Plant Disease & Climate Change: A Classroom Exercise Emphasizing Scientific Collaboration

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ABSTRACT

The proposed lesson, a model active-learning activity designed to give college students experience in synthesizing information and developing a solution, can be used to address socioscientific issues across fields. As a consequence of climate change, global temperatures are anticipated to rise. This rise in temperature is expected to have a negative impact on agricultural systems due in part to increased disease incidence and decrease in crop yields. This activity is written in the context of plant pathology and agricultural systems to emphasize the importance of collaboration and communication among scientists or experts in different fields to address global agricultural issues. Students will gain an understanding of the importance of agriculture on a global scale and work together to develop a solution through the development of an agricultural policy.

Key Words: *plant disease; agriculture; climate change; science policy; concept mapping; active learning; peer learning.*

Introduction

Challenges of food security and climate change are current agricultural socioscientific issues that are important for creating a sustainable future. The instructional strategy described here aims to use the socioscientific issue of rice susceptibility to a bacterial pathogen to improve student understanding of (1) the interactions between abiotic and biotic factors currently decreasing rice yield, or total crop production; and (2) the importance of communication between different fields to produce solutions to major issues affecting global food security. Focusing this exercise on an international research station will allow students to understand the importance of agriculture on a global scale, while also emphasizing the importance of scientific research in decision making. Climate change affects many aspects of modern life, especially in industries that rely on environmental products, such as agriculture, fisheries, and conservation. Therefore, this lesson plan is meant to be used as a model that can be adapted to other disciplines to increase peer learning by having students analyze and interpret data to cooperatively develop solutions to issues surrounding climate change.

The lesson plan implements various active-learning approaches, as research has shown that active learning is more effective than traditional teaching approaches for science, technology, engineering, and mathematics (STEM) students (Freeman et al., 2014). Students will be asked to define problems, interpret and analyze data, design solutions, and engage in discussion, all while developing a model. These learning objectives coincide with Science and Engineering Practices of the *National Generation Sciences Standards* while emphasizing active learning and peer learning in a STEM college classroom (Springer et al., 1999; Smith et al., 2009; NGSS Lead States, 2013).

This lesson plan has been adapted from Constible et al. (2007), which focused on teaching concepts of penguin ecology in light of climate change. However, this adapted version not only aims to teach students about issues in agriculture surrounding climate change, but also requires students to develop a feasible policy to address the issues currently affecting global food security. For this activity, the students will be invited to a "Food Security Summit" at the International Rice Research Institution (IRRI), located in the Philippines. The Summit will act as a conference to bring together student experts from different fields to synthesize data and develop a policy to combat the threat that climate change poses to rice production. The exercise presented here leads to an open-ended concept map, in which students will identify the most important data from their assigned field and how these data relate to other fields. The concept map will serve to illustrate the complexity of developing feasible solutions to produce a more sustainable future in terms of food security.

This in-class activity, though developed in an upper-level college plant physiology course, has been modified for an entry-level college classroom. Before the lesson, students should understand that (1) plants must respond to changes in their environment, (2) crops have been bred to specific environments, and (3) alterations in climate can affect crop yield. Modifications to the lesson plan and online resources for foundational plant biology and climate change knowledge have been provided in the "Instructor Notes" (see the Supplemental Material available with the online version of this article).

Relevant Background Information

By 2050, the world's population is expected to have increased by 2.5 billion, reaching a total population of 9.8 billion people (United Nations, 2017). Therefore, the pressure to increase food productivity has intensified (Ray et al., 2013). Adverse environmental stress, including heat stress, has a devastating impact on agricultural systems, accounting for >50% of crop yield loss (Boyer, 1982; Wang et al., 2003; Zhao et al., 2017). In addition, each year, plant pathogens account for an estimated global yield loss of 10–16%, resulting in an economic loss equivalent to $220 billion (Strange & Scott, 2005; Oerke, 2006). Therefore, developing more stress-resistant crop varieties and implementing new agricultural policies is vital.

Rice is considered one of the most important staple crops in the world. IRRI is devoted to rice research and breeding for increased yields in major rice-producing countries. According to IRRI, plant diseases account for ~37% of all rice production losses in Asia (Rice Knowledge Bank). One of the major yield losses for rice grain is bacterial blight, a disease caused by a bacterial pathogen, *Xanthomonas oryzae* pv. *oryzae* (*Xoo*) (Niño-Liu et al., 2006; Mansfield et al., 2012), leading to yield losses of ≤70% (Reddy et al., 1979; Mew et al., 1993). *Xoo* thrives in warm temperatures with high humidity and is able to spread from plant to plant through water dispersal, contact, or wind (Mansfield et al., 2012). *Xoo* will infect a rice plant through natural openings in a leaf or through wounds and will quickly spread throughout the plant through the veins (Jiang et al., 2020). In order for disease to occur, there must be an optimal environment, susceptible rice plants, and an aggressive pathogen. As of 2019, *Xoo* has been reported to be widely found in a majority of rice-growing regions across the globe (Naqvi, 2019). Thus, as global temperatures are expected to rise, more rice-producing areas may experience the optimal environment for *Xoo* growth, increasing the chance of disease.

The activity described below is designed to take place over a three-day period: 15 minutes on day 1; 40 minutes on day 2; and 60 minutes on day 3. We recommend this activity for smaller classrooms, averaging ~30 students (but we include some modifications for large classrooms below).

Learning Objectives

Students will collaborate to determine how a changing climate will impact agriculture in the context of plant pathology. Students should be able to

- engage in discussion and cooperation,
- interpret scientific data points and facts,
- collaborate in small groups to make an interconnected concept map, and
- synthesize information and discussion points to develop a solution.

Students should demonstrate knowledge of

- how climate change impacts plant systems,
- how environmental factors impact plant–pathogen interactions,
- how international affairs and decision making impact agriculture, and
- how information from different fields can address agricultural challenges through policy changes.

Materials

All of the following are available in the Supplemental Material (with the online version of this article).

Instructor's Food Security Specialist Card

The instructor will play the role of a global food security specialist that has asked the other specialists to meet to solve a global emergency. The instructor will present students with information to use in their problem solving and concept maps.

- *Food Security Specialist* – Expert in organizing and implementing a food security program through policies and procedures with local and international government agencies. Card will depict a graph showing the negative relationship between increased temperatures and rice yield (Figure 1). The instructor will present the graph to students when the Food Security Summit is introduced on day 1 of the activity.
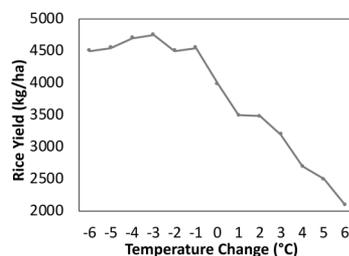

Figure 1. Instructor's food security specialist card. The instructor will play the role of a specialist and act as a mediator in the Food Security Summit scenario.

Specialty Group Identity Cards

Each specialty group card contains one of four possible specialty options along with the role each specialist will play (Figure 2), which should be distributed evenly throughout the class:
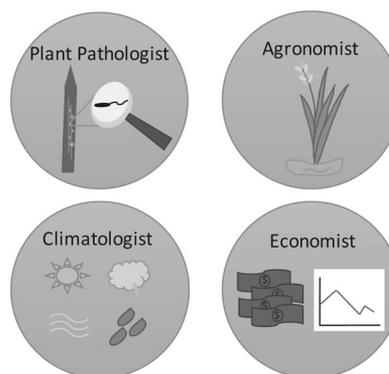

Figure 2. The four specialty group identity cards that will be assigned to students. Randomly assign students to a particular specialty. This will be the role they play in the Food Security Summit scenario.

- *Plant Pathologist* – expert on bacterial plant pathogens and plant defense responses
- *Climatologist* – expert on occurrences of tropical storms and factors contributing to changes in weather patterns
- *Agronomist* – expert on how to grow rice sustainably while also increasing grain production
- *Agricultural Economist* – expert on the monetary value of rice production and demand

Case Study Narrative

A case study narrative for each specialty group is provided (Figure 3). This case study will serve as background on how a similar agricultural issue has been solved; the example used will be the Hawaiian papaya ringspot virus epidemic. Each specialty group will have the same initial case study, presented from the perspective of their specialty and discussing how each specialty group contributed in responding to that epidemic.
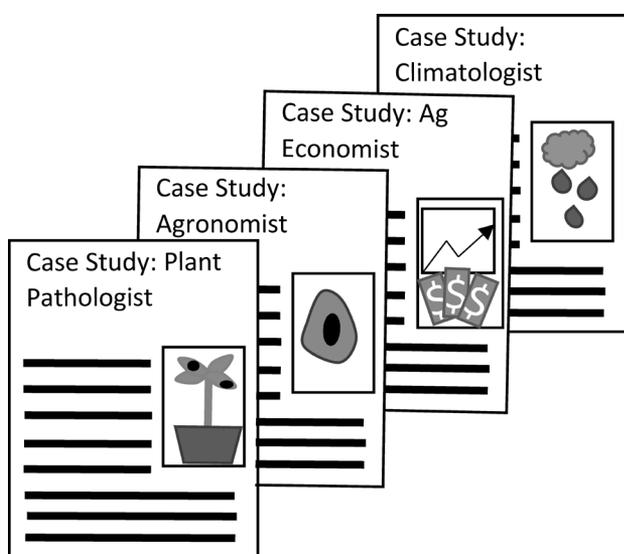

Figure 3. Examples of case study narrative for each specialty group. Each specialty will outline the Hawaiian papaya ringspot virus epidemic from the different specialty perspectives.

Specialty Group Data Cards

Data cards are to be distributed on day 2 of the lesson. These cards outline data points and facts relevant to the given scenario (effect of climate change on agriculture in context of plant pathology; Figure 4). Each specialty group has its own data cards.

- *Plant Pathologist* – has facts and data points to show increase in disease symptoms and counts from field data
- *Climatologist* – has facts and data points to show increase in tropical storm probability and temperature changes over the years
- *Agronomist* – has facts and data points to show decrease in rice growth/yield in response to increases in temperature
- *Agricultural Economist* – has facts and data points to show that increase in temperature leads to drops in yield and increase in production costs/loss of profitability due to drops in yield
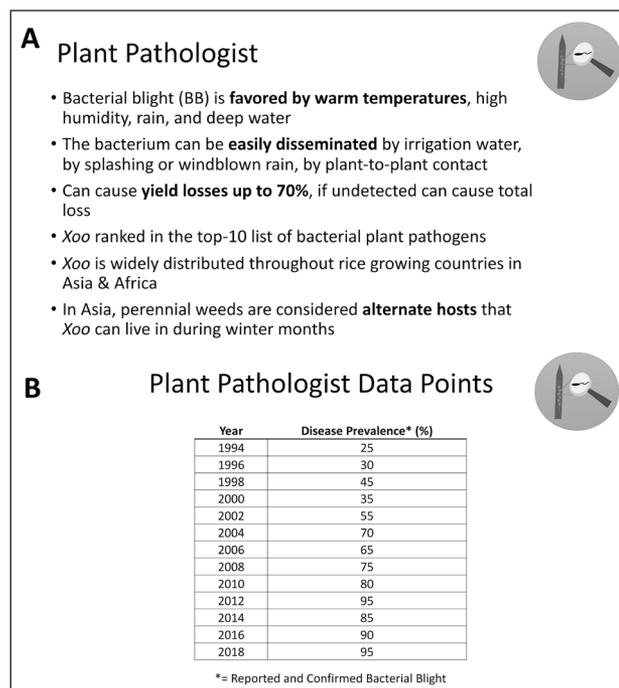

A Plant Pathologist

- Bacterial blight (BB) is **favored by warm temperatures**, high humidity, rain, and deep water
- The bacterium can be **easily disseminated** by irrigation water, by splashing or windblown rain, by plant-to-plant contact
- Can cause **yield losses up to 70%**, if undetected can cause total loss
- *Xoo* ranked in the top-10 list of bacterial plant pathogens
- *Xoo* is widely distributed throughout rice growing countries in Asia & Africa
- In Asia, perennial weeds are considered **alternate hosts** that *Xoo* can live in during winter months

B Plant Pathologist Data Points

Year	Disease Prevalence* (%)
1994	25
1996	30
1998	45
2000	35
2002	55
2004	70
2006	65
2008	75
2010	80
2012	95
2014	85
2016	90
2018	95

*= Reported and Confirmed Bacterial Blight

Figure 4. Example of a specialty group data card. Each specialty group will be given a data card with facts (**A**) and data points (**B**) specific to that specialty. Here is an example for the plant pathologist specialist group.

Concept Map Materials

Provide Post-It notes (7.6 × 7.6 cm) and Post-It note arrows along with large white self-stick chart paper (63.5 × 76.2 cm) for students to create easily edited concept maps for days 2 and 3 (Figure 5).

○ Game Play Specifics

Day 1: Introduction

The first day will require about 15 minutes of class time. The instructor should distribute specialty group identity cards equally throughout the class (i.e., in a class of 20, the instructor should provide five cards of each specialty). Each student must randomly choose a card from the stack of cards to determine specialty positions. Alternatively, students can choose a number from 1 to 4 and the instructor can randomly assign each number with one specialty group. After specialty groups are determined, each student will be assigned the case study narrative (about the papaya ringspot virus epidemic) corresponding to their specialty.

Assessment: Students will read the case study narrative as homework and summarize how their assigned specialty group helped solve the agricultural problem presented in the papaya ringspot virus case study. Instructors can provide the case study narrative either through an online management system or as a hard copy for students.

Day 2: Specialist Group Summit

Goal: Student groups understand how their specialty group impacted agriculture for the current rice yield issue from their specialty lens.
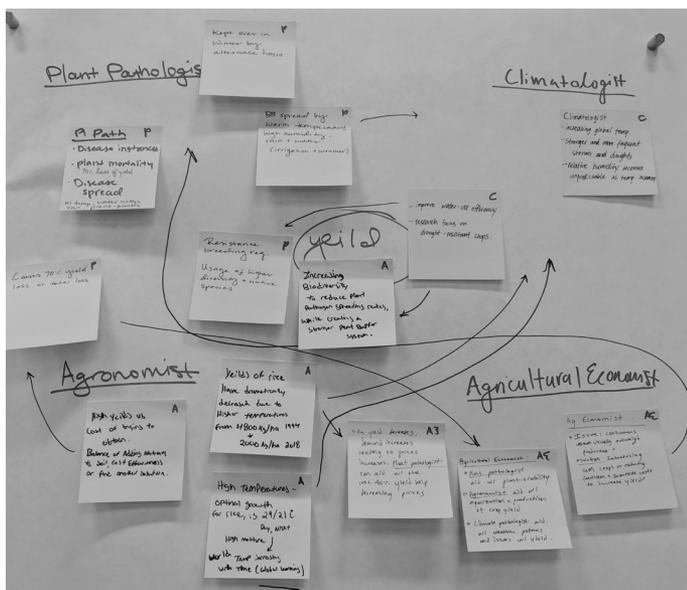
Figure 5. Example of a completed interconnected concept map by students. Providing Post-It notes for students allows the concept map to be more easily modified.

1. Allow students to brainstorm (about 3–5 minutes). Instruct students to write down their thoughts incorporating what they have learned from the papaya case study and previous classroom knowledge regarding the relationships between climate change, agriculture, and plant disease.

• Ask students: How would you define climate change? What are some factors that can affect climate change? Do plants get sick? What factors do you think affect a plant's health?

2. Introduce the activity. Introduce the example of rice production in the Philippines, bacterial disease of rice, and the IRRI. To help with introduction, a video can be used to introduce the importance of rice and/or plant bacterial disease. For example, the IRRI video "Rice Is Life in Asia" could be used (about five minutes long).

3. Introduce food security specialist role and the Food Security Summit to which the students have been invited.

• Teacher introduction: "Welcome and thank you for meeting with us today, especially on such short notice! You have all been asked here today because of your help and expertise during the Hawaiian papaya ringspot virus incident. My name is _____ and I am a food security specialist working with the International Rice Research Institute. I have invited you all to meet here today because you are the top in your field and I would like to ask for your expertise, again, in helping us today. As a food security specialist, I study and anticipate when catastrophic food security events may occur and aim to stop this from happening. Recently, it has come to my attention that we are seeing more disease outbreaks in rice paddies in the Philippines and a decrease in rice yields. I fear that if rice yields continue to decrease this rapidly and we do not find a sustainable solution soon, countries that rely heavily on rice as a staple crop will be in danger of not being able to feed their people. As such,

I hope that through collaboration of all your expertise we can identify the reasons for why we are seeing increased disease in rice production in the Philippines and come up with solutions to solve this problem!"

4. Pass out specialty data cards to students based on the previously assigned specialties (~20 minutes). Ask students to take a moment to review their specialty cards. Designate different portions of the room for different specialty groups, then ask students to separate into specialty groups. Allow students to work together in their specialty groups to outline cause-and-effect relationships from the central idea of decreased rice yield. Information provided by students can be based on specialty group data card, previous knowledge, and/or assigned reading.

• Ask students: How does your specialty research impact rice yield in the Philippines? What factors have your specialty group identified that are contributing to the decrease in rice yield in the Philippines?

• Ask students to think in terms of cause and effect when interpreting their specialty research data points and facts.

• Ask student groups to develop a concept map for how their specialty is impacting rice production in the Philippines (i.e., the climatologist student group could correlate that increased temperature leads to lower yields). Provide students with an example for how to start a concept map (Figure 6).

Assessment: Ask students to list the factors that their specialty group decided on when creating a concept map. Then ask them to number these factors in order of importance to rice production in the Philippines (the greater the importance, the higher on the list). Inform students that they should bring this write-up for day 3.

Day 3: Food Security Summit

Goal: Student groups connect how changes in climate are impacting agriculture in the context of plant pathology, with specialty groups working together and sharing their knowledge to come up with a solution (i.e., determine possible policy solutions).

1. Interconnected concept maps (~30 minutes): Randomly split up students into new student groups composed of a minimum of one student specialist per group (four students total). For large classrooms, the maximum number of students per type of specialist should be two (eight students total per group).

• Allow each student to introduce their field of expertise or specialty. Then ask each student to describe the cause-and-effect relationships their specialty group outlined to the new group. Specialists in each group should have their assessment from day 2, which outlines, based on their specialty, the factors important to rice production in the Philippines.

• Ask student groups to create a concept map incorporating information from each "specialist" in relation to how this could be leading to a decrease in rice yield (Figure 7).

• Once student groups have created an interconnected concept map linking how each specialty impacts rice production, ask these groups to come up with a possible solution to stop this food security crisis. Ask students to write this separately from the concept map.
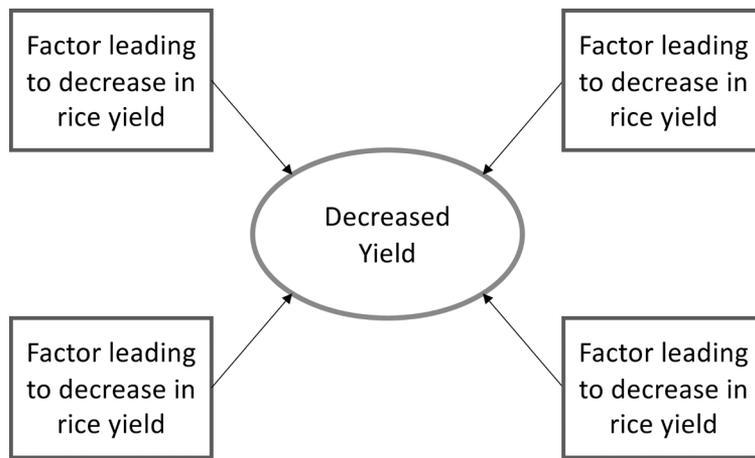
Figure 6. Example of how to start a concept map. After students have been separated into specialty groups, students will have to decide what factors most impact decreased yield from their specialty cards.
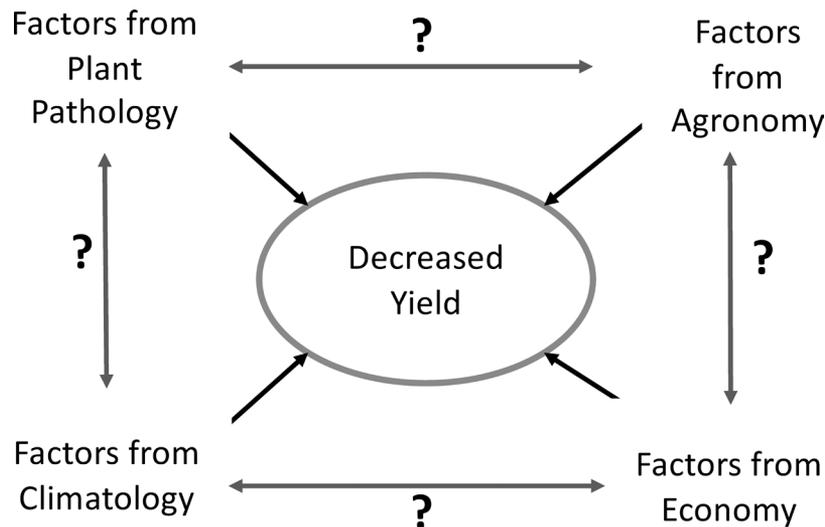

Figure 7. Example of how to form an interconnected concept map. Have students first determine which factors from each specialty group contribute to loss of rice yield, and second how these different factors interact between specialty groups. The model will help students conceptualize and visualize the purpose of the exercise.

2. Compare concept maps: Once all groups have completed the concept map, display the maps in the classroom and allow student groups to walk around to compare the different versions created.

3. Have a class discussion (~30 minutes) comparing and contrasting the interconnected concept maps. Prompt students to explore the importance of addressing the crisis and finding solutions.

• Ask students: How are environmental factors impacting the *Xoo* infection in rice? How is global climate change impacting rice production in the Philippines? Are there any ways we can reduce these expected negative impacts on agricultural systems? What are other aspects that we should be focusing on or considering? Why should we care about an epidemic that is happening in another country?

• Have each group propose a solution to the Philippines rice bacterial blight issue. As a class, determine pros/cons to each solution proposed. As a class, vote on the top two best (most feasible and thought-out) policy solutions.

Assessment: Assign students to write a brief paper, maximum one page, summarizing what they learned from the lesson and explaining the policy solution(s) their student group came up with during the class exercise and discussion.

○ **Discussion**

Here we have described an active-learning and peer-learning lesson plan that strives to teach students how to interpret and synthesize data from multiple disciplines to develop solutions to large

problems. Throughout this exercise, students will learn that collaboration and data interpretation are key for developing a feasible solution to the proposed problem. By using an agricultural pathosystem, we aim to inform students how environmental conditions can impact economically important plant systems, the role scientists and experts play in policy making, and how international affairs are important for maintaining global food security.

This lesson plan was implemented in an upper-level plant physiology college laboratory course, and 35% of students (7 out of 20) reported coming into the exercise with deep prior knowledge of interactions between environmental or biotic stressors on plants. However, among students that came in with very little to some understanding, there was an 85% increase (11 of 13 students) in understanding these interactions after completing the exercise. As a result, the student groups developed multiple feasible policy changes to address the *Xoo*–rice scenario, including increasing biodiversity in rice fields, improving water management, and producing drought-tolerant rice to limit *Xoo* spread. Students also proposed improving international agricultural trade so that people can rely on rice production from various areas.

This activity can be applied to have students address issues across various fields. In an ecology course, the question of conservation of species can be addressed by using this model and synthesizing information from ecologists, conservationists, climatologists, and wildlife organizations. Similarly, in a sociology course, students could ask how communities most impacted by climate change can adapt to sustain their livelihoods. Data can be interpreted by sociologists, economists, climatologists, and social workers. In any iteration of this model, the learning objectives of collaborative learning to interpret data and produce a solution are essential to addressing major questions affecting different fields in the context of climate change. Overall, this activity is an active-learning exercise designed to allow students not only to interpret data, but to develop a solution to the proposed problem through collaboration.

○ Supplemental Material

- Materials PDF includes Specialty Group Identity Cards, Specialty Group Data Cards, Instructor Cards
- Case Study Narratives PDF (note: in-text citations removed for easier student reading)
- Instructor Notes PDF

Acknowledgments

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