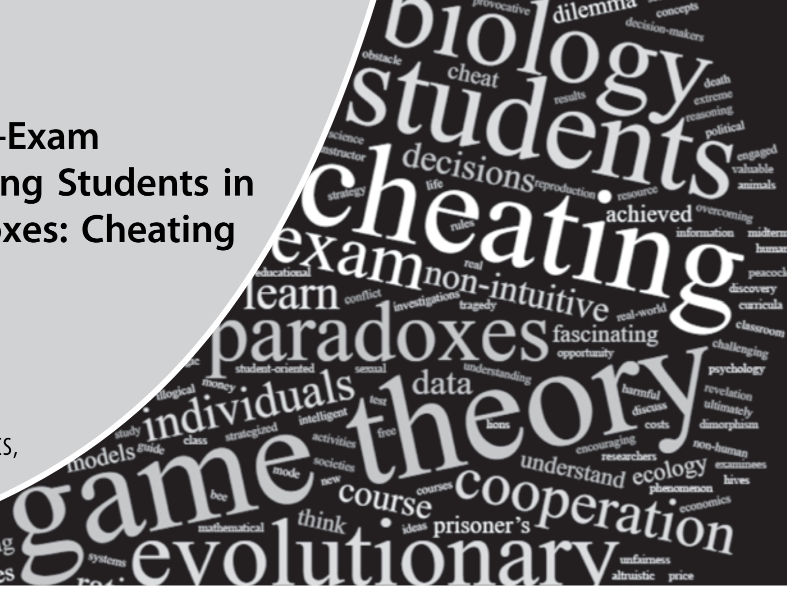
Evaluating an Open-Exam Approach to Engaging Students in Evolutionary Paradoxes: Cheating to Learn



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Abstract

Game theory is used in biology to understand why otherwise rational individuals make nonintuitive decisions regarding cooperation and competition. Recently, biology teachers engaged their students in game theory curricula by presenting them with a real-world game theory challenge: the opportunity to cheat on a game theory exam. Here we present a guide for other teachers to employ this provocative and educational classroom exercise, and discuss the results of the Cheating to Learn exercise in a biology class.

Key Words: *game theory; prisoner's dilemma; cooperation; cheating; evolutionary stable strategy; exam.*

○ Introduction

Nonintuitive concepts and puzzles of logic commonly found in evolutionary biology can be challenging to teach, but fascinating once learned. Such new ways of understanding need not be obstacles for students, but instead can be rewarding investigations into how we think about the things we think about. One such mode popular in biology—but also psychology, economics, political and computer science, and even poker (Chabris, 2013)—is game theory. Game theory is the study of mathematical models of conflict and cooperation between intelligent, rational decision makers. It is used in biology to understand why otherwise rational individuals make nonintuitive decisions regarding cooperation and competition (Alcock, 2013, p. 522). Game theory models include prisoner's dilemma (Axelrod & Hamilton, 1981), hawk-dove (Maynard-Smith & Price 1973), and tragedy of the commons (Loyd, 1833, p. 75; Hardin, 1968). Through these examples, students learn that cooperation in biological systems is not the norm, but instead must be achieved by overcoming the immediate costs to individuals involved.

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Evolutionary biology, in particular, is punctuated with the discovery and revelation of paradoxes—phenomena that, despite apparently sound reasoning, lead to a conclusion that seems senseless or illogical. Examples in nonhuman animals include extreme sexual dimorphism in peacock feathers (Trivers, 1972), infanticide by male lions (Hrdy, 1979), or individuals forgoing their own reproduction to help relatives, such as in bee hives (Hamilton, 1964). Paradoxes observed in human societies include the prevalence of ultimately harmful behaviors (e.g., over-eating or drinking) and apparently altruistic acts ranging from donations of time and money to risking death to save another. Often, students view such evolutionary paradoxes like the researchers before them—first as an obstacle, second as a fascination. Getting students past their initial apprehension about these paradoxes can be achieved through activities in which students make important decisions based on game theory.

In 2013, Dr. Peter Nonacs, with the assistance of teaching assistant Dr. Kenneth Chapin, conscripted students of the course Behavioral Ecology (EEB126, UCLA, 4 credits) to apply game theory ideas to real life by encouraging them to cheat on a midterm exam, of which game theory was the primary topic (Nonacs, 2013). Students were allowed to break all the rules of a traditional exam. Examinees were free to glean information from each other or any other resource, including the instructor, during the exam. In 2016, Dr. Loren Hayes employed Dr. Nonacs' idea while collecting data on how students taking his Behavioral Ecology course (Biol 4999/5999, University of Tennessee at Chattanooga, 4 credits) strategized for, and learned from, this

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exercise. Our aim in collecting these data was student-oriented; we aimed to examine if the Cheating to Learn approach burdened students with excess test anxiety or a sense of unfairness. Here, we describe Dr. Nonacs' approach, and provide data via Dr. Hayes course, to offer Cheating to Learn as a valuable exercise for teaching game theory and evolutionary paradoxes in university biology courses.

○ Application to the Curriculum

The critical thinking skills developed in this activity are broadly applicable to college and university courses such as animal behavior and evolutionary biology, but also any course in which game theory is a topic.

○ Objective, Challenge, Activities, & Rules

Objective

Students learn game theory principles while taking an exam in which they engage in game theory strategies by cooperating (working in groups) or defecting (working alone). From this perspective, a variety of game theory models can emerge from student interactions, including prisoner's dilemma, hawk-dove, and tragedy of the commons.

Challenge

Earn the best possible score on an exam.

Activities and Rules

One week prior to the exam, the instructor informed the students of the Cheating to Learn exam format. The instructor's description was purposefully vague, but conveyed that the exam would be hard, novel, and that the students could cheat. A sample statement:

> *The exam is going to be extremely hard and nothing like you have experienced in the past. I am going to allow you to CHEAT on the next exam. (pause for effect) You can work together, use resources including the internet, or ask others for advice. I do not care how you arrive at you answers, so long as you demonstrate an understanding of the material. Again, you can cheat. (pause for effect) The only rule is that you cannot break state or federal law.*

The instructor allowed for some time in class for students to discuss the exam. This step was important because students speculated on the content of the exam and how it would be graded, and planned their test-preparation and test-taking strategies. In this way, most students were making decisions based on game theory models.

On the day of the exam, students were given the entire class period (75 minutes) to complete a one-question exam to assess their understanding of game theory:

> *If evolution through Natural Selection is a game, what are the players, teams, rules, objectives, and outcomes? Please define terms and use examples from lecture, readings, and discussion to support your arguments.*

○ Data Collection

Prior to the exam, students learned the costs and benefits of different types of social organization (size, composition) and social structure (types of interactions among group members; Kappeler & van Schaik, 2002). Additionally, they participated in a prisoner's dilemma game (Morgan, 2003) and follow-up discussion aimed at increasing their understanding of how social factors (relatedness, familiarity, reciprocity) and costs and benefits affect decision making, such as cooperating or defecting.

Hayes' Biology 4999/5999 class consisted of 16 students. The class was strongly female biased (15 females: 1 male) and consisted of 14 undergraduate (4 juniors, 12 seniors) and 2 Masters students. During the exam period, the instructor collected data on the behavior of students and the types of nodes (one or more students working together as a unit; Wey et al., 2008) that formed. To index social organization, the instructor determined group size as well as the academic standing (index of status), and whether individuals were members of his research laboratory group (n = 4 students; index of relatedness). To index familiarity of group members, the instructor recorded the proximity of students in the lecture room (number of students per group within one chair of each other) and the laboratory working groups (4 groups of 4 students each) to which students belonged. This information was not analyzed statistically (because of small sample sizes). Rather, we used the information for discussion of factors that may contribute to seemingly altruistic behavior between students.

○ Analysis and Assessment

We used a Wilcoxon test to determine if there were significant differences between scores on the previous exam with traditional format and on the Cheating to Learn exam. To assess the variability differed between these exams, we calculated the coefficient of variation for both exams and compared variance with an F-test. Other statistical tests were not possible because of small sample sizes.

The students were asked to complete a short survey consisting of three quantitative and several qualitative questions. Quantitative questions addressed the effectiveness of the activity as well as the anxiety of students, both when informed about the exam format and during the exam, and were based on a 1–7 scale (1 = lowest, 7 = highest). The authors did not see the results of the survey until after final course grades were made available to students.

○ Outcomes

During the exam, the students (n = 16) initially formed eight nodes, including 4 groups (2–5 students per group), 2 singletons, and 2 singletons that later fused into a single group, resulting in seven total nodes. We examined these node types, including changes in type. The composition of nodes and instructor observations are shown in Table 1.

○ Analysis and Assessment

Compared to a prior traditional exam, Cheating to Learn exam scores improved for nine students, were the same for one student,

Table 1. Characteristics of student nodes during the Cheating to Learn review session and exam. Node size is the number of students per node.

Node size	Composition	Strategies during review and exam	Mean grade
2	Undergrads	Review: One worked alone, other was absent Exam: Some communication, partial independence	78
2	Grad	Review: Worked together Exam: Extended interactions, planning essay	85
5	Undergrads	Review: 4 from same group, 1 absent Exam: Left room, worked in student lounge	85
1	Undergrad	Review: Worked with other students Exam: Worked alone with earbuds in	90
3	Undergrads	Review: Same as exam node Exam: Worked in room, moved to hallway	92
1 or 2	Undergrads	Review: Did not work together Exam: Worked alone initially; one student sought input from an Evolution professor	80
1	Undergrad	Review: Worked alone Exam: Worked alone in room initially; left room and moved next to 3-person node	80

and decreased for six students. There was not a statistically significant difference in scores between the traditional exam (82.1% ± 2.3) and the Cheating to Learn exam (84.9% ± 1.2; Wilcoxon signed rank test: Z = -0.71, P = 0.48). We conclude that this approach is at least comparable to a tradition exam. The Cheating to Learn exam was less variable (coefficient of variation = 5.9; range: 78–95) than the prior traditional exam (coefficient of variation = 11.3; range: 67.5–95; F_{15} = 3.47, P = 0.021), likely a result of student cooperation. Working alone (n = 2, 85.0 ± 5.0), in groups (n = 12, 85.7 ± 1.4), or changed strategies (n = 2, 80.0 ± 0.0) had a minimal impact on the exam grade.

Students taking the survey (14/16) identified with the following majors: (a) BS, Biology/Pre-Professional track—6, (b) BS Biology/General—5, (c) BS Environmental Science—1, and (d) MS Environmental Science—2. We could not analyze statistically how academic status influenced student perceptions and anxiety levels because of the small sample sizes, and so provide qualitative and descriptive results instead. Overall, students rated Cheating to Learn as an effective teaching activity on a 1–7 scale (5.9 ± 0.3, range: 2–7). Seniors (n = 6) rated the activity the highest (6.1 ± 0.64, range: 5–7) and juniors (n = 4) the lowest (5.3 ± 2.2, range = 2–7). Masters students rated the activity a 5 or 7.

Students reported moderate levels of anxiety when informed of the exam format (3.9 ± 0.5, range: 1–7) and during the exam (4.2 ± 0.4, range: 2–7). Juniors (mean change = +1.8) and Masters (mean change = +4.5) expressed the greatest increase in anxiety, whereas seniors expressed a decrease in anxiety levels (mean change = -1.5). These data suggest that stress or anxiety as a consequence of the Cheating to Learn approach differs between students of different academic status, though we would need larger sample samples to test the null hypothesis. Answers to qualitative questions indicated that students preferred to work in groups because of perceived differences in intellectual ability and potential to produce the strongest answers. Students working alone expressed a preference for working independently.

○ Additional Activities

Review Session

An effective strategy is to hold a review session in which students work together to solve challenge problems. Correct answers can be rewarded with hints about the exam, some of which may require the students to practice game theory. For example, during a review session by Dr. Hayes, some students were given the option of receiving "three points for yourself or one point for you and everyone else on the exam." These students were instructed that they should not inform other students in the class about this reward prior to their decision. Students earning this reward chose to take the maximum number of points for themselves at the expense of the other students taking the class. The primary reason for this decision was concern for one's own grade. Numerous students who did not receive this reward indicated that they, too, would have chosen the selfish option. The aim of this exercise was to generate discussion about game theory prior to the exam. Thus, no one received additional points—a decision made so that some students would not go into the exam feeling at a disadvantage to others.

Instructors should allow students flexibility to work in groups or alone during the review session. During the review session, instructors should collect data on the number and composition of nodes for comparison with nodes formed during the exam and post-examination discussion.

Class Discussion

Class discussion is a vital to the success of Cheating to Learn. Through discussion, students will understand that they were playing a game and how Cheating to Learn relates to evolutionary theory. Topics for discussion include:

- **Decision making and the game:** Students should have an understanding how game currencies and outcomes relate to evolutionary biology. Currencies include the costs and benefits of game theory strategies. Game-related benefits such as shared resources or writing of exam answers are analogous to increased food intake in cooperatively hunting predators (Creel & Creel, 1995) or information sharing in colonial birds (Ward & Zahavi, 1973). Game-related costs such as unequal effort or stealing of ideas by some students are analogous to costs such as kleptoparasitism (Wood et al., 2015) or territorial resource contests (Chapin & Hill-Lindsay, 2016). Discussion can also focus on how strategies are motivated by the perceived effect of the game outcome (grades) on long-term fitness (e.g., acceptance into graduate or professional schools).
- **Individual contributions to the group:** In some groups, there may be considerable equity in data collecting, intellectual contribution, and writing. In other groups, there will be inequality in effort, with some groups exhibiting clear divisions of labor. Such variation is expected given the diversity of social strategies in animals. The focus of Hayes' post-examination discussion was on why individuals formed groups and sources of anxiety. Additionally, students can discuss how their groups compared to social species with division of labor (eusocial insects: Andersson, 1984; naked mole rats: Jarvis, 1981) and "egalitarianism" (lions: Packer et al., 2001). Additionally, discussion can focus on the types interactions among students (e.g., cooperation, arguing, scrounging) and the specific tasks of individuals (e.g., discussion leader, data collector, scribe) within nodes and how these behaviors relate to other species.
- **Evolution of altruism:** Altruism is a behavior in which individuals provide a resource to other individuals at a cost to themselves. On the surface, such acts contract evolutionary theory leading to one of the most challenging paradoxes in science: "Why do animals behave altruistically?" (Pennisi, 2005). Cheating to Learn provides a framework for discussing the theory of the evolution of altruism, including kin selection (Hamilton, 1964) and reciprocity (Trivers, 1972). In this discussion, students can identify the means by which individuals select recipients of altruism, including familiarity (Keller & Reeve, 1998), green beard preferences (i.e., preference for individuals with similar phenotypes; Dawkins, 1976, p. 368), and relatedness. In Dr. Hayes' class, students discussed how relatedness (Hayes lab members) and familiarity (lab working groups, proximity in the classroom) influenced the formation of nodes and decision making. Additional discussion focused on how developmental conditions (Ryan & Vandenbergh, 2002) and epigenetic effects (Ledón-Rettig et al., 2013) influence personality (Chapin, 2015) and behavior. These types of discussions would inform students of emerging theory while promoting discussion of how biology influences human behavior.

○ Cheating to Learn, Game Theory Models, and Application

Students should understand how the game they played relates to commonly used game theory models and modern events. One such model, the prisoner's dilemma (Axelrod & Hamilton, 1981), is used in biology to describe the paradox of cooperative behavior. Like most game theory models, the prisoner's dilemma is represented as a series of outcomes with varying costs and benefits depending on the actions of two opponents. Opponents, or players of the game, can choose to either cooperate (C) or defect (D). The prisoner's dilemma model follows a payoff scale such that $C_C > D_D > C_D = D_C$ (in which subscripts are opponent actions). Thus, cooperate-cooperate at first seems to have the highest payoff. However, if the initial player's benefits are maximized while second player is ignored, then $D_C > D_D > C_C > C_D$ occurs, such that defect-cooperate is the highest payoff for the initial player. The model illustrates that players, who should behave in their own interests, should never cooperate with opponents. The prisoner's dilemma model is widely applicable to evolutionary biology (e.g., why cooperate?) and issues such as the failure of nations to cooperate on global issues (e.g., climate change) or drug addiction in humans (in which the players are current and future selves). In class, students may try glean information from other students without reciprocating (D_C). This is the optimal strategy, but social interaction might encourage cooperation (C_C) instead.

In the hawk-dove model (also called snowdrift), optimal strategy depends on the choices of the opponent. The hawk-dove model is expressed as $C_C \geq C_D = D_C > D_D$ from the perspective of both opponents summed, but $C_D = D_C > C_D > D_D$ from the perspective of one player. A classic example is when two people accidentally drive into, and become stuck in, a snowdrift while driving a car. If both people stay in the car (both defect), they will die in the cold. If one person gets out to dig out the car, the other person should stay in the warm car instead of enduring the cold to help (if opponent cooperates, defect). If, however, one person refuses to leave the car, then the other should dig to prevent death (if opponent defects, cooperate). In class, students might help complete the exam, despite others not reciprocating (C_D) to earn the highest grade, despite—but to the benefit of—their classmates. Alternatively, students might cooperate (C_C) even though is a suboptimal strategy.

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