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CourseSource

Lesson

Life is Just a Game: An Active Learning Activity to Teach Life History Evolution

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Abstract

A novel activity was designed to introduce students to the concepts of natural selection and life history using an active-learning, constructivist format. It consisted of two parts: 1) a brief introduction to the basic mechanism of natural selection, and 2) a game that introduces life-history strategies. The activity was designed for use in the college classroom. It was shown to be an effective means of fostering a deep and transferrable conceptual understanding of the principles of natural selection specifically through the lens of life-history strategies. The activity is available in the supporting materials. It takes approximately one 50-minute period to complete.

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Supporting Materials: Supporting Files S1. Life History – Quizzes; S2. Life History – Presentation; and S3. Life History – Life History Game with Instructions.

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Learning Goal(s)

Students will:

- know the basic mechanism of natural selection.
- understand how natural selection drives changes in the life histories of organisms.
- know the basic tradeoffs that shape life histories (growth vs somatic maintenance vs reproduction, timing of maturity, terminal investment).

Learning Objective(s)

Students will be able to:

- explain how natural selection acts on existing variation and predict how subsets of the existing variation can become more or less common in a population over multiple generations.
- formulate plausible hypotheses regarding how the variation of a population will change based on provided environmental conditions.
- make reasonable predictions regarding how different environmental conditions (particularly high and low levels of extrinsic mortality) are likely to alter the life histories (age and size at maturity, timing of terminal investment).

INTRODUCTION

Natural selection is frequently taught to students in terms of traits that increase the survival of individuals as though survival was a direct surrogate for fitness. However, the fitness of an organism is determined not by survival, but by the number of copies of its genes that are passed to the next generation. Thus, lifespan is, in many instances, of less importance than the absolute number of offspring an organism can produce over the course of its lifetime. Reproductive success is the very currency of evolution. Counterintuitively, many organisms pass large portions of their lives without reproducing at all. Some reproduce many times (iteroparous) while others reproduce only once before death (semelparous). One may wonder why delayed reproduction would persist, or why an organism would reproduce a single time when multiple attempts are possible. Though much is understood by the scientific community regarding these questions, those answers are not always immediately clear for students or even instructors because they do not have a solid understanding of life history theory and how much evolution explains about the world around us beyond the evolution of traits related specifically to the survival of individuals.

Life history theory explains how organisms budget available energy to competing demands over the course of their lifetimes to maximize their total lifetime reproductive success (1). Available energy is often limiting to organisms. The primary energetic demands for organisms are growth, somatic maintenance, and reproduction, that are collectively known as life history components (2).

- **Growth** is the energy invested in increasing in body size. Body size can be very important as body size can be limiting to the size or number of offspring that can be produced at a given time, or the likelihood of attaining opportunities to mate.
- **Somatic maintenance** is essentially upkeep of the body. If an organism does not maintain the soma (body) it may die prematurely and not have as many opportunities to reproduce.
- **Reproduction** is energy put into forming offspring, including energy spent finding a mate and energy invested in the form of parental care.

Each life history component is very important to an organism and necessary if an organism is to produce viable offspring (have fitness). However, where energy is limited, it is impossible for an organism to invest maximally into all three competing demands simultaneously (1). For an organism to increase investment into any individual life history component, it must withhold resources from another (a tradeoff).

How much an organism invests into any one component may vary over the course of its lifetime, and natural selection favors strategies that produce the maximum number of viable offspring during the lifetime of an organism given the circumstances in which they live (2). For example, humans spend the first several years of life investing heavily in growth and somatic maintenance with little investment in reproduction. With the onset of puberty, they begin to transition away from growth and into reproduction. As adults, they invest primarily in reproduction and somatic maintenance with little if any investment in growth. Humans tend to reproduce multiple times over the course of their lifetimes and generally postpone reproduction until the growth phase of life is completed or nearly completed (3). Similarly, pacific salmon begin life in freshwater lakes and rivers, journey to the energy-rich ocean where they increase in size (investing exclusively into growth and somatic maintenance), and become many thousands of times larger than they were when they started life. However, after completing the growth phase of their lives, they return to the same waters where they hatched to spawn a single time and die (4). The differences in optimal strategy are due to differences in the environments in which they are found. Guppies from areas of high extrinsic risk (i.e., predation, harsh climate) begin reproducing at younger ages and subsequently smaller sizes (unless increased mortality of competitors results in increased per-capita energy availability allowing for more rapid growth) than those from areas of low extrinsic risk (5). Reproducing at a smaller size comes at a cost to the number of offspring that can be produced since large fish can produce more offspring than small fish. However, a large body size takes time to attain - increasing the chance of death before reproducing. If life expectancy is short, individuals that wait to reproduce until they are large are more likely to die without reproducing, whereas those that mature earlier, at a smaller size, are more likely to reproduce. Conversely, if life expectancy is long and one begins reproduction at a young age, the investment into early reproduction will necessarily come at the expense of either growth, somatic maintenance, or both, making large size and/or survival more difficult to attain when compared to those that delay the onset of reproduction even if they survive for a long time.

As we can see, an understanding of life history can contribute greatly to an overall understanding of behavior and evolution as differential reproduction is, in essence, the driver of all evolutionary processes. Cherrett (6) surveyed all members of the British Ecological Society and identified the 50 most important ecological concepts. Life history strategy was 9th on that list. However, life history theory is often overlooked, as it can appear to be somewhat less intuitive to both students and teachers. In fact, in a survey of several popular non-majors introductory biology texts, a discussion of life history strategies is noticeably absent (e.g., Belk & Maier's *Biology: Science for Life*, Simon's *Biology: The Core*, Krogh's *Biology: A Guide to the Natural World*, Shuster's *Biology for a Changing World*, and Bozzone & Green's *Biology for the Informed Citizen*). Lesson ideas for effectively teaching life history are also noticeably absent from the literature. To fill this void, we developed and tested an activity that will teach the basic principles of life history evolution within the confines of a single, 50-minute, class period.

Intended Audience

This activity has been tested, and shown to be effective, in first-year university biology for non-biology majors at a large research university. It has also been conducted in upper-division and graduate-level university classes for biology majors with apparent success (though no official data were collected).

Required Learning Time

The activity is broken into two parts: 1) The mechanism of natural selection, and 2) The life history game. You may choose to jump directly to part 2 and run just the game if you have previously covered the mechanism of natural selection. The game can be run in approximately 30 minutes. The activity in its entirety takes approximately one 50-minute class period or could be split into two periods of about 25 minutes.

Prerequisite Student Knowledge

This activity is designed so that people with little to no prior knowledge of biology or evolution can understand it and apply it, particularly in the context of life history. For students with a prior understanding of fitness and natural selection, it may be possible to forego Part 1 of the activity and conduct Part 2 independently.

Prerequisite Teacher Knowledge

To present this activity, instructors must possess a solid understanding of natural selection and how natural selection can act on existing genetic variation to increase or decrease the prevalence of a given attribute based on how that attribute alters the ability of organisms to successfully pass on their genes to future generations. Gregory (7) provides an excellent description for any instructors that feel that their understanding of natural selection may be lacking. Instructors must understand some of the fundamental tradeoffs of life history evolution. They must understand the allocation tradeoff between growth, somatic maintenance, and reproduction. They must understand the tradeoff between maturing early at a small size and maturing late at a large size. They must understand how the environment may influence how these tradeoffs will be balanced. Finally, the instructor must be comfortable conducting a discussion with their students, and engaging them in a dialogue, about this material. A basic description of these principles was included in the Introduction to this paper and can be reviewed before instruction.

SCIENTIFIC TEACHING THEMES

Active Learning

The following activities are designed to be utilized in a highly active classroom. We chose to make this an active learning activity as active learning is correlated with increased exam performance and increased likelihood of passing courses when utilized in STEM (8). In this activity, the students are active participants as they are continuously asked to discuss the examples being presented by routinely utilizing think-pair-share and whole-class discussion. All definitions to be given during this activity should first be discovered through group discussion and then formalized by the instructor. This activity gives students opportunities to examine real environmental factors and make informed predictions about the outcomes. It also allows them to actively participate in a game that will generate the variation of life history strategies that will be the springboard for a discussion of life history in general.

Assessment

To test the effectiveness of the activities on actual learning gains, we created five pairs of questions with a pair of questions testing five different principles. The first question pair tested students' understanding of the impact of predation on the age at which organisms mature and begin reproduction in different predation environments, which was not explicitly discussed during the activity. The second pair of questions tested students' understanding of the fundamental life history tradeoffs and how energy investment changes over time. These tradeoffs were never discussed but experienced as students completed the activity. The third pair of questions tested students' understanding of the mechanisms of natural selection as explained in the activity. The fourth pair tested students' understanding of terminal investment also as explained in the activity. The final pair tested students' ability to determine which of two life history strategies would be most successful in each environment as depicted by a graph making this both a test of conceptual understanding as well as a student's ability to interpret a graph. Each question pair was divided and assigned at random to one of two quizzes generating two parallel quizzes, version A and version B, to be utilized as pre-quizzes and post-quizzes (Supporting File S1. Life History – Quizzes).

Before beginning the activity, all students (n=100) were given a quiz. The version of the quiz (A or B) given to each student was assigned randomly. After pre-quizzes were collected, we administered the activity. Following the activity, the students were given the alternative version of the quiz (i.e., if they took version A as a pre-quiz, they took version B as a post-quiz and vice versa). This practice attempted to eliminate any possible test-retest effects, especially considering that the pre-quizzes and post-quizzes were given in such close temporal proximity. In addition, because half of the students took version A as a pre-quiz and half took version B as a pre-quiz, we hoped to control for any differences in performance due to unintended discrepancies in quiz difficulty.

To analyze the quiz data, collected quizzes were scored based on whether the student selected a correct or incorrect answer. Because surveys were anonymous (due to IRB constraints), it was not possible to match pre-quizzes with post-quizzes for each student. Thus, our pre-quiz condition was treated as an independent sample from our post-quiz condition. We therefore analyzed the data only in terms of comparing mean pre and post scores and the mean for the individual questions, and not via the paired samples t-test that would have been utilized had the quizzes not been anonymous.

Inclusive Teaching

These activities are designed to engage all students in the class to actively participate in both discussion and the activities. Because all students are actively engaged in the learning process, discussing their observations and thoughts in pairs, all students in the classroom will have opportunities to engage with and discuss the material, and the instructor can circulate and converse with students one-on-one and in small groups to ensure that all members of the class are included in the lesson and understand.

LESSON PLAN

Part 1. Introducing Natural Selection

Genetic variation is the raw material upon which natural selection acts. The following illustrates a mechanism by which to introduce this concept.

If possible, bring in multiple animals of the same species (e.g., goldfish, mice, garter snakes, geckos, insects). The key is that these individuals should have noticeable phenotypic variation. Pictures can also work if real animals are not available. Ask students to look for differences and come up with hypotheses to explain these differences (e.g., where they think each one would be most successful in its environment). This will illustrate not only the concept of variation but will also allow students to begin thinking about the importance of the environment in determining which traits will be favored, and thus maintained, in the population. After discussing this first example of variation, show a few images depicting other examples of variation. Utilize conspicuous phenotypic variation as much as possible. Humans, gray wolves, and flowers make excellent examples. Seek a working definition of variation from the class. The key is that the class understands that variation involves differences among organisms and that such differences exist. For an example presentation see (Supporting File S2. Life History – Presentation).

To illustrate the concept of natural selection, utilize the example of the peppered moth. Start by showing a photograph of a European robin or other insectivorous bird. Ask the students how birds look for their prey (by quickly scanning with quick, jerky movements). Inform the class that they are now European robins and that they are looking for a meal. Quickly scan through the images of several similar, light colored trees. Among the pictures, display one light-colored tree with both a light colored and dark colored moth on it. The trick is to scan through these pictures quickly enough that students are not able to fully focus on each picture, thus imitating the motions of a bird. Ask the class if they saw anything to eat. Most will say that they saw a dark moth. At this point, show them the images again and allow them to focus; point out that there was a light moth on the tree as well. Ask them which moth they think would be more common and why. Allow students to discuss this with their neighbors and then with the entire class. Following this, tell them how factories during the industrial revolution stained the trees black and show them a similar image but on a dark tree. Ask them which moth they think was more successful now and why. At this point they should understand that factors in the environment select from the existing variation to determine which will be most successful. It is important to emphasize that the variation already existed.

At this point it is important to help students see that success (fitness) is determined by the number of offspring produced over a lifetime. Showing a picture of two body builders ask which is the fittest. Take a vote, and then ask how many people didn't vote because they were holding out for this guy (and show the picture of the guy with a lot of kids). Ask why he was the fittest. The students will probably determine that it is because he has the most kids. To illustrate why this matters, refer to the previous example of the moths, use the following hypothetical example: moth Type 1 (light moth) produces, on average, two offspring that survive to reproduce and moth Type 2 (dark) produces three. Ask the class what color they think the trees are in this example (the trees should be the same color as moth Type 2). Using Table 1 show them what would happen to the ratios of moths after 10 generations. Figure 1 shows the same ratios graphically. Then ask the class what they think would happen after 100 generations. They should conclude that moth Type 1 will be extremely uncommon in the population. It might be worth mentioning that unless one allele is completely eliminated, the population could shift back if the environmental factors again change.

Generation	Type 1	Type 2	Ratio
0	1	1	1:1
1	2	3	1:1.5
2	4	9	1:2.3
3	8	27	1:3.4
4	16	81	1:5.1
5	32	243	1:7.6
6	64	729	1:11.4
7	128	2,187	1:17.1
8	256	6,561	1:25.6
9	512	19,683	1:38.4
10	1,024	59,049	1:57.7

Table 1. Example population growth for two morphotypes of moths (or other organisms) where one morphotype produces an average of two offspring per generation, and the other morphotype produces three.

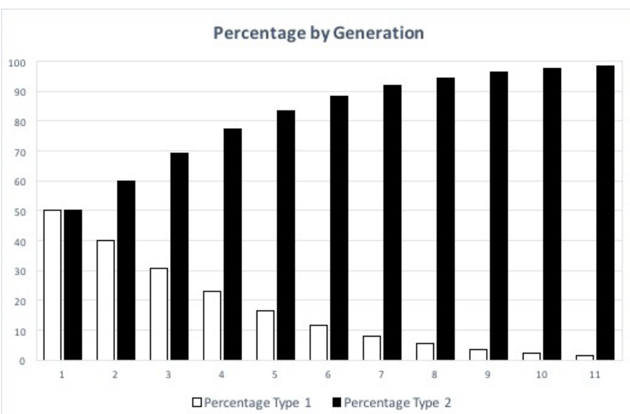

Figure 1. Bar graph depicting the difference in success of two different morphotypes that produce either 2 or 3 offspring per generation over ten generations as a proportion of the total population.

By now, students should understand well the relationship between variation and natural selection, and the importance of maximizing lifetime reproduction. They are now prepared to begin Part 2.

Part 2: Life History Activity

Students are now ready to begin learning the concept of life history. The following game illustrates this concept in a constructivist format where students can build the concepts for themselves as they experience the process.

Begin by handing out a copy of Supporting File S3. Life History – Life History Game With Instructions to each student. Students should work individually on this game, however, working in pairs is also an option. As a class, read the directions to the game and ensure that students fully understand the rules:

- The goal of the game is to have as many offspring as possible during your lifetime.
- Each week, you will receive 'Energy Points' which must be distributed to one of the three life history requirements (Growth, Maintenance, or Reproduction).
- For each point invested in growth, you will receive one additional energy point in the following round and each additional round.
- If you choose to invest in reproduction, you will not earn any additional points; however, the points invested represent the number of offspring you have produced.
- To survive to the next round, you must invest the number of energy points indicated in the Maintenance category; failure to invest the full amount will result in death at the end of that week.

You may choose to illustrate an example week or two, just to ensure that students understand what they are doing (see the PowerPoint presentation in Supporting File S2. Life History – Presentation). The example two weeks we used looks like the following: In Week 1, I am given 3 energy points. I invest 2 points in Maintenance (as I must do so to avoid death at the end of the round), and the remaining point in Growth. In Week 2, because I invested one point in Growth, I will receive 4 energy points instead of 3. Make sure that students understand that once they increase from 3 to 4, that they will never receive less than 4 again because any points invested into Growth will result in additional energy points in all future rounds. In Week 2, I am required to invest 2 points in Maintenance. This leaves me with 2 points to invest at my discretion. I may choose, for example, to invest 1 point into Growth and 1 point in Reproduction. Thus, at the beginning of Week 3, I will receive 5 energy points (the 4 from before, plus 1 more because I invested a second point into Growth) and I will have 1 total offspring. After reading the directions and going through one or two example weeks, instruct the class to begin. Give them enough time to fill out the chart completely through Week 7, but not enough time to overanalyze it (approximately 3-7 minutes). The purpose of this portion of the activity is merely to generate a variation of different strategies, not to figure out the best strategy (i.e., some student may choose to grow very large and reproduce very little until the end; others may choose to reproduce every week and grow very gradually)

Once they have completed the game, you will determine a winner. The winner is the student who has produced the most offspring (an ideal strategy that maximizes the number of offspring is shown in the example PowerPoint). List the number of offspring the winner (or winners) produced and ask whether they paid the Maintenance cost on the final week or not. To maximize the number of offspring, the Maintenance cost should not be paid in the final week. If no one chose this strategy, ask if it is necessary to pay Maintenance costs in the last week of the game. If they knew that the game was going to end (i.e., they had reached the end of their lifespan), there is no need to invest in survival to the next week. Students may bring up the legitimate argument that the organism may not know it is reaching the end of its life. Ask if it is advantageous to know and ask students to hypothesize how this ability might be influenced by natural selection. By putting all the Energy Points into reproduction in the final week, you can increase the total number of offspring with no real cost to the organism. Introduce the term that goes with this phenomenon: *terminal investment*. Continue to discuss this topic as seems appropriate. Perhaps discuss actual examples of terminal investment such as blue-footed boobies that fledge more chicks when they are immunocompromised (9). Ask the students about the consequences of terminally investing too early in life and what the benefits are for those that that terminally invest at the appropriate stage of life.

At this point, introduce a twist to the activity. Inform the class that in this environment winter came one week earlier (i.e., the game ended after Week 6). Determine a new winner by having students tally the number of offspring they had when excluding the final week. The new winner will likely not be the same student as before. Again, ask if the winner terminally invested and if not, how many offspring they could have had if they had done so at the right time.

Now inform the class that in this environment there are a lot of predators and organisms rarely live past three weeks. Determine a new winner by tallying offspring produced during Weeks 1, 2, and 3 only. As before, find out how many offspring would have been possible with proper terminal investment. Students should begin to see that the strategy they choose to utilize is heavily dependent on the environment in which the organism lives. Thus, life history is a phenotypic trait that is readily acted upon by natural selection just like any of the other typical phenotypic traits that we tend to associate with selection.

Ask students why they made the choices that they did and what they would change if they could start over. Hopefully, students will determine that what they would change would depend on the environment in which they lived. Ask students how this translates to what we find in the natural world, and whether or not natural selection can determine which life history strategy is most common in a population. Additionally, ask students about terminal investment. How do organisms 'know' the right time to terminally invest? Explain that this is a genetically determined factor that is under selective pressures and not because organisms are necessarily aware that they are playing this game.

At this point, you may choose to continue the discussion into factors that affect life history strategies. For example, stable environments with very few predators favor organisms that grow for longer as longer growth results in larger size and therefore enables large reproductive bouts and higher lifetime reproductive success. Varied, unpredictable environments favor "bet hedging" in that organisms are most successful that reproduce multiple times and that distribute reproduction over the course of their lifetimes so that some reproductive success occurs if an organism's lifespan is short, but allowing for more should it survive for longer. Dangerous environments favor heavy investment in reproduction early in life, as delaying investment would likely mean that organisms would die before getting the opportunity to reproduce. Timing of terminal investment is also affected by environmental factors that influence estimated lifespan.

This activity teaches about total reproductive investment in terms of total offspring, but not in terms of size versus number of offspring. This is an additional avenue that might be pursued in discussion. The key is to understand that there are three primary components of life history (growth, somatic maintenance, and reproduction) and that strategies vary within the animal kingdom (including humans) and are largely influenced by the environment through the process of natural selection.

Through this activity, students should build an understanding of the basic mechanism of natural selection as well as the various life history strategies. They should understand that life history strategies are acted upon by natural selection in a similar fashion to any other typical phenotypic trait. This activity is a way to allow students to build these concepts themselves in a constructivist fashion thereby leading to a higher likelihood of deep and lasting understanding (10-13). By teaching it in this manner, you are equipping students with a meaningful and transferrable conceptual understanding. See Table 2 on page 7 for the suggested teaching timeline.

TEACHING DISCUSSION

This activity was tested on 100 introductory biology for non-major students. We compared the group performance on the post-quiz given immediately following the activity to their performance on the pre-quiz given directly preceding the activity. To ensure that the scores were not different due to one test being harder than the other, students randomly received one of the two tests as the pre-quiz, and the other as the post-quiz. Both quizzes were utilized in both roles (as pre-quiz and post-quiz), yet no student received the same quiz for both the pre-quiz and post-quiz. Results show a statistically significant improvement on all five items (Table 3).

Item	M_{pre} (SD)	M_{post} (SD)	t	p
1	0.84 (0.37)	0.98 (0.13)	2.89	<0.01
2	0.64 (0.48)	0.97 (0.18)	4.91	<0.01
3	0.74 (0.44)	0.88 (0.32)	2.06	0.04
4	0.66 (0.48)	0.85 (0.36)	2.52	0.01
5	0.54 (0.50)	0.72 (0.45)	2.02	0.05
Total	3.41 (2.03)	4.40 (1.17)	3.28	<0.01

Table 3. Average performance on each item, pre and post; each item average is out of 1 point. The total average is out of 5 points.

Looking at the questions individually, we find a 37% increase in performance on the questions regarding life history tradeoffs (question 2) and a 19% increase in performance on the questions regarding terminal investment (question 4). Both of these items were regarding aspects of life-history evoltion that were explicitly taught during the activity. We observed a 14% increase in performance on the questions regarding the impact of predation on the age at which organisms mature and begin reproduction in different predation environments (question 1), a task regarding an aspect of life-history evolution that was not covered during the activity. We also saw statistically significant increases in scores on questions 3 and 5 which dealt with natural selection and fitness. These results indicate that the students, as a result of their experience completing the activity, did obtain the desired knowledge and understanding on all points, including those not expressely covered in the activity. Students were able to apply their understanding outside of the confines of the activity.

It is apparent that this activity can help students engage in and develop a real and workable understanding of both natural selection and life history evolution, which can assist students in obtaining a greater understanding of how natural selection shapes organisms outside of the more obvious examples of crypsis and other traits tied exclusively to survival.

SUPPORTING MATERIALS

- Supporting File S1. Life History – Quizzes
- Supporting File S2. Life History – Presentation
- Supporting File S3. Life History – Life History Game with Instructions (to print)

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REFERENCES

1. Stearns S. 1976. Life-history tactics: a review of the ideas. The Quarterly review of biology 51(1): 3-47.
2. Stearns S. 1992. The evolution of life histories No. 575: S81.
3. Ellis B. 2004. Timing of pubertal maturation in girls: an integrated life history approach. Psychological bulletin 130(6): 920. doi:10.1037/0033-2909.130.6.920
4. Groot C, Margolis L. 1991. Pacific salmon life histories. UBC press.
5. Reznick D, Butler M, Rodd F. 2001. Life-history evolution in guppies. VII. The comparative ecology of high-and low-predation environments. The American Naturalist 157(2): 126-140. doi:10.1086/318627
6. Cherrett J. 1989. Key concepts: the results of a survey of our members' opinions. In Symposium of the British Ecological Society.
7. Gregory T. 2009. Understanding natural selection: essential concepts and common misconceptions. Evolution: Education and Outreach 2(2): 156.
8. Freeman S, Eddy S, McDonough M, Smith M, Okoroafor N, Jordt H, Wenderoth M. 2014. Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences 111(23): 8410-8415. doi:10.1073/pnas.1319030111
9. Velando A, Drummond H, Torres R. 2006. Senescent birds redouble reproductive effort when ill: confirmation of the terminal investment hypothesis. Proceedings of the Royal Society B: Biological Sciences, 273(1593), 1443-1448. doi:10.1098/rspb.2006.3480
10. Howard D, Miskowski J. 2005. Using a module-based laboratory to incorporate inquiry into a large cell biology course. CBE-Life Science Education 4: 249-260. doi:10.1187/cbe.04-09-0052
11. Jensen L, Lawson A. 2011. Effects of collaborative group composition and inquiry instruction on reasoning gains and achievement in undergraduate biology. CBE-Life Science Education 10: 64-73. doi:10.1187/cbe.10-07-0089
12. Rissing S, Cogan J. 2009. Can an inquiry approach improve college student learning in a teaching laboratory? CBE-Life Science Education 8: 55-61. doi:10.1187/cbe.08-05-0023
13. Spiro M, Knisely, K. 2008. Alternation of generations and experimental design: A guided-inquiry lab exploring the nature of the her1 developmental mutant of Ceratopteris richardii (C-Fern). CBE-Life Science Education 7: 82-88. doi:10.1187/cbe.07-82-88.

Table 2. Life is just a game teaching timeline

Activity	Description	Time
Preparation		
	1. Bring 3 organisms of the same species with observable phenotypic differences. 2. Prepare a PowerPoint presentation like that described in the Lesson Plan or use the PowerPoint provided in the Supporting File S2. Life History – Presentation. 3. Print enough copies of Supporting File S3. Life History – Life History Game with Instructions so that each student can have one.	
Part 1. Introducing Natural Selection		
Observe and define variation	Ask students to look for differences between the three organisms that you brought to class. Have them come up with hypotheses to explain these differences (in what kind of environment each would be most successful). Observe other images of variation and define variation as a class.	10-15 minutes
Peppered moth example	Using the PowerPoint presentation, have the students, as European robins, find a peppered moth to eat among the trees. Have them determine which morphotype will be most common, and how that will change when the trees are stained black.	5 minutes
Reproduction and fitness	Using the hypothetical moth example included in Figure 1, demonstrate how slight differences in reproductive success accumulate over generations. Establish a clear definition for fitness and why it matters.	5 minutes
Part 2. Life History Activity		
Hand out game and explain rules	Pass out the copies of Supporting File S3. Life History – Life History Game with Instructions to each student and read the rules printed above the table on the figure.	3 minutes
Demonstrate example weeks, have the class complete the activity	In front of the class, fill out a couple of weeks as an example (especially so they can see that investment into growth results in increased energy points, and how to do a running total of offspring). Then give the class 2-3 minutes to fill out the table.	6 minutes
Find winner, discuss terminal investment	Find the student who has produced the most offspring (the most possible are 43 without terminal investment, or 48 with terminal investment). Ask if they could have had more if they hadn't invested in maintenance during the final week. Explain that ceasing to invest in anything but reproduction at the end is called terminal investment.	3 minutes
Have winter come early, find new winner, discuss terminal investment again	Have winter come one week early in this new environment. See how many offspring our previous winners had (if anybody had 43 or 48 it is likely that they now had 0). See if anybody had more at that point and crown a new champion. Ask our winner how many they could have had if they had known winter was about to come.	1-2 minutes
Have predation shorten lifespan to 3 weeks. Find winner, discuss terminal investment and the impact of environment on life history	Have predation reduce lifespan to 3 weeks. See how many our previous winner had, and see who had more. Ask our new winner how many they could have had if they had known they would only live three weeks. Have the class discuss how the environment impacts life history.	2-3 minutes
Discuss as a class what students would do if they could do it again, and how organisms know when to terminally invest.	Lead a discussion with the class where they discuss what they would do differently if they could do the activity again. This should lead to a conclusion that the best way to play the game depends on the environment. Discuss that to terminally invest properly, timing is everything. Discuss that selection favors individuals that do so at the appropriate time, and disfavors those that do so at inappropriate times.	4 minutes
Discuss environmental factors that may affect life history.	Ask the class to list environmental factors that could be selective pressures on life history (e.g., seasonality, climate, predation, disease).	5 minutes