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Title:

Population dynamics based on resource availability and founding effects: live and computational models

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Abstract

With the looming global population crisis, it is more important now than ever that students understand what factors influence population dynamics. The purpose of this paper is to present three learning modules offering authentic, student-centered investigations that explore rates of population growth and the importance of resources. These interdisciplinary modules integrate biology, mathematics, and computer literacy concepts aligned with the Next Generation Science Standards. Activities are appropriate for middle and secondary science classes, and introductory college level biology courses. Modules use fruit flies (*Drosophila melanogaster*) to model and measure population dynamics. Variables explored include initial population structure, food availability, and space of the enclosed population. Modules investigations incorporate experimentation, data collection and analysis, drawing conclusions, and application of studied principles to explore factors affecting population dynamics. In addition, we present a computational simulations where students can alter the same variables explored in the live

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experimental modules to test predictions in the consequences of altering the variables. Free web-based graphing (Joinpoint) and simulation software (NetLogo) allows students to work at home or at school.

Introduction

The Next Generation Science Standards (NGSS Lead States, 2013) focus on exploration of natural phenomena through practices consistent with those scientists employ in the development of scientific knowledge. One of the practices that separates NGSS from previous national science standards and frameworks is the use of models as tools for thinking, visualizing, and making sense of phenomena and experience (Krajcik & Merritt, 2012). Students can use models to make sense of what they observe and to make their thinking visible. Doing so allows them to share their explanations with other students and refine their models as they continue to study a phenomenon in different contexts. NGSS recommends that models to be used in *Developing, Evaluating, Using, and Revising* explanations and predictions of science phenomena. This paper presents three modules that use *Drosophila melanogaster* to explore the effect of the initial fly population, food availability, and space of an enclosed population on population dynamics. The activities use modeling to support student development of explanations to account for observed phenomena in population growth (Oh and Oh, 2011). The modules also apply common science practices that biomedical researchers employ today as they tackle population issues using the fruit fly as model (Pulver et al. 2011).

Life Cycle of the Fruit Fly and the Population Modules

Drosophila melanogaster, commonly known as a fruit fly, is a model organism used in research laboratories and classrooms around the world. They are easily obtainable from suppliers, and many people have them in their own homes. They can be purchased cheaply, or

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they can be captured for free by placing a banana in an open jar for a day or two. Fruit flies are easily cared for, and there are no health or ethical concerns regarding their use in classrooms.

The life cycle of *Drosophila melanogaster* is simple and predictable. Females lay up to 500 eggs on fermenting fruit. The male fertilizes the eggs, and in 24 to 30 hours the larvae emerge. Larvae are short, segmented, and whitish yellow in color and crawl around, gorging themselves on available food sources. Larvae progress through three distinct stages, as denoted by changes in their mouth hooks (small, black hooks at the anterior of the larvae). It is not relevant to discern the different larval stages in the modules presented. Toward the end of their larval stage, fruit flies begin climbing the walls of their enclosure, eventually becoming immobile as they transition into the pupa stage. At this time they turn dark brown in color and form a hard outer shell. They will remain in this state for about a week, after which time they emerge as adult fruit flies. An adult female fruit fly can begin to mate about two days after emerging.

Knowing the life cycle of *Drosophila melanogaster*, educational modules can be designed to explore a variety of biological processes. This paper will focus on using fruit flies to examine population dynamics. The first module explores population growth in a population beginning with one female fruit fly compared to a population beginning with three female flies. Investigations focus on the total numbers of individuals within a population and the rates of growth across the different treatments. The second module examines the effect of food availability on population growth, and the third module explores the effect of enclosure size on growth of the population. More specifically, this last module examines how the dynamics of similar populations differ if one population has significantly more space available than the other. Separately, each module highlights one limiting factor in population dynamics. Together, the

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modules illuminate relationships among different abiotic factors influencing population dynamics, with a specific focus on population growth. The combinations of modules cover the three-dimensionality of NGSS (i.e., Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas) using authentic science investigations. Further, the modeling activities promote critical analysis and use of empirical data to construct working explanations in ways consistent with practices Krajcik and Merritt (2012) recommended to promote students learning in science. NGSS connections for each module are presented at the end of this article in Tables 3 and 4.

Overview of Modules

The modules are presented in three distinct investigations that can be implemented separately or concurrently as a modular set. Each module requires setup of the fruit fly environments and anesthetization chambers (described in the following sections). Setup procedures are simple and can be performed by students from middle grades and beyond. Data from investigations will offer sufficient evidence for students to formulate working explanations on the effect each variable (i.e, initial population, food availability, space availability) has on population growth. Thus, modules work well early in a unit of study on population dynamics, interactions within ecosystems, and similar topics addressed in NGSS and undergraduate level coursework in biological sciences. Table 1 summarizes variables explored in the modules and expected outcomes.

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Table 1.

Summary of Variables and Expected Outcomes for Three Population Dynamics Modules

Criteria	Module 1	Module 2	Module 3
Variable Explored	Number of females in initial population (1 compared to 3)	Food availability	Space availability
Expected Finding	Populations beginning with more females grow larger and faster than initial populations with only one female.	Populations with greater food availability grow larger than populations with less available food.	Populations with larger space availability grow faster than populations with less available space.

Preparation Procedures for Three Population Dynamics Modules

The following section summarizes procedures for setting up the environments and anesthetizing fruit flies. Table 2 summarizes materials needed for the three modules. Full modules including instructions, video clips of procedures, data tables, and additional material can be found on the web link given at the end of this manuscript.

Impact of Initial Population (Module 1)

The first module examines how properties of the initial population alter a population's dynamics. Six equal sized vials need to be prepared for this investigation, each containing equal amounts of food substance. We recommend using 25 x 95 mm vials and moist yellow corn meal for the food substance. After the food has set, each vial should be labeled with a letter (i.e., A through F) for identification throughout the investigation. It is recommended that students prepare their own vials with careful guidance from the teacher. After procuring a cotton ball to seal each vial, the apparatus is prepared for fly occupancy.

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Table 2.

Summary of Materials Needed for Three Population Dynamics Modules

Module 1 Materials	Module 2 Materials	Module 3 Materials
For each student group: 6 small vials (25x95 mm, .e.g, Cat#:32-120 https://geneseesci.com/) 1 Fine point permanent marker 6 cotton balls Fly food substance Wild type <i>Drosophila melanogaster</i> (6 males, 12 females) Means to anesthetize flies (carbon dioxide, ether, FlyNap, cold) Hand lenses/ 1 dissecting scope Paint brush/forceps (to move flies) Fruit fly sex determining guide Data table Computer with JointPoint, Excel, or other spreadsheet software program	For each student group: 3 large, plastic food storage containers - size of shoe box 1 Fine point permanent marker 3 cotton balls Play-Doh 3 baby food jars, or similar 3 small petri dishes 3 large petri dishes 3 sheets filter paper Digital balance Fly food substance (i.e. yellow corn meal) Wild type <i>Drosophila melanogaster</i> (3 males, 3 females) Means to anesthetize flies (carbon dioxide, ether, FlyNap, cold) Hand lenses/ 1 dissecting scope Paint brush/forceps (to move flies) Fruit fly sex determining guide Data table Computer with Excel or other spreadsheet software program	For each student group: 3 large vials (6oz; Square Bottom; e.g.: Cat#:32-130BF https://geneseesci.com/) 1 Fine point permanent marker 3 large cotton balls or sponge stoppers Fly food substance Wild type <i>Drosophila melanogaster</i> (3 males, 9 females) Means to anesthetize flies (carbon dioxide, ether, FlyNap, cold) Hand lenses/ 1 dissecting scope Paint brush/forceps (to move flies) Fruit fly sex determining guide Data table Data from Module 1 Computer with JointPoint or Excel, or other spreadsheet software program

Fruit flies will need to be anesthetized and selected for each vial. Wild type fruit flies can be anesthetized using any variety of methods, but placing the vial in crushed ice offers a quick and easy anesthetization for this procedure. Refer to our webpage link given at the end of the paper for more details.

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Once anesthetized, students can use a hand lens, dissecting scope, or even the naked eye to identify the sex of each fly using secondary sexual characteristics, such as appearance of the genitals and sex combs. The sex combs, or black bristle areas on the male's forelegs, are an efficient way to differentiate males and females and can be viewed with the naked eye. With the use of a small paintbrush the flies can be brushed off a paper and into a container.

In the first three vials (A-C), place one anesthetized male and one female. Keep the vial on its side to prevent the flies from falling into the food. Insert the cotton ball into the vial, and wait for the flies to regain consciousness before turning the vial upright. Repeat the procedure with the vials D-F with the exception of placing three females, rather than one, in each of these vials. Once the flies have all regained consciousness in all six vials, turn them upright and place the vials in a safe location that receives regular day and night light cycles. If groups of students have their own set of vials, each group should have distinct names or marks to differentiate their vials from other groups' vials.

Monitor the vials daily for pupa formation. This will be marked by larvae climbing the vial walls, becoming stationary, and turning dark brown in color. After the first pupa forms, the vials should be checked for new pupa twice daily. Each pupa should be marked with a fine point permanent marker on the exterior of the vial. In a data table, document the date, time, and number of new pupa after each monitoring period. Continue documenting new pupa formation until a new adult emerges (ecloses) from its pupa casing.

At this point, remove all adults from all vials in order to differentiate the original population from the F1 population. For classes that do not meet every day at least the adults can be removed on a set schedule. In a new data table, begin counting the newly eclosed adults twice daily. Just as before, document date, time, and number of new adults. After checking each vial,

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remove the newly eclosed adults. Continue this process until no new adults form or sufficient data has been collected to draw conclusions on population sizes across the two environments. This module also provides students a quick qualitative view of the results as they can readily note differences in the number of pupa in the two environments, justifying the need to count pupa over time (Coffey & Atkinson, 1996).

Impact of Food Availability (Module 2)

The second module examines how food availability can alter a population's dynamics. A large, plastic, rectangular storage container (shoe box size) serves as the environment for the three trials. Modeling clay will be used to seal the container and prevent fruit flies from escaping into the classroom. Tupperware-type containers also can be used with holes cut in the lids and snapped shut. The environment setup will include creating a location for the food source, water supply as well as creating a fly-proof seal where the lid and base of the container meet. Begin setup by cutting a small hole in the lower side of the storage container, about a fourth of the way down along the long side. On the lid, use a marker to mark the spot directly below the hole when the container is closed. The hole will serve as the entry point when adding flies to the environment and adding water over the food dish to keep the food moist. Remove the lid, and place it on a flat surface. If the plastic lid is not sealing well, press the modeling clay (we found Play-Doh works well) into the ridge of the lid that makes contact with the container.

Prepare a water apparatus using the jar, a large Petri dish, and filter paper. Fill the jar with water, and line the large Petri dish with filter paper. Place the Petri dish over the mouth of the jar, and invert the apparatus such that the jar is sitting upside down in the Petri dish and water can saturate the filter paper. Place this apparatus on the lid of the container, opposite the side of

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the container previously marked. Weigh out 0.5 grams of fly food (we recommend yellow corn meal) and place it in a small Petri dish on the marked spot of the lid. The Petri dish should be under the hole cut in the side of the container. This way water drops can be added throughout the experiment to keep the food moist.

With the food dish and water supply in place, snap the container to the lid. The modeling clay will extrude towards the interior and exterior of the container. Using more modeling clay, pack in the lip of the lid all the way around the container. The goal is to create a fly-proof seal. Prepare a cotton ball to be placed in the whole above the food dish. Complete the preparation of the other two containers in a similar manner using 1.0 grams and 1.5 grams of food in the second and third containers, respectively. Mark each container A-C for identification purposes.

With the enclosures prepared, the flies can be added. Students can follow the same fly selection procedure discussed in Module 1. Place one male and one female anesthetized fruit fly into the first container (marked A) through the small hole above the water apparatus. Be careful not to allow anesthetized flies to fall into the food. Seal the hole with the cotton ball. Complete this process two more times for the remaining containers. Place the three containers in a safe place with normal light and dark cycles.

Monitor the containers periodically. Every few days (3-4 days), the food will need to be moistened. Using the hole currently plugged with a cotton ball, carefully add water to the food with a syringe, pipette, or squirt bottle. Be diligent not to allow any of the flies to escape. When all flies within a container die, open the container and document the number of dead adults. It may take as long as two months for the populations to die out.

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Impact of Space Availability (Module 3)

The last module examines how increasing the available space alters a population's dynamics. To complete this module, students will need the data from Module 1 to serve as a comparison. Large vials (6 oz) will serve as the environments in this module. Prepare the vials for fruit fly occupancy in a similar manner as describe for Module 1. Since the vials are larger, cotton balls may be too small to seal the mouth of the vial. A sponge stopper may be required. Sponge stoppers can be purchased commercially or made from high-density polyurethane foam purchased at a local box store or fabric store. This allows air to move freely in and out of the vials while keeping the flies sealed inside the container. As discussed in Module 1, anesthetize the flies to be placed in the vials. In each of the three vials, place one male and three females to allow the population to grow quickly for observed effects.

As previously discribed, monitor the vials daily for pupa formation. After the first pupa forms, the vials should be checked for new pupa twice daily. In this module the newly emerged flies should be left in the containers to examine the total number of adults that the limited food can sustain (thus, sustainability of a population is measured). Each pupa should be marked with permanent marker on the exterior of the vial. In a data table document the date, time, and number of new pupa for each monitoring period. Continue documenting new pupa formation until the total elapsed time is roughly equivalent to the elapsed time in the pupation portion in Module 1.

Analyzing Collected Data

Analysis of data collected from Modules 1 and 3 can be performed in similar ways. In each investigation, students should have created tables to include dates, times, number of pupa and adults for each observation. A graph can be created to illustrate the patterns for both modules

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on the same graph. Alternatively, students can be presented Excel templates to guide their data input. Prepared datasheets are available on the accompanying website listed at the end of this paper. Excel will adjust the data into the format necessary for use in *Joinpoint*, a freeware statistical analysis program. Students can use Joinpoint to perform piecewise linear regressions on the data, graph the data as a scatterplot, and output the regressions on the graph and in tables. These exercises allow students to compare how quickly the populations grew during different phases of the experiment. The benefit of using piecewise linear regressions is that students are more likely to be familiar with the basic concept of the slope of a line than they are to be familiar with quadratic or exponential functions and their applications. Collaboration with a mathematics teacher also can offer an opportunity for students to explore and critique different methods for analyzing the data.

The data from Module 2 will be analyzed using Excel. After using the provided template to input data, students will be able to create a bar graph that displays how food availability influences population size. Unlike the analysis performed in Modules 1 and 3, this process relies less on interpreting statistical outputs. Graphing principles applied in this module include how to read a graph, identify patterns from the graph, and draw conclusions from the data.

Drawing Conclusions and Student Assessment

After collecting and analyzing their data, students will be ready to draw conclusions based on their analysis. The text that accompanies each module (see link for webpage at end of document) includes questions to guide students through the conclusion process. Joinpoint graphs and regressions from Module 1 will illustrate that initial populations with more females can both grow faster and larger. This can be determined by examining the slopes of the regressions and comparing the graph for the trials with two adults to the graph for trial with four adults. The

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same process is applied to the data from Module 3. The exception, of course, being that the data analysis from Module 3 is compared to the comparable analysis performed in Module 1. The comparison should show that more space allows populations to grow faster and larger. Students should be required to use data they collect to substantiate claims they make in conclusions.

Conclusions from Module 2 are not as statistically obvious as those of Modules 1 and 3. Students will create bar graphs from their data and then make height comparisons across the bars to draw conclusions, rather than relying on statistical outcomes from a linear regression. By comparing the heights of the bars within the graph, students should observe a relationship in which more food corresponds to larger populations.

In addition to the questions used to guide students in drawing conclusions, each module includes two sets of questions at the end of the module. *Conclusion questions* guide students to describe their conclusions and reflect on how the results may have altered or built upon prior knowledge. *Challenge questions* allow students to bring components of the module together to synthesize new ideas and make predictions. They also require students to apply the principles discovered in the module to other scenarios.

Modifications and Extensions

Since each module addresses an individual component that influences population dynamics, teachers may elect to utilize some modules and not others. This allows modifications to meet unit outcomes with respect to both time restrictions and level of rigor intended for learning outcomes. Module 2, for example, requires less in-depth analysis than that which is required in Modules 1 and 3, employing the use of bar graphs to draw conclusions.

Teachers can also modify the modules to use low-tech options for data analysis. The Joinpoint analysis, for example, could be replaced by analysis by hand. Though less statistically

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accurate, students could plot the data points on graph paper and draw their own piecewise lines of fit. They could then draw on basic algebra skills to compute the slopes of those lines. This method should still elucidate the principles at work, and it would also give students valuable practice at graphing data by hand. If a classroom is using Vernier hardware (<http://www.vernier.com>) students also can generate graphs using data they collected and use Vernier's built in graphical functions for calculating slope of lines.

Modifications can easily be implemented in these modules to expand the study focus. In addition to initial population structure, food availability, and space availability, students could design experiments to address how other variable influence population dynamics. Light, temperature, and moisture variance, for example, could be tested to observe the effect each of these factors have on how quickly or to what size a population grows. Though they may not have any affect, students would get more exposure to experimental design and population dynamics applied to real applications in various fields (Wall et al., 2014).

Population Modeling

There are several types of models presented in these exercises. The use of live flies in various types of environments to monitor population dynamics directly can serve as a model to represent other organisms, such as humans. The food limitation environment in Module 2 models the effects of access to food on population growth. Students can use data from Module 1 and Module 3 to make predictions for Module 2 outcomes. In addition, they can create explanatory models to illustrate their explanations for observed outcomes. Throughout the investigations, models should be revisited and modified as more data is acquired and processes are discussed. Additional readings can substantiate student claims and further their understanding. Thus, the

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four main aspects in using models (*Developing, Evaluating, Using, and Revising*) naturally fall into place with these population dynamic investigations (Krajcik and Merritt, 2012).

In conjunction with these modules, we also have developed computer simulations that demonstrate the same principles. Using Netlogo modeling software, students can run a simulation that corresponds to each module. Just as in the live models, students will be able to alter specific variables, such as amount of food and number of initial females, to test their hypotheses. In the space of one classroom session, they can run several experiments to explore effects of several variables because of the short time necessary to run each trial. Computer simulations are both cheaper and faster to implement than their live counterparts because the software is free and the time to run computer simulations is significantly less than the live experiments. With ease students can address other situations, such as the number of males in the initial population (i.e., three males compared to one male) in one class session. All three modules for the computational focus could, in fact, be completed within a single class period. “In most cases simulations are best used after students experience the physical phenomena,” (Sneider et al., 2014) since the computer simulations remove the personal interaction of running live experiments and can leave students unclear about the authenticity of simulation outcomes.

Classroom Implementation of Modules

All three models have been implemented in middle and secondary classrooms. Over 200 middle school students from 10 seventh grade classes participated in the module investigations. In addition, 100 secondary students enrolled in AP biology classes also participated in these investigations. In general, students were highly engaged in using the models.

Outcomes from the implementation revealed that Module 2 was well adapted for the middle school classroom whereas Modules 1 and 3 were more appropriate for secondary classes.

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Students at both levels were highly engaged in the investigations, but secondary students quickly identified a variety of population factors to test such as potential environmental conditions affecting population dynamics (constant dark or light; cold temperature or with a heat lamp; substances added to the food), whereas middle school students required more scaffolding to identify possible factors. Students at all levels worked in pairs or triplets on the investigations. Secondary students also had tacit knowledge of Excel and graphical analysis software on computers. The middle school students were less experienced with these programs and had limited access to technology. Therefore, secondary students were able to complete the NetLogo environmental simulations whereas middle level students were limited to the live investigations and graphing using paper and pencil methods. Middle school students also demonstrated difficulty creating graphs, and identifying corresponding axes scales, underscoring the need for students to participate in investigations requiring these skills. Completing all three modules simultaneously proved to streamline the implementation and offered students a complex data set to compare findings across the experimental environments.

Several issues that emerged in module implementation included sorting female and male flies and weighing the food substance. Sorting fruit flies was best completed by providing students vials of 10-15 flies. Larger numbers of flies in vials made the task more difficult for students and created more concern that the flies would wake up from cold anesthesia before sorting was complete. A classroom helper also was used to distribute the sexes into the respective experimental containers.

Another bottleneck was weighing of fly food. Wet cornmeal fly food was used in the investigations. One electronic scale per class proved to be too limiting in weighing food material for all of the groups. Three or four scales sped up the weighing process making it more

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manageable. The weighing out of the food could be done ahead of time but this eliminates an opportunity for middle school students to learn how to use an electronic balance. For example, during the implementations, many of the middle school students were not familiar with tarring the weigh paper before measuring out the food. This was a new skill learned as they setup their experimental environments.

Other small issues that might need to be addressed include escaped flies in the classroom and planning a schedule to moisten the fly food. Fruit flies that escape during experimental setup can easily be caught using a variety of flytraps. A simple trap can be created with a plastic cup and paper towel or coffee filter. Place a small amount of food in the base of a plastic cup. Then create a funnel from a coffee filter or paper towel, cutting a small hole at the very base of the funnel. Place the funnel in the cup folding the open ends over the cup edge and securing the ends with tape or rubber band. The flies will crawl into the cup to find the food, but will not be able to find a way out. Food moistening also needs to be schedules weekly. Moistening the food on Friday ensures the flies will have a food source during the weekend. One additional day, Tuesday or Wednesday, also might be added to the schedule to keep the food moist.

Assessment data from module implementation will be presented in subsequent publications. Pre-assessments indicated students had little understanding of the effect initial female populations might have on population growth whereas students' demonstrated greater understanding of the effect of limited food availability on population growth. However, their understanding of the role space plays in population dynamics also was limited. Many middle school students held the naïve notion that fruit flies are too small for a space to make a difference in their population size. Analysis of pre and post assessments will be presented in future publications.

Conclusion

With the world on the cusp of a population crisis, there has never been a more important time for students to understand what factors influence a population's growth (UNESCO, 1999; Lutz, 2013; United Nations, 2014). These modules incorporate biological concepts, mathematical analysis, and computer skills to expound on some of the intricacies of how a population changes. The experiments performed are simple and consist mostly of creating an environment in which the populations can thrive. The modules also take up limited class time, for the data collection takes but a few minutes a day. The principles learned via these experiments will grant students a better understanding of both the ecological underpinnings of a population as well as the implications for current human population growth. The investigations presented in all three modules offer the potential to study a diverse array of factors affecting population dynamics, such as temperature, type of food, pollutants in the food, noise, and lighting. For more advanced classes, studies can include exploration of the effect that mutations have on *Drosophila* populations. Science supply warehouses, such as Bloomington Stock Center (<http://flystocks.bio.indiana.edu/>) offer established mutations that correlate to human diseases (Casci and Pandey, 2015; Sun and Chen, 2015; Taniguchi and Moore, 2014; Vos et al., 2015), offering the potential for students to pursue wide-ranging inquiries and research on human-related diseases. This provides a stimulating approach for students to learn science and is one reason the national standards implemented this model over a decade ago (NRC, 2000). Facilitating guided investigations and open inquiry while acquiring new knowledge creates a challenge for many teachers (Abrams, Southerland, & Silva, 2007; Appleton, 1995; Nadelson, 2009), but these modules are designed to assist teachers with both. Finally, Tables 3 and 4 summarize the main connections to NGSS for middle and secondary grades. Only the main

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connections were listed. The interdisciplinary nature of the investigations provides opportunities for a diversity of connections across NGSS and Common Core State Standards for mathematics.

Table 3.

NGSS Middle School Connections to the Three Population Growth Modules

Performance Expectation	Science & Engineering Practices	Disciplinary Core Ideas	Cross Cutting Concepts	Mathematics
MS-LS1-5	Developing and Using Models Constructing Explanations and Designing Solutions Engaging in Argument from Evidence Obtaining, Evaluating, and Communicating Information Scientific Knowledge is Based on Empirical Evidence	LS1.B: Growth and Development of Organisms	Cause and Effect Scientific Knowledge Assumes an Order and Consistency in Natural Systems	Model with mathematics. <i>(MS-LS3-2)</i> 6.SP.B.4 6.SP.B.5
MS-LS2-1		LS2.A: Interdependent Relationships in Ecosystems LS2.C: Ecosystem Dynamics, Functioning, and Resilience	Cause and Effect Stability and Change Scientific Knowledge Assumes an Order and Consistency in Natural Systems	

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Table 3.

Summary of NGSS Secondary Connections to Three Fly Population Modules

Performance Expectation	Science & Engineering Practices	Disciplinary Core Ideas	Cross Cutting Concepts	Mathematics
HS-LS2-1.	Developing and Using Models Constructing Explanations and Designing Solutions Engaging in Argument from Evidence Obtaining, Evaluating, and Communicating Information Scientific Knowledge is Based on Empirical Evidence	LS2.A: Interdependent Relationships in Ecosystems	Cause and Effect Scale, Proportion, and Quantity	MP.2 Reason Abstractly MP.4 Model with Mathematics HSN.Q.A.3 Choose level of accuracy
HS-LS2-2.		LS2.A: Interdependent Relationships in Ecosystems	Cause and Effect Stability and Change Scientific Knowledge Assumes an Order and Consistency in Natural Systems	
HS-LS2-6.		LS2.C: Ecosystem Dynamics, Functioning, and Resilience LS4.C: Adaptation LS4.D: Biodiversity and Humans		

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A webpage developed to support implementation of the three modules can be found at the link that follows. The website includes datasheet templates, module procedures, student questions, and explanatory videos are available to support teachers in implementing the modules.

Website link:

<http://web.as.uky.edu/Biology/faculty/cooper/Population%20dynamics%20examples%20with%20fruit%20flies/TheAmericanBiologyTeacher-PopulationDynamicsWebpage.html>

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