (Answer based on neurovirology module and previous course content)

Part II:

Three days after coming back from the doctor, Finley's mother went into his room to see if he wanted dinner. "Finley, time to eat." He was waking up from a nap. "Finley, are you okay?" she asked, concerned. "I don't feel so good, mom," mumbled Finley, slurring his words. She helped him sit up and felt his forehead to see if fever had returned.

"Well, you don't seem to have a fever again. Let's try and eat some food, maybe that will help." She then helped him get out of bed and into the kitchen.

When Finley was eating, he kept dropping food because his hands were shaking, and he had extreme difficulty bringing his chopsticks to his mouth. He kept accidently hitting his nose or chin. "Finley, do you want me to help you?" asked his mom. When he answered, she noticed that he also couldn't focus straight on her and instead his eyes would bounce away (Huang et al.,1999; Bae et al., 2013; Kandel et al., 2013; Jain et al., 2014; Cook-Snyder, 2020c). Finley's mother knew something was wrong and brought him to the emergency room.

The ER doctor walked into the room, "Hello, my name is Dr. Chen, and you must be Finley. Can you tell me what is going on?" Finley told her, "My arms don't seem to be working right and I don't feel very good," again slurring his words (Kandel et al., 2013; Cook-Snyder, 2020c).

"Okay, and according to your chart, you've been sick recently?" asked Dr. Chen. "Yes, he was just at the doctor three days ago and the pediatrician diagnosed him with Hand, Foot, and Mouth Disease," replied Finley's mother (Rhoades et al., 2011; Chen, et al., 2020).

"I see. His blood work also shows that Finley had viremia, specifically Enterovirus 71 (EV71). Enterovirus 71 is known to cause Hand, Foot and Mouth Disease, so this is making more sense. Finley also has increased amounts of lymphocytes and monocytes in his blood. Well, before I can make a diagnosis, I would like to take an MRI." Dr. Chen said (Rhoades et al., 2011; Chen et al., 2020; Racaniello, 2020a). Finley's expected MRI results are shown in Figure 1 (modified from Figure 2A in Shen et al., 1999; and Figure 1B in Huang et al., 1999).

"Based on the expected MRI results and the viremia, it looks like Finley has rhombencephalitis. This is a pretty serious diagnosis. He's lucky that you brought him in," said Dr. Chen. "I'd like to admit him to the hospital for care." She discussed the treatment plan with Finley's mom and left the room (Huang et al., 1999; Chen et al., 2007; Jubelt et al., 2011; Jain et al., 2014; Chen et al., 2019).

Dr. Chen recommended a treatment called Ribavirin, an antiviral treatment. She presented the data in Figure 2 (modified from Figure 1B in Li et al., 2008) and Figure 3 (modified from Figure 3B in Zhang et al., 2012).

Part II Questions:

1. What are Finley's new signs and symptoms? (Answer based on case study and previous course content).

2. Looking at Figure 1, what brain regions are marked by the arrows? Use full neuroanatomical descriptions to explain your answer. (Answer based on previous course content).

3. Could damage to these brain areas cause the signs and symptoms seen in Finley? (Answer based on previous course content).

4. Hypothesize how Finley may have developed rhombencephalitis. In other words, propose a possible mechanism of pathogenesis for how the virus infected the CNS. (Answer based on neurovirology module).

5. Using Figure 2 and 3, would Ribavirin be an effective treatment? Depending on your answer, either explain a possible mechanism of action for Ribavirin or possible solutions to make the drug effective. (Answer based on case study).

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