

Using Student Perceptions and Cooperative Learning to Unpack Primary Literature on Global Change

Jasmine M. Crumsey Forde^{1*} and Amanda Rugenski¹

¹Odum School of Ecology, University of Georgia

Abstract

This case describes a three-part assignment in which students discuss key processes that regulate the stability and resilience of the Earth system and our increased risk of generating large-scale abrupt or irreversible environmental changes. Here, we use the planetary boundaries concept as a case study. Students are first asked to complete a pre-reading assignment in which they illustrate their perceptions of the degree to which human activity has changed nine earth system processes (e.g., nitrogen cycling, biodiversity loss, ocean acidification). Students then read primary literature on the planetary boundaries concept and complete a reading assurance assignment in which they summarize the reading and reflect on questions generated by the reading. In class, students work together in assigned groups to create a diagram of their collective perceptions and identify processes for which there was the largest misalignment with those presented in the paper. Students then discuss and summarize the evidence used by the authors to justify where these processes stand with respect to the safe operating space for humanity. The lesson concludes with a facilitated discussion and lecture on sustainability governance. This lesson provides students with a “capstone” activity to integrate ecological concepts discussed over the course of a semester and frames a larger discussion on socio-ecological aspects of global environmental change.

Citation: Crumsey Forde JM, Rugenski A. 2020. Using student perceptions and cooperative learning to unpack primary literature on global change. *CourseSource*. <https://doi.org/10.24918/cs.2020.35>

Editor: Tammy Long, Michigan State University

Received: 5/18/2020; **Accepted:** 7/14/2020; **Published:** 10/8/2020

Copyright: © 2020 Crumsey Forde and Rugenski. This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License, which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original author and source are credited. The authors affirm that they have received written permission to use and adapt the main figure of Rockström et al. 2009 from both the authors and publisher.

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. Perceptions and Cooperative Learning – Lecture Presentation Slides; S2. Perceptions and Cooperative Learning – Reading Assurance Assignment and In-Class Polling Questions; S3. Perceptions and Cooperative Learning – Assignment 1 Worksheet; S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet; S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions; S6. Perceptions and Cooperative Learning – Individual Student Work Examples; and S7. Perceptions and Cooperative Learning – Group Work Examples

*Correspondence to: 140 E Green St, Athens, GA 30602. Email: jcrumsey@uga.edu.

Learning Goal(s)

- Visually communicate individual perceptions of the degree to which humans have altered earth system processes.
- Interpret primary literature and determine whether the data support or refute placement of the safe operating space and status of earth system processes with respect to thresholds.
- Summarize scientific arguments based on evidence from primary scientific literature.
- Appreciate how different earth system processes affect each other in an ecological context.

Learning Objective(s)

- Students will be able to identify key points and define key terms (e.g., planetary boundary, threshold, Anthropocene) established in the primary literature.
- Students will be able to predict consequences of human activities on key earth system processes relevant to global environmental change.
- Students will be able to identify processes for which human activity has caused changes that exceed the proposed planetary boundary.
- Students will be able to evaluate and summarize evidence used to define thresholds for key earth systems processes and discuss and evaluate variation and uncertainty in data.

INTRODUCTION

Providing meaningful opportunities for students to engage with primary literature can be challenging in undergraduate lecture courses, even when teaching upper-division science majors (1). Active learning approaches used to incorporate primary literature into standard curricula can effectively familiarize students with the nature of scientific reasoning (2-4), increase students’ self-confidence in their ability to read and comprehend scientific articles (5,6), and enhance science communication skills (7,8). Here, we describe an active learning experience structured

to encourage individual accountability, guide comparative discussions among peer groups, and inform student perceptions of global scale changes in earth system processes.

This lesson addresses global-scale environmental changes resulting from human-driven pressures on Earth systems. We use the planetary boundary concept presented in Rockström et al. 2009 (9), which defines a safe operating space for humanity for nine processes that regulate the stability and resilience of the earth system (Figure 1A). If these boundaries are crossed there are risks for irreversible environmental change with significant

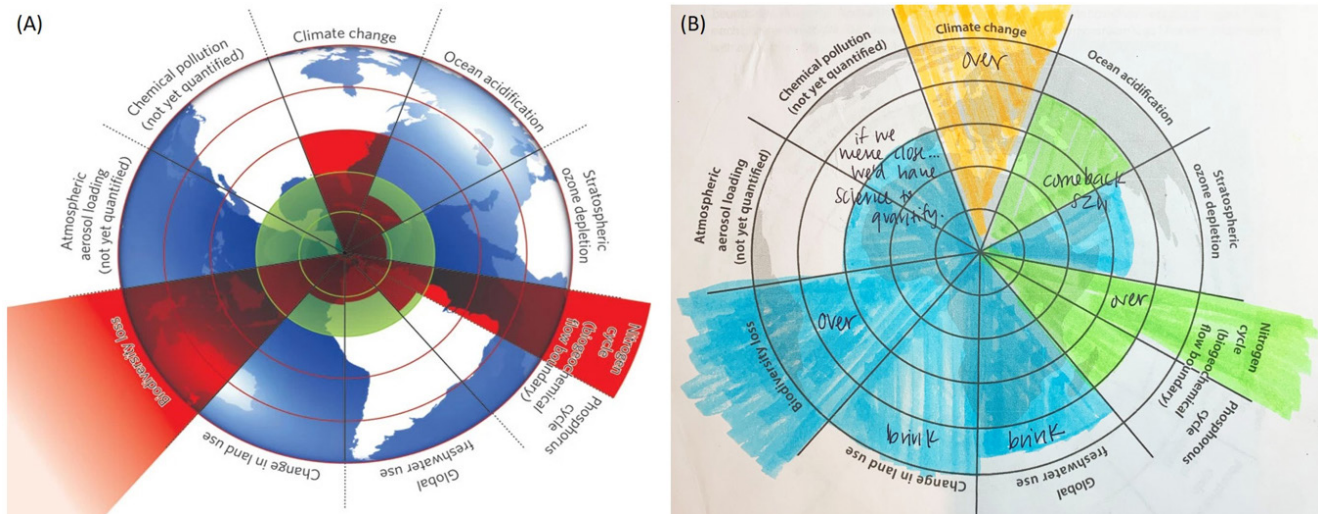


Figure 1. (A) Planetary boundaries analysis from Rockström et al. (2009). The inner green circle represents the proposed 'safe operating space' with proposed boundary levels placed at its outer border. The red wedges represent the estimated current status of control variables for each planetary boundary. For example, the authors determine a safe rate for biodiversity loss of <10 extinctions per million species per year. The wedge for this boundary extends beyond the outermost circle indicating a current rate that exceeds the space available in the figure (biodiversity loss has an estimated current boundary level of >100 extinctions per million species per year). Reproduced and modified with permission from Springer Nature. (B) Example of a student's prediction of the current status of each planetary boundary prior to reading the assigned paper. In class, students were asked to fill in the modified figure (red wedges omitted) by drawing wedges to illustrate their initial perceptions of the degree to which human activity has changed each of the 9 earth system processes. Students are asked to interpret each concentric circle as a 20% change in a planetary boundary level since pre-industrial times (1950 - present).

consequences for humanity. Seven changes addressed in this case are climate change, increased ocean acidification, declines in stratospheric ozone concentration, increased inputs of nitrogen and phosphorus to ecosystems, increased global freshwater use, increased land use change, and declines in biological diversity. Sudden and non-linear environmental changes result from going beyond what is defined as 'thresholds'; these changes are likely to have variable impacts at regional scales and further emphasize the need for human societies to become more sustainable by operating within set boundaries (10,11). Many class lessons focus on addressing one Earth process or stressor at a time; however, in this lesson we ask students to consider multiple earth system processes simultaneously to synthesize material presented throughout a course or multiple classes. This lesson was part of a class series on global-scale changes in biodiversity, climate, and earth system processes with a final lecture linking science, policy, and sustainability (Supporting File S1. Perceptions and Cooperative Learning – Lecture Presentation Slides).

Intended Audience

We developed this lesson for undergraduate students in a large-enrollment general ecology course at a research university. This course serves a variety of STEM majors including ecology, biology, and environmental engineering; ~300 students completed this lesson over two iterations of the course. Students in this course completed this lesson as one of six assignments that used an assigned peer-reviewed article to illustrate the application of ecological concepts to complex systems. This lesson was also used in a field-based ecology course taught in a small-enrollment study abroad program. In both courses, this lesson accompanied a lecture on the ecology of climate change and served as a capstone activity during one of the final class sessions for the semester. This lesson is well suited for similar courses that cover most of the earth system processes

described in the Rockström et al. 2009 paper, allowing this lesson to encourage retrieval of information learned earlier in the semester or quarter.

This lesson can also be adapted to support interdisciplinary learning in courses that serve non-STEM majors. We suggest retaining use of the TED talk and in-class assignments described herein. However, instructors can instead focus on a subset of planetary boundaries that provide compelling cases for the intersection of social, ecological, and economic issues. Such planetary boundaries include climate change, land-system change, biodiversity loss, nitrogen flows, and freshwater use; these topics are discussed within most textbooks used in an environmental science curriculum (e.g., 12). Additional entry-level resources on these topics can include news articles that address business and sustainability actions related to planetary boundaries research and the background information on the UN Sustainable Development Goals (Table 1).

Required Learning Time

This lesson was part of a class series on global-scale changes in biodiversity, climate, and earth system processes. Within the university, class sessions were 50 minutes in duration; the lesson was completed in ~90 minutes over three class sessions. At the end of the first class session, 30 minutes were used to introduce students to the planetary boundaries concept and to have students complete the first assignment (Table 2). Following a brief overview of key terms and earth system processes used in the planetary boundary concept (Slide 1 in Supporting File S1. Perceptions and Cooperative Learning – Lecture Presentation Slides), each student was given a printed copy of the first assignment in which estimates of planetary boundary levels had been redacted from the primary figure (Supporting File S3. Perceptions and Cooperative Learning – Assignment 1 Worksheet; Figure 1A). Students were then asked to use the

remaining class time to fill in the modified figure by drawing wedges to illustrate their initial perceptions of the degree to which human activity has changed each of the 9 earth system processes (Figure 1B).

After class, we then provided the TED talk, scientific article (9), and reading assurance assignment questions via an online course management system; students submitted the reading assurance assignment prior to the following class session. In the second class session, students sat with assigned 4-person groups. The session started with a mini-lecture that discussed the main findings of the article, followed by completion of the group activity (Figure 2). The last 15-20 minutes were used for a subset of groups to report back to the class and to facilitate a class-level discussion. In the following class session, 20 minutes were used to provide an overview of an updated analysis of planetary boundaries (10) and to transition into a lecture on social governance of global environmental change issues.

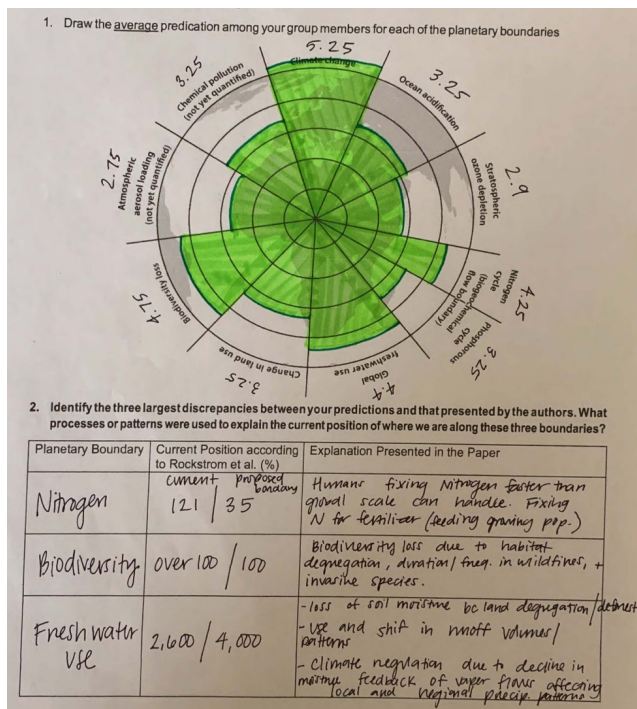


Figure 2. Example of completed in-class group assignment after all members of a peer group had read Rockström et al. (2009) and discussed their predictions.

In a general ecology course taught during a study abroad program during the same semester, the lesson elements described above were completed across two 75-minute class sessions. Under similar time constraints, we strongly recommend teaching this over multiple class periods if possible, to give students more time to illustrate perceptions, discuss perceptions held by those in the class, and unpack findings described in both papers.

Prerequisite Student Knowledge

Students should understand ecological concepts underlying the earth system processes addressed by the planetary boundaries concept. In the case of biogeochemical cycling, we taught students about major reservoirs and transformations of nitrogen and phosphorus, how humans alter nutrient inputs to ecosystems, and how these elements limit primary productivity in terrestrial and aquatic ecosystems. Coverage of these topics

was already part of the general ecology course, and were covered in two class sessions (one focused on nitrogen and the other focused on phosphorus). Prior class sessions also focused on climate, ocean acidification, biodiversity loss, and land use as topics. A brief overview of ozone depletion and freshwater use were thus covered as part of the short lecture delivered before the group activity. Students were asked to omit planetary boundaries that were not yet quantified by the authors when working in their groups.

Prerequisite Teacher Knowledge

Instructors should be familiar with the planetary boundary concept as well as the societal and ecological implications discussed as an extension of this research. Key resources for preparation include three sources of primary literature (Table 1), and a TED talk delivered by Johan Rockström that was also used as an introduction to the class session. The instructor does not need to have a comprehensive background in earth system sciences or social-ecological systems to understand these references. Specifically, the instructor should be familiar with the nine planetary boundaries defined by the authors, which of these have been transgressed (climate change, biodiversity loss, and nitrogen cycling), and the significance of crossing thresholds for the processes described.

We suggest heavier use of Steffen et al. 2015 in advanced undergraduate courses while maintaining use of Rockström et al. 2009 for general biology/ecology courses. As our course serves a broad diversity of STEM majors and functions as a foundational ecology course, Rockström et al. 2009 works well for a couple of reasons. For example, Rockström et al. 2009 is the introductory paper for the planetary boundaries concept and provides clear explanations for the selection and evaluation of focal earth system processes. Easily accessible outreach material that was created based on this paper is also very useful for instructors and students (e.g., TED talk and the Stockholm Resilience Center webpage). In courses that serve similar student audiences, it is useful to use Steffen et al. 2015 for in class and group discussions (Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions) to further help students synthesize, evaluate, and critique the thresholds for the planetary boundaries during the last (third) class session.

For advanced undergraduate courses (e.g., ecosystem ecology, global change), it may be better to use Steffen et al. 2015 after students have read Rockström et al. 2009. Here, additional time would be needed to unpack new terminology (e.g., core boundaries, novel entities) and consider regional-level boundaries developed for biosphere integrity, biogeochemical flows, land-system change and freshwater use. If using Steffen et al. 2015 as a primary article for students, we advise making it clear that the TED talk provides framing for the class discussion and presents the planetary boundary concept using the original analysis published in 2009. We also encourage instructors to visit the Stockholm Resilience Center webpage that provides an overview of the updated analysis (Table 1).

SCIENTIFIC TEACHING THEMES

Active Learning

Active learning strategies used in this lesson include a pre-class reading assignment, group discussion, and collaborative work in small groups. Classroom assessment techniques (13)

included a 'background knowledge probe,' modified to collect visual information on students' prior knowledge of the topic (Figure 1B); and in-class polling, used during the lecture to ask students where they placed the safe operating space for humanity as a 'preconception/misconception check' (Supporting File S2. Perceptions and Cooperative Learning – Reading Assurance Assignment and In-Class Polling Questions).

Assessment

We assigned a six-question reading assurance assignment to evaluate students' ability to identify key points and synthesize the relevant scientific information presented in the assigned paper (learning objective 1). We provide the questions for this assignment in Supporting File S2. Perceptions and Cooperative Learning – Reading Assurance Assignment Questions. For assessing learning objective 2, students completed individual worksheets purposed to probe their background knowledge (Supporting File S3. Perceptions and Cooperative Learning – Assignment 1 Worksheet). Completion of both assignments prior to the second class session were required for students to receive full credit, but each was only assessed for completion. These assignments can also be graded for accuracy in smaller enrollment courses or in courses with adequate support for instruction and grading.

Both formative and summative assessments were used to assess learning objectives 3 and 4. An in-class polling question was used to assess students' prior conceptions of the extent to which humans could alter earth system processes without compromising the system's resilience and stability (referred in the focal paper as the 'safe operating space for humanity'). In-class worksheets completed by student peer groups were collected and used as formative assessments (Supporting File S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet). Student groups were given complete/incomplete marks and feedback for their statements summarizing evidence used to define thresholds for selected earth system processes. The group activity provides an opportunity for students to self-evaluate their learning by not only comparing their predictions to findings presented in the paper, but also by accounting for the predictions of their peers. We also designed four multiple choice questions that spanned cognitive levels (knowledge, comprehension, application, analysis) for the unit exam (Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions). Examples of student work are provided (Supporting File S6. Perceptions and Cooperative Learning – Individual Student Work Examples; Supporting File S7. Perceptions and Cooperative Learning – Group Work Examples). At course end, a reflection prompt was used to assess how the students ranked this case study for effectiveness out of six in-class case studies completed over the course of the semester (see Teaching Discussion).

Inclusive Teaching

Students who complete this lesson explicitly hold different perceptions of how human activity has changed various earth system processes and the degree to which humans can safely alter these processes without crossing biophysical thresholds. Such perceptions would be difficult to draw out particularly in a large-enrollment course without purposeful opportunities to promote students' sense of belonging and self-efficacy (14,15). In this lesson, these perceptions are illustrated in the first component of the assignment and used to determine three

planetary boundaries that groups summarize in class. This activity thereby encourages students both to consider how others' perceptions might differ in regards to a given planetary boundary and the degree to which others' perceptions and their own align with our current scientific understanding.

The class sessions in which this lesson takes place, are designed to promote participation of all students in several ways. First, a student response system (Kahoot!) was used to ask where students placed the safe operating space for humanity prior to reading the paper (Supporting File S2. Perceptions and Cooperative Learning – Reading Assurance Assignment and In-Class Polling Questions). Students answered this question using personal accounts that were established at the beginning of the semester to facilitate in-class participation during all class sessions. Responses are then made visible to the entire class and used to frame instructions for the in-class group assignment. This question is used to give instructors a sense of the variability in responses that students will be discussing and serves as a transition between a short introductory lecture and the collaborative group activity. The instructor and teaching assistants circulate among the groups to ensure that discussion time is equally shared. Timing prompts can also be given to ensure each member of the group has an equal time to share their predictions prior to compiling group results and discussing the paper. In addition, we recommend that the instructor require each group to appoint a student to be a discussion moderator to ensure equal participation of all group members; this is particularly critical in large-enrollment courses in which instructor access to each group is limited by seat arrangement. To complete guided discussion questions (Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions), we suggest first having students perform a Think-Pair-Share and then reconvene as a 4-member group to develop answers to each question. The instructor can then call on groups randomly and/or call on specific groups that arrive at particular answers to each question for the full class discussion. Having students complete both formative assessments through use of the guided discussion questions and summative assessments (Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions) encourages students to engage with their peers and the material both in and out of class.

LESSON PLAN

Course Context and Course Situational Factors

This activity is designed as part of the final course unit on ecosystems, biodiversity, and climate change. This unit is one of 4 units taught in a 4-credit upper level General Ecology course. Organismal Biology and one semester of General Chemistry serve as prerequisites for this course, though students taking either of these courses as co-requisites have successfully completed this activity. We thus believe the activity could be adapted for lower division students who have not yet taken either an introductory biology or chemistry course.

Each unit in the General Ecology course was designed to include at least one Ecological Applications assignment of this kind. These two-part assignments included an out-of-class Reading Assurance Assignment completed solo (due by the start of class) and an in-class Application Assignment completed with a team (due by the end of the class session). On each assignment, students work in groups of 3-4 on class activities throughout

the semester. Students are assigned to groups at the beginning of the semester and work with the same group throughout the semester. Students had completed five Ecological Application assignments before completing the activity described here, with feedback and assignment grades provided by the instructor on each completed assignment. Groups with stable memberships had thereby established productive working relationships before this particular activity.

To date, this lesson has been facilitated in both small- and large-enrollment courses by a single instructor and teaching assistant. The lesson follows instruction on biogeochemical cycles, ocean acidification, large-scale patterns in biodiversity, and precedes a lecture on the ecology of climate change. Enrollment in these courses ranged from 15 - 200 students during the semesters in which the case study was implemented. The course was taught in a standard classroom, a collaborative Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP) classroom, and in a field-based classroom used for study abroad programs. The standard classroom had long tables with fixed swivel chairs seating ~20 students to a row. Both the SCALE-UP and field-based classrooms offered much more freedom of movement, with tables large enough for students to work in groups of 4, moveable chairs or benches, and portable white boards. As class sessions in both the standard and SCALE-UP classroom were set up in 50-minute time blocks, facilitation of the lesson remained largely the same, with the instructor and teaching assistant rotating among groups as needed. The lesson design was also kept largely the same in the field-based classroom, with the addition of more time added from group- and class-level discussions.

Timeline of Lesson

Pre-class Student Preparation

This activity addresses global-scale environmental changes resulting from human-driven pressures on Earth systems, sudden and non-linear environmental changes resulting from going beyond what is defined as ‘thresholds’, and how human societies can become more sustainable by operating within set boundaries. Seven changes addressed in this case are climate change, increased ocean acidification, declines in stratospheric ozone concentration, increased inputs of nitrogen and phosphorus to ecosystems, increased global freshwater use, increased land use change, and declines in biological diversity. The students should already be familiar with each of these concepts through previous lectures and/or Ecological Application assignments in this course, as well as through topical coverage in pre-requisite courses. A brief overview of each planetary boundary defined by the authors is also covered in a short lecture preceding the in-class group assignment.

Students will also need to understand concepts discussed in-depth in the paper including planetary boundaries, thresholds, the ‘Anthropocene’, and global sustainability. Following the case introduction, students submit a photo of their pre-reading worksheet (Supporting File S3. Perceptions and Cooperative Learning – Assignment 1 Worksheet) to a homework folder on the D2L course management system. Out of class, students then (1) watch an assigned TED talk delivered by Johan Rockström, “Let the environment guide our development”; (2) read the scientific article about defining planetary boundaries and a safe operating space for humanity (9); (3) and complete the

reading assurance assignment as homework (Supporting File S2. Perceptions and Cooperative Learning – Reading Assurance Assignment Questions). Students submit their answers to the reading assurance assignment questions to the same online homework folder before the following class session begins.

Pre-class Instructor Preparation

Instructors will need to establish 3-5 member student groups for this lesson. In our course, groups were created using a “Groups” tool in the D2L classroom management system, which allows the instructor to specify the number of students assigned to a group and automatically generate numbered group assignments visible to each student. Use of this tool also allows for the assignment of a group grade that applies to each student assigned to a particular group. Literature suggests that instructors should form 3-5 member student groups rather than permitting self-selection by students (16). In small-enrollment courses, instructors can also consider creating groups based on student characteristics that can contribute to effective group collaboration and performance; such as creating groups that are gender balanced, are ethnically diverse, and/or have members with different problem-solving approaches (e.g., 17).

Our large enrollment class thus had ~45 groups of 3-4 students formed by the instructor at the beginning of the semester; these group assignments were retained for the entire semester. Numbered cards were set up throughout the lecture hall ahead of each class session in which group work was required. Groups were combined as needed due to changes in student enrollment over the course of the semester or when only two of four group members were in attendance for a particular in-class assignment.

In preparation for guiding students through this lesson, instructors first prepare the short introductory lesson used to introduce the planetary boundaries concept and key terms. Also needed are prepared copies of the individual worksheet (Supporting File S3. Perceptions and Cooperative Learning – Assignment 1) that each student will use to illustrate their initial perceptions of the degree to which human activity has changed 9 earth system processes. If using an online classroom management system, instructors should post a pdf of the article (9) so that it becomes accessible after students have watched the TED talk. A survey tool like Qualtrics or Google Forms can be used to create the reading assurance assignment (Supporting File S2. Perceptions and Cooperative Learning – Reading Assurance Assignment Questions); a link to this survey should then be sent to students. Homework folders must then be established so that students can submit individual assignments before the start of the next class session. If only using hard copies, the instructor should prepare copies and distribute the article to each student in class. The instructor can reserve time to open the second class session with the first 10 minutes of the TED talk instead of having students view this outside of class if necessary. Instructors should assign the reading and reading assurance assignment at least 1-2 days before having students complete the group activity. In our undergraduate General Ecology course, students had ~2 days to complete the reading. For the case study, instructors should prepare copies of the in-class group worksheet (Supporting File S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet). If showing the video in class, instructors should check that the embedded links to the video file functions properly with their classroom equipment. Instructors and students can access the video directly through the TED

website at: https://www.ted.com/talks/johan_rockstrom_let_the_environment_guide_our_development?language=en#t-602988

Introduction to the Case

We begin the case study activity with a short lecture that walks students through background on each of the nine planetary boundaries, provides formal definitions of key concepts like thresholds, and presents the central figure of the Rockström et al. 2009 paper. We then explain to the students that the aim of this case study is for them to discuss how their perceptions differed from the findings presented in the paper within their group. On the group worksheet, students will map the ‘average’ perceptions that the group held before reading the paper, and use this to identify and discuss three boundaries that were most incongruent with their initial perceptions. We explain that the aim in this case study is to present an opportunity to focus on their misconceptions and seek out concrete information within the paper; the aim is to bring their understanding in line with our scientific understanding of Earth systems. Students are instructed to omit boundaries that were not quantified by the authors in their analysis.

Discussion of Article

After the case is introduced, students use their individual worksheets and the assigned paper to complete the group worksheet (Supporting File S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet). Instructors can quickly assess drawings and answer student questions on summarizing points in the paper while rotating through the classroom. Once most groups have finished, the last 10-15 minutes of class are used to wrap up the activity. Instructors can ask several groups to be ready to share out in advance. We started with one group willing to share one of the boundaries they summarized; this group and all subsequent groups then used assigned group numbers (1-50) to choose another group at random. The instructor can facilitate the whole class discussion by asking if other groups added additional details from the paper for a particular boundary, or asking groups that identified boundaries that have not yet been discussed to share out. With time permitting, guided discussion questions can also be used by the instructor to prompt active reflection and facilitate a class-level discussion (Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions). We then give student groups instruction for the online submission of their assignment to a group assignment folder on the D2L course management system.

Concluding the Case: Summarize Group Perceptions and Discussion Points

In the final class session, the wrap-up for this case is embedded in the last course lecture focused on the Ecology of Climate Change to align with the course textbook. Concluding the case can also happen without the climate change lecture described below by using the guided discussion questions and presentation of the updated planetary boundaries analysis (10,18).

We began by reviewing key ecological concepts covered throughout the semester, and transition into a wrap-up discussion of the case that is framed by changes in Earth’s climate. Students are provided with a brief overview of how several of the earth system processes considered by the planetary boundary concept have been altered as a result of feedbacks between natural systems and climate. This point is linked back to the course textbook by examining overall patterns of warming since the

Industrial Revolution as well as differential patterns of warming across Earth’s surface. The lecture then redirects students back to the key figure in the assigned paper from the case, and highlights the earth system processes for which observed changes extended beyond the proposed planetary boundary (biogeochemical flows, land system change, and biodiversity losses; 9). It is important here to clarify that the 2009 paper discusses global-scale shifts in climate and earth system processes. The wrap-up thus provides a brief overview of the regional-scale variation in earth system processes with respect to proposed planetary boundaries (10) to further highlight variability in feedbacks between natural systems and climate at regional and local scales.

The lecture moves into coverage of key publications on the state of Earth’s climate, major changes in Earth systems, and international policy agreements. To wrap up the case and close the course, the lecture finishes by playing 4 minutes of the TED talk titled, “5 transformational policies for a prosperous and sustainable world” by Johan Rockström, delivered in November 2018. This video can be accessed at: https://www.ted.com/talks/johan_rockstrom_5_transformational_policies_for_a_prosperous_and_sustainable_world?language=en. Students are asked to make note of (1) conditions required to both achieve the highest number of UN Sustainable Development Goals and maintain a resilient earth system; and (2) policies to achieve sustainable world development while keeping the earth stable and resilient (i.e., within proposed planetary boundaries).

Grading the Individual Reading Assurance Assignment and Group Work

Before working through the case study, each student completes (1) the introductory worksheet that captures students’ perceptions of how humans have altered earth system processes and (2) the individual readiness assurance assignment. A scanned or photo copy of their worksheet and assignment answers are submitted for a grade. A due date and time for the online submission of these assignments is set up in the online classroom management system. We use Qualtrics as a survey platform to distribute the reading assurance assignment and to examine student answers. We export all responses to an Excel file and review one question at a time, highlighting answers that are too short, vague, or that do not address the question. We then assign students no credit (no submission), half credit (vague or inaccurate response to two or more questions), or full credit (detailed responses expressed in student’s own words provided to all questions) for this assignment. It takes 30-45 minutes to grade 200 responses using this approach and grades are assigned with feedback in the online classroom management system. Groups submit their completed worksheet to a separate assignment folder in the online classroom management system at the end of the class session. This assignment is graded both for completion and for responses that clearly reflect a discussion of viewpoints and the paper. The quiz is worth a total of 15 points with the individual quiz making up 5 of the points and the group quiz grade making up 10 of the points. Students are required to submit the reading assurance assignment and pre-reading activity in advance of completing the case study in order to receive credit for completing the in-class group work. The grading was designed intentionally to place equal weight on individual and group work, while also requiring that students be prepared to contribute to group conversations.

TEACHING DISCUSSION

The overall goals of this lesson are to teach students about earth systems processes in an ecological context and to have students effectively communicate their perceptions of environmental change to their peers. We further aimed to develop skills that will enable students to critically interpret and summarize information in primary literature. In order to assess whether student learning objectives are being achieved, both formative and summative assessments are used.

Group worksheets and guided discussion questions (Supporting File S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet; Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions) can be used as a formative assessments of student groups. Student answers are graded for completion and are checked for accuracy by the instructor. We used the D2L course management system to provide feedback to student groups on their work. This approach lets the instructor determine whether students understand the information presented in the assigned paper and provides an opportunity to provide additional instruction in the following class session. Answers to these formative assessment questions suggest that the learning goals are being met, as most groups were able to summarize most key pieces of evidence provided by the authors to justify the placement of planetary boundaries.

Students also answer summative assessment questions that we have written (Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions) to determine their comprehension of the material taught in this lesson. As this lesson precedes the final class session for the course, these questions were included on a cumulative final exam that covered material from the entire semester. Student performance on these questions varied, but in every case a majority of the students were able to correctly answer the assessment questions. Taken together, the designed assessment questions allow us to evaluate our learning goals and provide support for the effectiveness of this lesson in achieving these learning goals.

The larger goal of incorporating Ecological Application assignments into the design of the course stemmed from our interest in helping our students learn how to comprehend, summarize, and interpret data from scientific publications; this is a key skill to build over time particularly for upper-level students in science majors (19,20). At the beginning of the semester, we prepared students for these assignments by first providing and discussing a video on how to read, take effective notes, and summarize the main points of scientific research articles; this video can be accessed at <https://www.youtube.com/watch?v=t2K6mJkSWoA>. As part of the first assignment in which students read a peer-reviewed article, we created a cooperative learning activity in which 4-member groups were asked to construct a “one sentence summary” that required them to pull information from each section of the paper (Introduction, Methods, Results, Discussion). We then discussed what types of information were shared in each section of a scientific paper and identified main points needed to effectively summarize the paper. If using this lesson as a stand-alone activity, we advise instructors to facilitate a similar activity prior to this lesson to scaffold students’ ability to read primary scientific literature. By scaffolding the process of comprehending primary literature

and linking this to opportunities for knowledge application, instructors allow students to gain experience in extracting meaningful conclusions from novel data sets and in discussing their application to real world issues (21).

Student Reactions to the Lesson

In general, this lesson is well received by the students. They do have some initial difficulty with summarizing points that support the placing of particular boundaries, but this is a key facet of the assignment where students work together to revisit the paper in class and discuss how to interpret the data presented. One of our goals in designing this and other similar Ecological Application Assignments that are used in the ecology course is to teach students how to effectively read primary literature and link their perceptions of the world to ecological data.

At the end of the on-campus course, students were asked to rank the EA Assignments from most (rank = 1) to least (rank = 6) effective in the degree to which it enhanced their understanding of an ecological system. Forty one percent of student respondents that attended these class sessions ranked this assignment as one of their top two. Students commented on there being value to making predictions prior to reading the paper in that they could see others points of view, and “create logic for why we chose what we chose, and then afterward change that logic based on what we learned”. They found the exercise to be impactful as a concluding exercise for the last unit of the course (unit 4) where there was a focus on ecosystem processes, including the nitrogen and phosphorus cycles, biodiversity, and climate change. Also notable was students’ ability to relate the content to their everyday lives by recalling “what is talked about in the media” and recognizing what they “didn’t know about how much what humans do is affecting the Earth”. Further, students found the planetary boundaries figure to be an “effective way of visualizing the main concepts” and its interpretation “reassuring to know that not every aspect of the planet was doomed”. As evidenced here, we hope that students learn to use scaffolding tools and support systems leveraged in these assignments on their own when confronted with novel scientific information.

Possible Improvements and Modifications

Modifications to this lesson will largely depend on class session time. We found that time for guided discussion following the group activity was fairly limited in the large-enrollment course. This is in part due to the greater amount of time needed to facilitate discussions among student groups and the need to cover remaining content in the textbook. Under similar teaching conditions, instructors may consider dedicating less time to finishing planned course content and building out this lesson by an additional 15-20 minutes. Guided discussions were more successful in small-enrollment classes both on campus in class sessions of identical length (50 minutes) and in longer class sessions designed for students completing General Ecology abroad.

SUPPORTING MATERIALS

- Supporting File S1. Perceptions and Cooperative Learning – Lecture Presentation Slides
- Supporting File S2. Perceptions and Cooperative Learning – Reading Assurance Assignment and In-Class Polling Questions
- Supporting File S3. Perceptions and Cooperative Learning –

- Assignment 1 Worksheet
- Supporting File S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet
- Supporting File S5. Perceptions and Cooperative Learning – Discussion and Assessment Questions
- Supporting File S6. Perceptions and Cooperative Learning – Individual Student Work Examples
- Supporting File S7. Perceptions and Cooperative Learning – Group Work Examples

ACKNOWLEDGMENTS

We thank Ashley Lavere for serving as a teaching assistant in the on-campus courses in which this lesson was taught, Benjamin Taylor for modifying the planetary boundary figure to enable the design of assignment worksheets, and the students in ECOL3500 courses at the University of Georgia for participating in this lesson and providing valuable feedback. We also thank the University of Georgia Center for Teaching and Learning as this lesson was created as part of a course curriculum redesign through the Active Learning Summer Institute.

The planetary boundary figure in Supporting File S3. Perceptions and Cooperative Learning – Assignment 1 Worksheet, and Supporting File S4. Perceptions and Cooperative Learning – Assignment 2 Worksheet are edited from a scientific publication (Rockström et al. 2009. *Nature*, 461, 472-475). We have written permission to use these figures from both the authors and the licensed content publisher, Springer Nature. Copyright permission was obtained through the Copyright Clearance Center (copyright.com). Documentation of the copyright permission can be provided if necessary. Written permission was obtained for exemplary student work and all names have been redacted.

REFERENCES

1. Rauschert ES, Dauer J, Momsen JL, Sutton-Grier A. 2011. Primary literature across the undergraduate curriculum: teaching science process skills and content. *Bul. Ecol. Soc. Amer.* 92:396. doi: 10.1890/0012-9623-92.4.396
2. Muench SB. 2000. Choosing primary literature in biology to achieve specific educational goals. *J. College Sci. Teach* 29:255-260.
3. DebBurman SK. 2002. Learning how scientists work: experiential research projects to promote cell biology learning and scientific process skills. *Cell Biol. Educ* 1:154-172. Doi: 10.1187/cbe.02-07-0024.
4. Round, JE, Campbell AM. 2013. Figure facts: encouraging undergraduates to take a data-centered approach to reading primary literature. *CBE Life Sci. Educ.* 12(1):39-46. doi: 10.1187/cbe.11-07-0057.
5. Hoskins SG, Lopatto D, Stevens LM. 2011. The CREATE approach to primary literature shifts undergraduates' self-assessed ability to read and analyze journal articles, attitudes about science, and epistemological beliefs. *CBE Life Sci. Educ.* 10(4):368-378. doi: 10.1187/cbe.11-03-0027
6. Gehring KM, Eastman DA. 2008. Information fluency for undergraduate biology majors: applications of inquiry-based learning in a developmental biology course. *CBE Life Sci. Educ.* 7(1):54-63. doi: 10.1187/cbe.07-10-0091
7. Mulnix AB. 2003. Investigations of protein structure and function using the scientific literature: an assignment for an undergraduate cell physiology course. *Cell Biol. Educ* 2: 248-255. doi: 10.1187/cbe.03-06-0025
8. Murray TA. 2014. Teaching students to read the primary literature using POGIL activities. *Biochem. Mol. Biol. Educ.* 42(2):165-173. doi: 10.1002/bmb.20765
9. Rockström J, Steffen W, Noone K, Persson Å, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sörlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, Foley JA. 2009. A safe operating space for humanity. *Nature*. 461:472-475. doi: 10.1038/461472a
10. Steffen W, Richardson K, Rockström J, Cornell SE, Fetzer I, Bennett EM, Biggs R, Carpenter SR, de Vries W, de Wit CA, Folke C, Gerten D, Heinke J, Mace GM, Persson LM, Ramanathan V, Rayers B, Sörlin S. 2015. Planetary boundaries: Guiding human development on a changing planet. *Science*. 347(6223):1259855. doi: 10.1126/science.1259855.
11. Lade SJ, Steffen W, de Vries W, Carpenter SR, Donges JF, Gerten D, Hoff H, Newbold T, Richardson K, Rockström J. 2020. Human impacts on planetary boundaries amplified by Earth system interactions. *Nat. Sustain.* 3:119-128. doi: 10.1038/s41893-019-0454-4
12. Cunningham WP, Cunningham MA. 2021. *Environmental science: A global concern*. New York, NY: McGraw-Hill.
13. Angelo TA, Cross KP. 1993. Techniques for assessing course-related knowledge and skills. In *Classroom Assessment Techniques: A Handbook for College Teachers*. 2nd Edition (pp. 119 - 158). San Francisco, CA: Jossey-Bass.
14. Alfasi M. 2003. Promoting the will and skill of students at academic risk: An evaluation of an instructional design geared to foster achievement, self-efficacy and motivation. *J. Inst. Psychol.* 30(1):28-40.
15. Zumbrunn S, McKim C, Buhs E, Hawley LR. 2014. Support, belonging, motivation, and engagement in the college classroom: A mixed method study. *Instr. Sci.* 42:661-684. doi: 10.1007/s11251-014-9310-0
16. Wilson KJ, Brickman P, CJ Brame. 2018. Group work. *CBE Life Sci. Educ.*, 17(1), fe1. doi: 10.1187/cbe.17-12-0258
17. Treen E, Atanasova C, Pitt L, Johnson M. 2016. Evidence from a large sample on the effects of group size and decision-making time on performance in a marketing simulation game. *J. Market Educ.*, 38(2): 130-137. doi: 10.1177/0273475316653433
18. Schlesinger W. 2009. Planetary boundaries: thresholds risk prolonged degradation. *Nat. Clim. Chang.* 1(910):112-113. doi: 10.1038/climate.2009.93
19. Marsh TL, Guenther MF, Raimondi SL. 2015. When Do Students "Learn-to-Comprehend"? Scientific Sources?: Evaluation of a Critical Skill in Undergraduates Progressing through a Science Major. *J. Microbiol Biol. Educ.* 16(1):13. doi: 10.1128/jmbe.v16i1.828
20. Nelms AA, Segura-Totten M. 2019. Expert-Novice Comparison Reveals Pedagogical Implications for Students' Analysis of Primary Literature. *CBE Life Sci. Educ.* 18(4):ar56. doi: 10.1187/cbe.18-05-0077
21. Shannon S, Winterman B. 2012. Student comprehension of primary literature is aided by companion assignments emphasizing pattern recognition and information literacy. *Iss.Sci. Tech. Librar.* 68(4). doi:10.5062/F4TB14TS

Table 1. Scientific articles used in this case study and background papers/online resources for instructors.

Reference	Note
Rockström, J., Steffen, W., Noone, K., Persson, Å., et.al. 2009. A safe operating space for humanity. <i>Nature</i> 461: 472-475	Source material for case study introduction and group activity; also read by students. Provides high-level analysis of nine processes that regulate the stability and resilience of the Earth system and quantitative planetary boundaries. Pre-reading assignment and worksheets are provided in Supporting Files S2-S4. Formative assessment questions are provided in Supporting File S6.
Rockström, J., W. Steffen, K. Noone, Å. Persson, et.al. 2009. Planetary boundaries: exploring the safe operating space for humanity. <i>Ecology and Society</i> 14(2): 32	Background reading for instructor for case study introduction and group activity. Provides original analysis that identifies nine processes that regulate the stability and resilience of the Earth system and quantitative planetary boundaries.
Schlesinger, W. 2009. Planetary boundaries: thresholds risk prolonged degradation. <i>Nature Climate Change</i> 1(910), 112-113	Background reading for instructor to facilitate discussion following group activity prior to introduction of Steffen et al. (2015). Provides responses of multiple experts to the planetary boundaries concept and challenges in defining these boundaries.
Steffen, W., K. Richardson, J. Rockström, S.E. Cornell, et.al. 2015. Planetary boundaries: Guiding human development on a changing planet. <i>Science</i> 347: 736, 1259855	Background reading and source material for wrap-up lecture and discussion. Provides the most recent update of the planetary boundaries framework. Guided discussion questions are provided in Supporting File S5.
Lade, S.J., Steffen, W., de Vries, W. et al. Human impacts on planetary boundaries amplified by Earth system interactions. <i>Nature Sustainability</i> 3, 119–128 (2020).	Recent article published after this lesson was designed and implemented. Recommended as additional background reading and source material for wrap-up lecture. Provides analysis of interactions between the Earth system processes represented by the planetary boundaries and investigates consequences for sustainability governance.
https://www.stockholmresilience.org/research/research-news/2015-01-15-planetary-boundaries---an-update.html	Stockholm Resilience Center webpage providing a summary of updated research published by Steffen et al. 2015. Recommended as an online resource for instructors using the updated analysis of the planetary boundaries framework in their course.
https://www.stockholmresilience.org/news--events.html	Stockholm Resilience Center web archive for news articles that discuss economic and sustainability actions related to planetary boundaries research. Recommended as an online resource for instructors modifying the focus of this lesson for non-STEM majors or a discussion of social-ecological issues.
https://unfoundation.org/what-we-do/issues/sustainable-development-goals/?gclid=Cj0KCQjwI4v4BRDaARIsAFjATPIb5scVEIzyjpVvVdbuwnsNtpwH2hCFBh4YuV7IjpRifMIFdLPTjblaAq9AEALw_wcB	United National Foundation webpage for the Sustainable Development Goals adopted in 2015. Recommended as an online resource for instructors modifying the focus of this lesson for non-STEM majors or a discussion of social-ecological issues.

Table 2. Recommended timeline for the lesson

Activity	Description	Estimated Time	Notes
Preparation for Class			
Prepare student-facing materials	<ol style="list-style-type: none"> 1. Make copies of individual and group worksheets. 2. Print reading assurance assignment worksheets or post reading assurance assignment to course website. 3. Bring copies of individual worksheet and reading assurance assignment worksheet (if printed) to class session 1. 4. Bring copies of group worksheet to class session 2 for each student group. 	Outside of class	Worksheets and reading assignments are provided in Supporting Files S2 - S4.
Class Session 1 (30 minutes within a 50-minute class session)			
Case introduction	Instructor introduces the planetary boundary concept and tells students that they will focus on illustrating perceived changes in our Earth system.	~ 15 minutes	
Student perceptions worksheet - draw	Students complete worksheet 1 and submit a photo of their work.	~15 minutes	Assignment submissions enabled through D2L course management system.
Watch TED talk	Student groups watch the TED talk "Let the environment guide our development." Video can also be shown by the instructor in class if time permits; we suggest showing 0:00 - 10:07 minutes if taking this approach.	Outside of class or in class	Video transcript can be accessed from: https://www.ted.com/talks/johan_rockstrom_let_the_environment_guide_our_development/transcript?language=en
Background reading	Students read the assigned reading as homework prior to coming to class session 2.	Outside of class	D2L course website used to time posting of the reading after class session 1.
Individual reading assurance assignment	Students answer the 6-question assignment individually and submit their answers before class session 2.	Outside of class	Assignment made available through Qualtrics. Students submit survey completion confirmation received via email.
Class Session 2 (50 minutes)			
Mini lecture on planetary boundaries concept	Background on earth system processes assessed at global scale in analysis of planetary boundaries, thresholds, the safe operating space for humanity, and the Anthropocene.	15 minutes	Lecture slides provided in Supporting File S1. An overview of the nine planetary boundaries can also be found at: https://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html
Group misconceptions and summary worksheet	Student groups complete worksheet 2 and submit a photo of their work to their group assignment folder.	20 minutes	Assignment submissions enabled through D2L course management system.
Discussion	Instructor facilitates class-level discussion in which students report pre-reading perceptions of safe operating space for humanity and earth processes for which they held largest misconceptions. Groups report out on explanations summarized from the paper.	5-10 minutes	Kahoot! was used as a classroom response system throughout the semester. Question provided in Supporting File S2.

Activity	Description	Estimated Time	Notes
Class Session 3 (50 minutes)			
Mini lecture	Background on earth system processes assessed at global and regional scale in updated analysis of planetary boundaries (Steffen et al. 2015).	10 minutes	Updated analysis planetary boundaries framework (1). Guided discussion questions for lecture and in class discussion (Supporting File S5, time permitting).
View TED talk	Students watch minutes 6:10 – 11:55 of the video played by the instructor.	10 minutes	Video file is embedded in the PowerPoint. Transcript can be accessed from: https://www.ted.com/talks/johan_rockstrom_5_transformational_policies_for_a_prosperous_and_sustainable_world/transcript?language=en
Ecology of Climate Change Lecture	Students take notes on remaining lecture slides which transition into a broader discussion on the ecology of climate change.	~30 minutes	This class session is the final class session of the semester. This material is derived from the final chapter of the course textbook: (9th ed.) Smith, T. M., & Smith, R. L. (2015). Elements of ecology. San Francisco, CA: Pearson Benjamin Cummings.