OPEN ACCESS Freely available online

CourseSource

Lesson

Understanding Gastric Acid Secretion: An Active Learning Approach

Jordyn W. Dickey, Kristen H. Kimball, and John M. Redden*

Department of Physiology and Neurobiology, University of Connecticut

Abstract

The human digestive system is a diverse network of cells, tissues, and organs that is regulated by systemic (e.g., nervous and endocrine systems) and local factors (e.g., secretions, pH, and the microbiome). Given the volume of content and the dense physiology involved, this system is difficult for instructors to teach and equally challenging for students to understand. This is especially true in our two-semester Human Anatomy and Physiology course for pre-health students at the University of Connecticut. In the Spring 2017 semester, we developed and implemented an active-learning based approach when teaching the histology and regulation of gastric secretions—a physiology-intensive topic within the digestive system unit. Our lesson included a team-based case study on gastric ulcer formation and *Helicobacter pylori*, a guided drawing depicting the molecular mechanisms of HCl secretion, a concept map linking the cells with their secretions, a think-pair-share on pharmacological regulators, and a reflective assignment placing the content within a broader societal context. Consistent with the themes of active learning, the lesson is suitable for any physiology instructor seeking to create a more engaging classroom, and provide students with opportunities to problem solve, think critically, and build relationships between course content and real life.

Citation: Dickey JW, Kimball KH, Redden JM. 2020. Understanding gastric acid secretion: An active learning approach. *CourseSource*. https://doi.org/10.24918/cs.2020.38

Editor: Neena Grover, Colorado College

Received: 7/7/2018; **Accepted:** 8/28/2020; **Published:** 10/8/2020

Conflict of Interest and Funding Statement: None of the authors has a financial, personal, or professional conflict of interest related to this work.

Supporting Materials: Supporting Files S1. Gastric Acid Secretion – Regulation of gastric secretion video; S2. Gastric Acid Secretion – Blank parietal cell template; S3. Gastric Acid Secretion – Completed parietal cell template; S4. Gastric Acid Secretion – GI concept map instructions; S5. Gastric Acid Secretion – GI case study presentation; S6. Gastric Acid Secretion – Common questions; S7. Gastric Acid Secretion – GI pre-class reading article link; S8. Gastric Acid Secretion – GI case study worksheet; S9. Gastric Acid Secretion – Pre-activity checklist; and S10. Gastric Acid Secretion – Post-class reflection activity.

***Correspondence to:** 75 North Eagleville Road U-3156, Storrs CT 06269. Email: john.redden@uconn.edu.

Learning Goal(s)

- Understand the anatomical organization of the gastric mucosa.
- Appreciate the relationship between the digestive system and the nervous/endocrine systems.
- Understand the cells, channels, and transporters responsible for acid secretion in the stomach, and how their functions are regulated by hormones, autonomic neurons, and pharmaceuticals.
- Understand the role of *H. pylori* in ulcer formation.

Learning Objective(s)

- List the channels, transporters, and receptors found on each membrane face of parietal cells.
- Explain the mechanism through which the proton pump is regulated by gastrin, histamine, somatostatin, and acetylcholine.
- Predict the effects of pharmaceuticals that are active in the stomach and their impact on GI function.
- Justify *H. pylori* as the cause of gastric ulcers.

INTRODUCTION

At the University of Connecticut, Human Anatomy and Physiology is a two-semester integrated course for pre-health students comprised of both a lecture and a laboratory component. The lecture portion of the course, which meets three times a week for 50 minutes, is supplemented by an hour-long online prelab module and a two-hour face-to-face laboratory. We introduce the digestive system about midway through the second semester, after completing units on the cardiovascular, respiratory, and immune systems. General features of the autonomic and endocrine systems are taught in stand-alone units in the first half of the course during the Fall semester, and then applied in more detail to specific organ systems in the second half of the course.

As with other systems, the digestive system unit is taught hierarchically, with an overview of gross anatomy, histology, and general physiology preceding a more complex discussion of the secretory, digestive, motility, and regulatory hallmarks of each phase of the integrated meal response. The rationale for this approach is to have students develop a "big picture" framework that can be used to organize complex regional specializations found in specific tissues and cell types and place the details within the context of the entire system. For example, there is an overarching organizational pattern within the digestive tract highlighted by four common tissue layers (serosa, muscularis externa, submucosa, mucosa). Starting from this assumption frees up more time to talk about the individual specializations in each layer within each region. In particular, there is a high degree of variability in the epithelia that form the lumen, as these are the primary secretory and absorptive cells of the gut.

In our course, we use the epithelia of the gastric pit to demonstrate regional diversity. This single region contains

parietal cells, which secrete hydrochloric acid and intrinsic factor; chief cells, which secrete the peptidase pepsinogen; enterchromaffin-like cells, which secrete histamine; G cells, which release the hormone gastrin; D-cells, which secrete somatostatin; and mucous-producing cells. However, as is the case with other complex physiological topics, understanding each component of the digestive system by itself does not necessarily result in a complete understanding of the system, or reveal the interdependency of the components. For example, pepsinogen is a zymogen, or inactive enzyme, that requires hydrochloric acid for conversion into its active form, pepsin. Hydrochloric acid from parietal cells is "turned on" by gastrin and histamine, and inhibited by somatostatin (Supporting File S1. Gastric Acid Secretion – Regulation of gastric secretion video).

Moreover, all of the events that take place within this tissue operate within the broader context of protein digestion, which depends on internal control systems like the parasympathetic nervous system, or external factors like the presence of food. This is not something that is easily impressed upon students, many of whom struggle to transition from lower-order to higher-order learning or cannot move beyond simple relationships between individual cells and their functions. These misunderstandings about molecular and systems physiology may be rooted in a student's inability to relate the material to everyday life, as identified by the National Research Council (US) Committee on Education in their report *Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences* (1). Therefore, affective learning is an important consideration in courses like anatomy and physiology and should be specifically targeted.

In order to try to support these real-world connections, we elected to incorporate an interactive case study into our lesson, which we adapted from the National Center for Case Study Teaching in Science (NCCSTS) (9). This case investigates the competing theories of *H. pylori* infection and excess acid secretion as the causative agent of most gastric ulcers, which are a relatively common health problem. As the original emphasis of this case was on the scientific method, not on gastric physiology, it was most likely intended for a grade school audience. Therefore, we changed or supplemented many of the visual elements of the original case study to make it more suitable for a college physiology course (e.g., we included histology). We also rewrote the embedded questions to focus student learning onto the molecular physiology of the gastric pit. Despite having to make modifications, we were drawn to this high-quality case from NCCSTS because it requires students to design simple experiments of their own and to predict/interpret results from Nobel-prize winning studies conducted by Barry Marshall, Robin Warren, and others (Supporting File S5. Gastric Acid Secretion – GI case study presentation).

Compounding this problem, our experience is that traditional lecturing on this topic does not sufficiently engage students (2). This not only results in learning gaps for students, but also contributes to wasted classroom time; the information often needs to be reviewed and repeated in subsequent classes. In accordance with the goals of the 2009 AAAS Vision and Change in Undergraduate Biology Education summit, which stressed the importance of "outcome-oriented, active biology learning focused on deep conceptual understanding" we are making ongoing attempts to address these problems by adding relevance to the course content through real-life applications, and replacing lecturing with hands-on teaching methods whenever possible (3). In building an interactive classroom, we hope to make these challenging concepts more accessible.

A specific disconnect between knowing a fact and understanding a concept occurs when learning about acid secretion in the gastric pit – a complex process involving interplay between hormones, the nervous system, and secretory epithelia. Understanding systems-level physiology is often an expressed goal of many courses (including ours), and this complexity in the digestive system offers an excellent opportunity to make progress towards achieving it. Currently, there are very few active learning lessons that address the complex interactions in the digestive system. Examples currently available are focused largely on understanding the gross anatomy of the digestive system (https://www.teachengineering.org/lessons/view/cub_human_lesson04), lack the scope necessary for a college or university level course (https://www.biologycorner.com/anatomy/chap15.html), or do not target pre-clinical students (https://serc.carleton.edu/sp/library/visualizations/examples/48581.html). This lesson is an attempt to remedy the disconnect between facts and concepts in the digestive system by building in real-world connections, such as familiar pharmaceuticals, and bolster student interest in the course material. Further, the entire lesson hinges on peer discussion and hands-on activities to "bring the material to life" for college students to the greatest extent possible.

Intended Audience

This lesson is intended for undergraduate students majoring in biological sciences, allied health sciences, pharmacy, nutrition, biomedical engineering, pathobiology, physical therapy, or occupational therapy. The scope would be appropriate for sophomores and juniors studying the health sciences who have had an introductory course in general cell biology.

Required Learning Time

This lesson was given in place of a traditional 50-minute class period, and covered roughly the same amount of material that would be covered if lecturing. In total, the pre-class components should take approximately 20 minutes to complete. The post-class reflection assignment (Supporting File S10. Gastric Acid Secretion – Post class reflection activity) should take approximately 10 minutes. Thus, the complete lesson should take just over one hour for most students to complete.

Prerequisite Student Knowledge

Students should have a basic understanding of cell biology, including membrane polarity, channel mediated transport, and G-protein coupled receptors. In order to label the parietal cell diagram, students will have to locate receptors and ion channels on either the apical or basolateral membrane. Furthermore, they will need to have enough background knowledge to predict the effect of receptor/channel activation. Knowledge of the gross anatomy and histology of GI tract, including the four tissues layers (serosa, muscularis externa, submucosa, mucosa) is also helpful. It is also assumed that students are familiar with the principles of endocrine function (e.g., transport via the blood) and nervous system (e.g., synaptic transmission). For context and deeper understanding, it is recommended that students are familiar with the organization of the autonomic nervous system (in this case, the parasympathetic division and vagus nerve). There is also an assumed knowledge of basic GI terminology

such as secretion and reabsorption (Supporting File S1. Gastric Acid Secretion – Regulation of gastric secretion video).

Prerequisite Teacher Knowledge

Instructors should be comfortable explaining the gross anatomy and histology of the GI system, including how organs, tissues, and cells are interconnected. Instructors should also be able to discuss secretions of the gastric mucosa, match them to specific mucosal epithelia, and to their molecular mechanism of action. For example, instructors should know that parietal cells secrete hydrogen and chloride ions (H^+ and Cl^-, respectively) to form hydrochloric acid in the lumen of the gastric pit, and that histamine receptors on parietal cells are Gs coupled G-protein coupled receptors that increase cAMP and lead to proton pump phosphorylation.

Instructors not familiar with the hierarchy of the GI system, the gastric mucosal cells and their secretions, or how hydrochloric acid is formed should review the pre-class video (Supporting File S1. Gastric Acid Secretion – Regulation of gastric secretion video). Facilitators or assistants should have thoroughly reviewed the case study presentation and associated notes (Supporting File S5. Gastric Acid Secretion – GI case study presentation and S6. Gastric Acid Secretion – Common questions).

SCIENTIFIC TEACHING THEMES

Active Learning

Our lesson emphasizes the importance of student-student and student-instructor interactions within the classroom. While instructors are available for clarification, the responsibility for learning the material is placed on the learner/student. The activities students work through (provided as supplements) are generally accepted in the practice of scientific teaching, including think-pair-share questions, concept maps, and case studies (10).

Assessment

Assessment can be conducted using a student-reported assessment of learning gains (SALG) (8) and students' scores on exams. Formatively, instructors or facilitators can also gauge student understanding based upon their responses to the questions posed during the case, and by the appropriate placement and supporting explanation of drug mechanisms on the parietal cell diagram. In our case, concepts covered during the activity were included on the next exam which consisted of multiple-choice questions. For example, students were asked to match secretory cells with their secretions, to place receptors and ion channels on the appropriate membrane, and to match receptors with their molecular mechanism of action. Student feedback and SALG were conducted using surveys deployed through the course learning management system (LMS). Students gave positive feedback on the activity, with most students perceiving increases in learning and enthusiasm about the overall approach in comparison to lecture.

Inclusive Teaching

This lesson is interactive, tasking students to work together to link, locate, and define structures within the GI system. The cooperative nature inherent in the small group format may increase student engagement, leading to an increase in learning gains (4). Further, because the activities rely on a visual-spatial element (drawing), students may see an increase in information recall compared to more conventional methods (5). Throughout the lesson, students are tasked with drawing (a concrete experience) as well as interpreting and assessing scientific data. In our course, as in most A&P courses at this level, some of the content introduced by the activity (e.g., the pharmacology) is novel to students. This should place students on equal footing at the beginning of the activity, and prevent prior knowledge from life or academic experience from giving certain students an advantage over their peers. Moreover, the reflective questions included in the case study have students look at ethnic variations in ulcer susceptibility, as well as the intersection of health and socioeconomic status (e.g., an ulcer patient without health insurance might rely more on less efficacious over-the-counter treatments like antacids, whereas someone with health insurance would presumably have access to proton pump inhibitors, calcium channel blockers, and antibiotics).

LESSON PLAN

Pre-Class Assignments

Before this activity, students attended a lecture presentation on the anatomy of the digestive system, and were given an overview of the major GI processes (secretion, absorption, motility, and digestion). The lecture immediately preceding this class had covered material through the cephalic phase of the integrated meal response. For this lesson, lower order prerequisite information (anatomy, cell types, secretion, etc.) was introduced in a pre-class video (Supporting File S1. Gastric Acid Secretion – Regulation of gastric secretion video). Students were given a diagram of a parietal cell and asked to fill it in as a homework assignment after watching the video (Supporting File S2. Gastric Acid Secretion – Blank parietal cell template), but before coming to class. To provide context for the lesson, students were also asked to read a news article about the discovery of chemical digestion in the stomach by William Beaumont/Alexis St. Martin (Supporting File S7. Gastric Acid Secretion – GI pre-class reading).

Setup for In-Class Lesson

The lesson set up involves preparing the poster paper, parietal cell templates, and case study presentations. Instructors or learning assistants should distribute these materials to students before or upon their arrival to the classroom. We found it helpful to place all materials into a large envelope ahead of class in order to ensure that provisions had been made for every group, and to prevent students from beginning the activity before they had been given instructions. If students are to work in groups (recommended), their work areas should be labeled with a group number or letter (e.g., Group 5) to prevent confusion and save time at the beginning of class.

In-Class Lesson/Activity

The in-class lesson is comprised of three main parts: a concept map, a guided drawing of the parietal cell, and an interactive case study exploring the history and pathology of gastric ulcers.

When students arrive, they will meet at a table or wall area clearly labeled with the group letter or number that they were assigned before class. Instructors or learning assistants should introduce themselves, and give each student a copy of the concept map activity sheet (Supporting File S4. Gastric Acid Secretion – GI concept map instructions), after which the

members of each group will begin to link together all of the related terms. Students were advised to write out the components on sticky notes before placing them on the poster paper and drawing arrows or lines to connect the terms. For example, a group might connect parietal cells with HCl, knowing that HCl is the secretion associated with this cell type. HCl might then be connected to pepsinogen, a proenzyme secreted by the chief cells, because the acid catalyzes the conversion of this precursor into its active form, pepsin. The concept map was created on the walls of the classroom using hanging poster paper, sticky notes, and markers. Our students had some familiarity with concept maps already, but the materials provided with the lesson assume no prior knowledge.

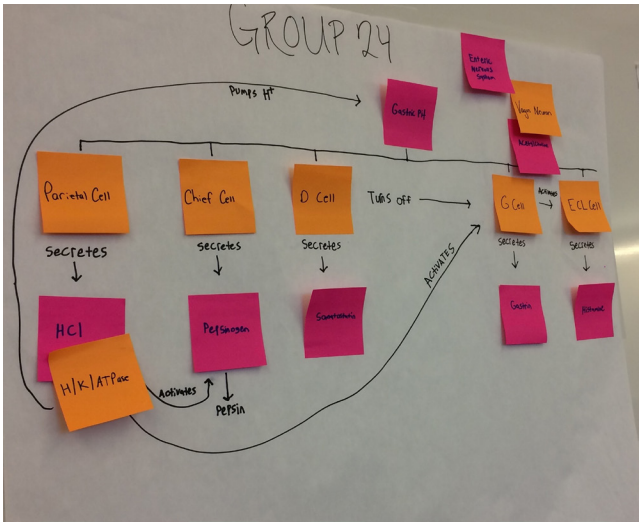

Figure 1. Image of concept map.

While the instructor or facilitator should answer student questions, he or she should not take a central role in determining how to organize the concept map – inherent in the success of the concept map is that it allows students to work independently and develop novel frameworks with which to organize material. It is essentially an externalization of their thought process and will often be different than the instructor's view.

When students have completed their concept map, the facilitator should inspect it and probe the group's understanding. For example, a facilitator might ask why the group connected parietal cells to hydrochloric acid, after which students should indicate that these cells secrete HCl. If the students are incorrect or unsure, facilitators should offer the correct answer and then explain why. Secondarily, if a secretion affects another component within the concept map, it is important to indicate that as well. After the concept map has been reviewed, group members should see how seemingly disparate cells work together to accomplish their function. Time permitting, students can also walk around the room to view other groups concept maps to reinforce the idea that there are multiple correct answers.

During the next part of the activity, students were instructed to place ion channels, transporters, and pharmaceuticals on a template of a parietal cell that was pre-drawn on white poster paper. This aligned with their pre-class assignment (Supporting File S2. Gastric Acid Secretion – Blank parietal cell template). Facilitators will have a completed parietal cell available to reference if the group needs clarification (Supporting File S3. Gastric Acid Secretion – Completed parietal cell template). As before, the facilitator's primary job is to assess the group's understanding. He or she may ask what the consequences of inhibiting the H/K/ATPase (proton pump) would be, or how increased cAMP concentrations would affect signaling pathways. Examples of facilitator questions can be found in Supporting File S6. Gastric Acid Secretion – Common questions.

For our course, we impressed upon the students that the names of these drugs were ancillary concerns and that the value in the lesson was on the mechanism. The purpose of introducing pharmaceuticals here is to relate course material to real life and identify the consequences of inhibiting or stimulating different ion channels or transporters. On an exam in our course, the name of the drug would be coupled with a description of how it works, and students would be asked to evaluate the effects of inhibition, stimulation, or any potential side effects. Interestingly, given the common incidence of gastric ulcers, many students were already familiar with some of the medications, which provided additional avenues for discussion within the groups.

After recreating the pre-class diagram on the white poster paper as a group, each individual student was asked to research one of the pharmaceuticals found in the case (Supporting File S5. Gastric Acid Secretion – GI case study presentation, slide 7) using a cell phone, tablet, or laptop. Five minutes were allotted for this part of the activity. (The drugs chosen are highly studied and commonly prescribed, so it is fairly easy to research the mechanism in a short period of time.) Facilitators can assist as necessary. Using the same template as before, students will apply their understanding of ion channels and transporters that they identified in the previous part of the activity by drawing or placing an index card with the drug on the template. Afterward, each student should provide an explanation for how their drug impacts the system. For example, how will pantoprazole affect the pH of the gastric lumen? Is it inhibitory or stimulatory? Facilitators can expand the discussion by asking how these drugs might be used in a clinical setting in order to link the course material to its real-world applications.

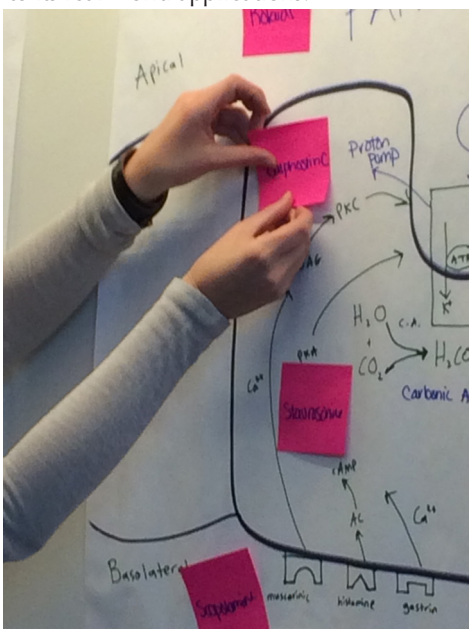

Figure 2. Image of pharmacology.

Lastly, to provide some context for this information, we discussed the pathology of gastric ulcers using the case we adapted from the National Center for Case Study Teaching in Science. This case effectively demonstrates how the scientific consensus evolved over time to better reflect the evidence, a key hallmark of the scientific method. The scientific method is often overlooked in courses like ours due to time constraints and a bias toward research findings over research methods. Given that the causative agent (*H. pylori*) is revealed at the case's conclusion, facilitators should not correct students if they answer the embedded questions incorrectly; rather, they should ask why the group believes an answer is correct, and explain the correct choices at the end. Since the questions are layered, many times student mistakes can be self-correcting. This problem-based learning (PBL) not only helps to hone analytical skills – it helps broaden an understanding of scientific practices (7).

Post-Class

At the conclusion of the in-class portion of the activity, students were given a list of prompts for further consideration through the course LMS (S10. Gastric Acid Secretion – Post-class reflection activity). The questions were designed to: reinforce concepts learned during the activity (e.g., how might aspirin play a role in ulcer formation?); prime students' thought processes for the subsequent class meeting (e.g., why doesn't everyone with *H. pylori* infection develop ulcers?); and provide an opportunity to reflect on the real-world implications of this material (e.g., how would a patient's prognosis change if their socioeconomic status only allowed them to treat their ulcers with over-the-counter medications?).

TEACHING DISCUSSION

Pre-Class Preparation

In designing this activity, we tried to use common, inexpensive materials so that the lesson was accessible to all; most of the pre-class preparation consists of gathering and organizing materials already available to instructors. Instructors should have pens, markers, and poster paper for each student group. These can be purchased at an office supply store or through online retailers like Amazon. The total cost for running the activity for 400 students was under $20. While not required, sticky notes were helpful in our concept map activity – students could write out each component on a sticky note, place it on the poster paper, and draw arrows connecting them to others. If mistakes were made, the sticky notes could be easily rearranged.

Instructors should have the case study presentation (Supporting File S5. Gastric Acid Secretion – GI case study presentation) loaded onto computers for each group, and a facilitator or designated student to present the PowerPoint presentation. If class computers are unavailable, students can be asked to bring personal laptops to the activity. Alternatively, instructors can present this case study in a traditional lecture setting, and ask for volunteers to answer the embedded questions. Instructors will need a template of the parietal cell (Supporting File S2. Gastric Acid Secretion – Blank parietal cell template) or an analogous template. Students should be familiar with the concepts discussed in the pre-activity video (Supporting File S1. Gastric Acid Secretion – Regulation of gastric secretion video) and have completed the pre-class template (Supporting File S2. Gastric Acid Secretion – Blank parietal cell template).

Logistics & Variations

While we include specific supporting materials, our lesson is broad; alterations can be made to tailor the plan to a more or less advanced audience as necessary. In more advanced courses, greater emphasis could be placed on pharmacological mechanisms, side effects, and pathology. In a lower-level course, more emphasis could be placed on gross anatomy or histology. Our activities were completed by groups of five or six students, which we believe is an optimal number to promote collaboration and active learning among all participants. We find that larger groups may sometimes become paralyzed by indecision when given open-ended activities, especially concept maps. In smaller groups, we find it is more likely for one individual to dominate the group's decisions. Given that our course is large, we randomly assigned students to a group prior to class using the "Groups" feature in our LMS. Groups could also be formed spontaneously in the class between nearby students or, in a smaller course, could be hand-picked to promote interactions between higher and lower performing students. As a variation, activities could be replicated with larger groups with space constraints by using a think-pair-share format. In fact, even online courses could likely replicate most elements given access to a virtual chat or discussion board.

If instructors cannot break the class into smaller groups, or find assistants or facilitators to lead groups, it is possible to work through some of these activities in a traditional lecture format. In this instance, the concept map could be drawn on a whiteboard or projector by the instructor, who would ask students to raise their hands and offer suggestions on how to connect the terms. Similarly, the gastric pit template could be instructor-drawn but student-created; the instructor could place an ion channel on the template and then ask students to describe its function. The case study presentation would be most easily transposed into a traditional lecture format: the embedded questions could be answered by individual students raising their hands, or by students working with their "neighbors." In this large lecture setting, however, there is likely to be less student engagement, a crucial factor in the success of our activity. Similarly, since the concept map would be created by many different students, its organization would not be unique to each student or group. This may limit students' ability to directly compare their thought processes to that of their peers. The cooperative nature of the activity – a key component cited by our students for its success – would be hindered in this large class setting.

Timing

Although most information was covered thoroughly in the lesson and was reiterated in group discussions, we view the pre-class activity as an essential component of the lesson (Supporting File S1. Gastric Acid Secretion – Regulation of gastric secretion video). Filling in the template of the parietal cell ahead of class (Supporting File S2. Gastric Acid Secretion – Blank parietal cell template) is not essential to the success of the activity, but does reduce the time required to complete the activity in class. Since the lesson, by design, is broken into a series of separate but interconnected activities, it could be extended into a second class period if more time is desired

or needed. In this case, we would suggest that the first class period ends with the discussion of the pharmaceuticals. Since this activity involves molecular processes, it is usually very discussion-rich and, therefore, the most flexible in terms of time—discussions can be either extended or curtailed as necessary. Reviewing these mechanisms or revisiting this discussion would also be a good strategy for starting the following class, since it summarizes much of the content in this lesson that students find challenging.

Lesson Effectiveness

Students and facilitators alike remarked that the activity was engaging and intellectually stimulating. Of note, several respondents indicated that the activities were helpful in moving beyond simple memorization of course material. One student wrote: "I found the small group activities to be incredibly helpful. Having a few students to discuss any confusion with, along with the very informative facilitators provided a great learning environment. It can be easy to zone out in lecture and miss important information, but in this small setting it was far more engaging and made comprehending the information, not just memorizing it, much easier."

An unintended but welcome consequence of the activity was that students felt more comfortable asking questions – and having them answered – in the group setting. Large lecture classes are intimidating, and while we stress early on in the course that students should interrupt and ask if they need clarification, it is not a common occurrence. This is reflected in a student comment: "The group activities allow the class to be a bit smaller. Sometimes I don't want to ask questions in class because I fear it will cause the class to get behind on lecture (also I feel the questions I ask might be stupid, or pointless). That said, the group activities allow my questions to get answered, and to be sure the concepts are drilled in my head."

In more formal assessments of perceptions, acquired through a "wrapper" survey at the end of our course, students responded positively about the activities. While some students (<5%) expressed disappointment with the activities, the overwhelming majority indicated they not only enjoyed them, but benefitted from them. Students who described themselves as "visual learners" were particularly drawn to the activity. As one respondent noted, "It helped create a visual memory of the information that was a lot easier to recall then just looking at my lecture notes." Similarly, another student said: "I am more of a visual learner, so being able to see the diagrams drawn out, helped me to connect different topics and how they related to each other. I think this should continue [in the future]."

Some students, though, did find faults with the activities. One student found that "Researching the drugs did not help me understand the material better", while another felt that the activities were not specific enough and "[did not provide] information to study." In other words, the fluid discussions and problem solving did not offer enough tangible study materials to refer back to after the activity.

Summary

We present this lesson plan as a simple and effective alternative to lecturing on the principles of regulation and secretion within the digestive system. The lesson entailed a pre-class lecture and assignment for students, an in-class collaborative activity, and a reflective homework assignment. The structure of the lesson allows students to develop a unique framework to organize the often-challenging concept of gastric secretion – one that involves visualization, critical thinking, and peer discussion. To our surprise, we lost very little "content" by teaching the class this way. This, paired with the general student enthusiasm, has created momentum to develop similar activities for other units.

SUPPORTING MATERIALS

- S1. Gastric Acid Secretion – Regulation of gastric secretion video
- S2. Gastric Acid Secretion – Blank parietal cell template
- S3. Gastric Acid Secretion – Completed parietal cell template
- S4. Gastric Acid Secretion – GI concept map instructions
- S5. Gastric Acid Secretion – GI case study presentation
- S6. Gastric Acid Secretion – Common questions
- S7. Gastric Acid Secretion – GI pre-class reading (Web Article link: https://mynorth.com/2017/05/the-gruesome-medical-breakthrough-of-dr-william-beaumont-on-mackinac-island/)
- S8. Gastric Acid Secretion – GI case study worksheet
- S9. Gastric Acid Secretion – Pre-activity checklist
- S10. Gastric Acid Secretion – Post-class reflection activity.

ACKNOWLEDGMENTS

The authors wish to acknowledge funding from the Large Course Redesign Grant initiative from the University of Connecticut's Center for Excellence in Teaching and Learning (to JMR) and the Undergraduate Honors Program (to JWD). We also wish to thank Dr. Radmila Filipovic, Mr. Fred Murphy, and Mr. Shanu George for their assistance and feedback during the development of the activity.

REFERENCES

1. Council NR. 2011. Challenges and Opportunities for Education About Dual Use Issues in the Life Sciences. The National Academies Press, Washington, DC.
2. Palis AG, Quiros PA. 2014. Adult learning principles and presentation pearls. Middle East Afr J Ophthalmol.
3. Woodin T, Carter VC, Fletcher L. 2010. From the National Science Foundation Vision and Change in Biology Undergraduate Education, A Call for Action -- Initial Responses. Education.
4. Kooloos JGM, Klaassen T, Vereijken M, Van Kuppeveld S, Bolhuis S, Vorstenbosch M. 2011. Collaborative group work: Effects of group size and assignment structure on learning gain, student satisfaction and perceived participation. Med Teach.
5. Wammes JD, Meade ME, Fernandes MA. 2016. The drawing effect: Evidence for reliable and robust memory benefits in free recall. Q J Exp Psychol.
6. Kolb AY, Kolb DA. 2005. Learning styles and learning spaces: Enhancing experiential learning in higher education. Acad Manag Learn Educ.
7. Allchin D. 2013. Problem- and case-based learning in science: An introduction to distinctions, values, and outcomes. CBE Life Sci Educ.
8. Williams AE, Aguilar-Roca NM, Tsai M, Wong M, Beaupr? MM, O'Dowd DK. 2011. Assessment of Learning Gains Associated with Independent Exam Analysis in Introductory Biology. CBE Life Sci Educ. 10:346-356.
9. Hannam K, Hagley R. 2008. An End To Ulcers?
10. Handelsman J, Miller S, Pfund C, Teaching WP for S. 2007. Scientific Teaching. W. H. Freeman.

Table 1. Timeline of Activity Components

Activity	Description	Estimated Time	Notes
Preparation for Class (Instructors)			
Upload pre-class materials to Blackboard; Assign students to groups; Prepare drawing materials	1. Upload the pre-class video, parietal cell template, and link to the ulcer article. 2. Assign students to groups. 3. Prepare poster paper, markers, sticky notes, and instructions for the activities. (Day of Activity) 4. Distribute two sheets of large poster paper, markers, and sticky notes to group areas prior to arrival. 5. Load case study presentation onto classroom computers (if using).	About 40 minutes	• Pre-class materials are S1. Gastric Acid Secretion – Regulation of gastric secretion video, S2. Gastric Acid Secretion – Blank parietal cell template, and S7. Gastric Acid Secretion – GI pre-class reading. • Instructors may pre-draw the parietal cell on the poster paper to save time • If course computers are available, load them with the case study Powerpoint (S5. Gastric Acid Secretion – GI case study presentation). If unable, have facilitators bring personal laptops for group use
Preparation for Class (Students)			
Prior to class, students will complete the online module	6. View pre-class video on the regulation of acid secretion. 7. Complete a blank template of parietal cell based on the video. 8. Read the short article about the pathology of gastric ulcers.	About 30 minutes	• The pre-class video is located in S1. Gastric Acid Secretion – Regulation of gastric secretion video. • The blank template is provided in S2. Gastric Acid Secretion – Blank parietal cell template. • The link to the ulcer article is located in S7. Gastric Acid Secretion – GI pre-class reading. • To incentivize preparation for the in-class exercises, instructors may create a quiz that students complete after the module.
In-Class Activities			
Students meet with their group and complete a concept map, apply pharmaceuticals to the parietal cell, and work through a guided case study on gastric ulcer pathology	9. With guidance from the facilitator, the group creates a concept map. 10. Groups work together to place structures on a parietal cell. 11. Group begins the case study and accompanying worksheet. 12. Students research and predict effects of different gastric drugs. 13. Case Study concludes.	About 50 minutes	• Concept map instructions are provided in S4. Gastric Acid Secretion – GI concept map instructions • Facilitators or instructors may refer to the question prompts to drive discussion provided in S6. Gastric Acid Secretion – Common questions • Case study worksheet is S8. Gastric Acid Secretion – GI case study worksheet • List of drugs is embedded in the case study Powerpoint in S5. Gastric Acid Secretion – GI case study presentation
Post-Class Activities			
Questions and survey	14. Students reflect on the role of socioeconomics in the treatment of gastric ulcers. 15. Students provide feedback on the activity through a survey (optional).	About 20 minutes	• Post-class reflection is S10. Gastric Acid Secretion – Post-class reflection activity • This could be used for formative assessment to assess student learning gains from activity or preparation.