A hands on educational module to teach aspects of human dietary health using fruit flies as a model.

By (a team of undergraduate students, high school science teachers, a graduate student and a high school student- all to be named).

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**Abstract**

This module highlights a teaching exercise to explore a variety of biological processes related to human nutrition and related health issues. The module capitalizes on the tremendous amount of knowledge on the life cycle, physiology, genetics, and behavior of *Drosophila melanogaster* to investigate the effects of diet on development, survival, behavior, environmental stressors, and physiological functions such as heart rate and neural-muscular function with sensory-motor integration. Students and teachers can develop their own flavor to the modules with exploration in the effect from various available mutations in Drosophila. Many stock lines are available which relate to human diseases providing the potential for students to pursue a wide-range of inquiries on human-related diseases such as diabetes and Metabolic Syndrome. This unit contains pedagogical support to assist teachers with facilitating open inquiry to acquire new knowledge. The interdisciplinary nature of the investigations provides opportunities for diverse connections across the NGSS for high school teachers and as a college level course-based undergraduate research experience (CURE) and/or active-learning laboratory undergraduate research experience(ALLURE) to address authentic research questions related to diet and health in model invertebrate organisms.

**Student and teacher focus**

For this educational module the students should be provided with the detailed protocols and links to web sites which have been constructed to explain the various components of the educational module. The module is produced specifically to relate human health issues to the exercises with using fruit flies as the animal model. The content is all open source. The open video sources also explain how to go about each of the activities while leaving a lot of leeway for new ideas of students to modify and improve techniques. This unit contains pedagogical support to assist teachers with facilitating open inquiry to acquire new knowledge (Abrams et al., 2007; Appleton, 1995; Nadelson, 2009).

The aims for the students conducting the module is to estimate the developmental time of larvae, survival of larvae and adults and behavioral changes in larvae and adults to various diets mimicking human consumption and therapeutic diets. In addition, the students should be gaining some knowledge about human health and the effects of diet on health. The aim for the instructors is similar to the goals of the next generation science standards (NGSS) outlined for high school science curriculum (i.e., Science & Engineering Practices, Disciplinary Core Ideas, Cross Cutting Concepts) and Common Core State Standards for Mathematics for high school teachers. Integrating research experiences into undergraduate courses at a college level is now playing catch up to the concepts of the NGSS being implemented in high schools. The acronyms are course-based undergraduate research experience (CURE) and active-learning laboratory undergraduate research experience(ALLURE) as well as undergraduate research experience (URE) which is more of the research focus as individuals or groups with in a class or an entire class as compared to a wide range of approaches advocated for NGSS (Rowland et al., 2012; Auchincloss et al., 2014). Having students involved in research hands on projects also helps students develop and apply scientific practices (Coll, France, & Taylor, 2005).

**Content provided to Students**

The fruit fly, *Drosophila melanogaster*, as a larval stage and as an adult are commonly used a model organism in research to understand biological principles. The fruit fly became well recognized as a model for studying genetics (Rubin and Lewis 2000; Morgan 1910) much like the genetic discoveries using the pea plant for botany (Ellis et al., 2011; Henig, 2000). There are various human genetically linked diseases which are being modeled using *Drosophila* since the genes which code for proteins are similar for basic biological function such as ones for ionic exchange, glucose metabolism, building contracting muscle and producing a functional nervous system (more refs here, Reiter et al. 2001).

The life cycle of *Drosophila melanogaster* is relatively simple and easily followed. After males fertilize the eggs and the female lays them on a substrate in 1 day the larvae will emerge at room temperature (21oC or 70oF). Larvae develop through three stages which are easily identified by morphological changes in their mouth hooks used for feeding. In the late 3rd instar stage the larvae crawl out the food and find a place to become a pupa. After about 7 days the pupa eclose as adult fruit flies. The adults typically live for 2 to 3 weeks depending on the crowding and environmental conditions.

Using practical scenarios, such as focusing on a human health issues related to diet and a dietary problem which may be linked as an underlying cause of metabolic syndrome, can help unravel complex biological systems and provides one with an authentic context in which to learn and apply scientific concepts. This module starts out in providing an introduction about diets and health. Then we address why the fruit fly is used as a model organism for this particular educational module. Since our goal is for not only college level programs to be able to use this model and build on it but also for high school programs. Thus, some schools have very limited financial resources so we focus in how to conduct this module on a low budget with being as practical as possible while not compromising the level of understanding the science to be gained. There is a short description how to make a simple microscope for observing larvae so this step would not be a limiting factor for conducting the module with limited microscopic equipment. The exercise walks one through how to conduct various behavioral measures in larvae followed with how to measure developmental time as a larva to a pupa. In building on past published educational exercises, we introduce a means to blend in survival studies of the adults and population dynamics. Investigations in the effects of diet on adult behaviors are highlighted. In addition, a specific diet such as the ketogenic diet is a thematic focus for addressing the effects on behavior and function related to the suggested mechanism of action in mammals in treatment of epilepsy. Lastly, a well-developed physiological assay in monitoring the heart rate in larvae is discussed as a bioassay for health of the larvae exposed to various diets.

Need to develop paragraph here….The diets and health

 -Fructose ? Corn syrup in so many foods

 -High proteins for body builders

 -High fat- in American diets but also used for health treatments.

For starting out with a foundation to build various other experimental paradigms, we use diets consisting of a mix in various forms of fructose, glucose, peptones, coconut oil (i.e, fat) and a cornmeal mix (i.e, a standard mix for culturing *Drosophila*).

Procedures with larvae

1. Place about ten 1st instars or 2nd or 3rd instars into a dish containing the diet of choice for each condition to be examined.

2A. Determine the time period of exposure to the diets for behavioral assays as larvae.

2B. If using the larvae for developmental timing to pupation then observe every day and mark on the vial when pupa form.

3. Continue to repeat this procedure for each diet and make sure to label vials. Conduct assays below accordingly.

Procedures with adults

1. Know the age of the adults from the time of eclosion. If a vial has many pupa and adults, empty the adults out and then start experiments where one knows a window of time the pupa have eclosed to adults ( within 1 day for example).

2. Determine the time period of exposure to the diets for behavioral assays.

3. If one is using the adults for survival assays then mark the vials with type of food, starting number of flies and record daily the viable flies (note if flies were stuck in food and died as a result or other such variables). Do not conduct behavioral assay on these flies as they may be harmed by the assays and a true survival just based on diets cannot be assessed.

4. Conduct the behavioral assays of choice taking note of the variables such as sex, time of exposure to the diets and type of diet.

**Individual educational units for the module**

Movies provided go along with introductory text, protocol text and sample graphs of data, as well as notes to instructors for each activity.

The YouTube movies listed are as follows:

1. Introduction to “A model for learning about aspects of metabolic syndrome” (LaShay Byrd) https://youtu.be/FZ1kB1\_9QMM

2.  Diets for metabolic syndrome (by LaShay Byrd and Jenni Ho)

https://youtu.be/22Onri7mPdg

3.  Stages of larvae (by Jenni Ho)

https://youtu.be/ZVMnsA2o44U

4.  Making a simple microscope (by Ruth Sifuma)

https://youtu.be/wTSynwmyHBQ

5.  Body wall movements (by Brecken Overly)

https://youtu.be/smXe5axLZE8

6.  Mouth hook movements (by Hunter Maxwell & Crysta Meekins )

https://youtu.be/wynMJjyTt1s

7. Ethograms and why ethograms (by Brittany Slabach)

https://youtu.be/8MMOJj4nMY0

8. The HAT behavioral assay for larvae (by Maddie Stanback & Emma Rotkis)

https://youtu.be/fG7iFRF9HDg

9. Development of fruit flies as a measure of pupation rate (by Clare Cole & Kay Johnson)

https://youtu.be/qoFhLFie3K0

10. Anesthetize adult flies for transfering them (by Samantha Danyi)

https://youtu.be/ZfbN1GTu-Gg

11. Light and gravity sense in adults (by Sushovan Dixit)

https://youtu.be/zSJHN2NSrHk

12. Effects of ketogenic diet specifically (by Madan Subheeswar)

https://youtu.be/UiPDIEDa\_mk

13. Measuring heart rate in larvae (by Ann Cooper et al.,2009)

Cooper, A.S., Rymond, K.E., Ward, M.A., Bocook, E.L. and Cooper, R.L. (2009) Monitoring heart function in larval *Drosophila melanogaster* for physiological studies. Journal of Visualized Experiments (JoVE) 32: http://www.jove.com/video/1596/monitoring-heart-function-larval-drosophila-melanogaster-for )

14. The effect of thermal stressors on larvae and adults fed various diets.

 (by Alexandra Stanback)

 TBA

15. A summary of this educational module (LaShay Byrd is working it up).

**Detailed descriptions for each activity**

**1. Introduction to “A model for learning about aspects of metabolic syndrome”**

**Metabolic syndrome**

NIH terms for it

<http://www.nhlbi.nih.gov/health/health-topics/topics/ms>

Refs:

<http://care.diabetesjournals.org/content/34/2/497>

<http://www.ncbi.nlm.nih.gov/pubmed/18397447> rural kids

<http://bmcpublichealth.biomedcentral.com/articles/10.1186/1471-2458-10-141>

2.  Diets for metabolic syndrome

D-glucose , fructose, and sucrose are used as sources of carbohydrate; synthetic soy bean extract is used as a protein source ; and 100% coconut oil is used as a lipid source. The concentrations of each of the above nutrients are able to be varied.

Owusu-Ansah, E. and Perrimon, N. (2014) Modeling metabolic homeostasis and nutrient sensing in Drosophila: Implications for aging and metabolic diseases. Dis Model Mech. 7(3): 343–350. doi: 10.1242/dmm.012989

**3.  Stages of larvae**

<https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=12&ved=0ahUKEwjL6Jvp54LYAhXDmOAKHb86AOcQFghYMAs&url=http%3A%2F%2Fcomp.uark.edu%2F~mlehmann%2Fpost.pdf&usg=AOvVaw0DAs1nw1-6hsry1oGXhrfW>

<https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=16&ved=0ahUKEwjL6Jvp54LYAhXDmOAKHb86AOcQFgh0MA8&url=https%3A%2F%2Fcarnegiescience.edu%2Fpublications_online%2FDrosophila_Guide2.pdf&usg=AOvVaw2D3ze9Hlt4ZuQLFWqQ9HYQ>

**4.  Making a simple microscope**

 Explained in YouTube video (very easy)

**5.  Body wall movements**

Open source file:

Majeed, Z., Koch, F., Morgan, J., Anderson, H., Wilson, J., and **Cooper, R.L. (2017)** A novel educational module to teach neural circuits for college and high school students: NGSS-neurons, genetics, and selective stimulations. F1000Research. F1000Research: Immediate & Transparent Publishing for Life Scientists. F1000 Research Ltd, Middlesex House, 34-42 Cleveland St, London W1T 4LB, UK. <https://f1000research.com/articles/6-117/v1>

**6.  Mouth hook movements**

Open source file:

Majeed, Z., Koch, F., Morgan, J., Anderson, H., Wilson, J., and **Cooper, R.L. (2017)** A novel educational module to teach neural circuits for college and high school students: NGSS-neurons, genetics, and selective stimulations. F1000Research. F1000Research: Immediate & Transparent Publishing for Life Scientists. F1000 Research Ltd, Middlesex House, 34-42 Cleveland St, London W1T 4LB, UK. <https://f1000research.com/articles/6-117/v1>

**7. Ethograms and why ethograms**

Define Ethology: <https://en.wikipedia.org/wiki/Ethology>

<https://www.britannica.com/science/ethology>

Movie we made explains why we use ethograms.

**8. HAT ASSAY:**

Defined in this publication: Titlow, J.S., Rice, J., Majeed, Z.R., Holsopple, E., Biecker, S., and Cooper, R.L. (2014) Anatomical and genotype-specific mechanosensory responses in *Drosophila melanogaster* larvae. Neuroscience Research 83:54-63. doi: 10.1016/j.neures.2014.04.003. [PDF]

**Locations and careful description**

Head

1. Side of head lateral

2. ½ way along side

3. Side of caudal end.

**9. DEVELOP OF FRUIT FLIES-PUPATION RATE:**

Defined in this publication: Potter, S., Krall, R.M., Mayo, S. Johnson, D., Zeidler-Watters, K., and Cooper, R.L. (2016). Population dynamics based on resource availability and founding effects: live and computational models. The American Biology Teacher 78(5): 396–403, ISSN 0002-7685, electronic ISSN 1938-4211. [PDF]

**10. Anesthetize adult flies for moving them around**

Movie above explains this procedure.

**11. Light and gravity sense in adults**

Open resource: Badre, N.H., and Cooper, R.L. (2008) Reduced calcium channel function in *Drosophila* disrupts associative learning in larva, and behavior in adults. International Journal of Zoological Research 4 (3):152-164.

<http://web.as.uky.edu/Biology/faculty/cooper/COOPER-PUBLICATIONS.htm>

**12. Effects of ketogenic diet specifically**

<http://www.medicaldaily.com/role-diet-and-metabolism-epilepsy-fruit-fly-study-promises-hope-treating-seizures-269693>

**Why use this ketogenic diet?**

* **Significant research with reduction in seizures (30% free, 60% reduced)**
* **The “ketone bodies” circulate in the blood and provide alternative fuel source for tissues and brain**
* **Promising future research**
* **Atkins diet: high fat, high protein, low carb**

**13. Measuring heart rate in larvae.**

Cooper, A.S., Rymond, K.E., Ward, M.A., Bocook, E.L. and Cooper, R.L. (2009) Monitoring heart function in larval *Drosophila melanogaster* for physiological studies. Journal of Visualized Experiments (JoVE) 32: http://www.jove.com/video/1596/monitoring-heart-function-larval-drosophila-melanogaster-for)

**Materials for one set up**

**A list of equipment and supplies needed for a class of 24 students (8 setups with 3 students per station)**

Forceps

Dissecting microscope (self-made ones are feasible)

Larvae crawling on a 2% apple juice agar plate made in Petri dishes (about 8.5-9 cm diameter).

Vials with cotton balls to grow larvae

Fine tipped Sharpe pens

4 Vials or tubes: about 9.4 height, 2.4 cm diameter (top), 2.25cm diameter (bottom).

For each student group:

6 small vials (25x95 mm, Cat#:32-120 https://geneseesci.com/)

1 Fine point permanent marker

6 cotton balls

Fly food substance

Wild type *Drosophila melanogaster* (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

**High school relevance:**

Throughout the module students will have an opportunity to engineer a range of models to demonstrate and test the impact of different variables on human systems using fruit flies as an example. 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 emphasis on using models as tools for thinking, visualizing, and making sense of phenomena and experiences (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 construct and share their explanations with other students and refine their models as they continue to study a phenomenon in different contexts. NGSS recommends that models be used to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.

Focusing on metabolic syndrome as a theme provides students with an authentic context in which to learn and apply scientific concepts. Doing so can also help students develop and apply scientific practices (Coll, France, & Taylor, 2005). Using models to explore and construct scientific explanations promotes metacognitive thinking, communication skills, and creates opportunities for students to participate in the development of scientific knowledge (Gilbert, Boulter, & Elmer, 2000). The use of physical models with guided inquiry supports the conceptual nature of the topic (Coll et al., 2005; Ucar & Trundle, 2011). Further, in defining components of a complex biological problem, students and teachers can progress through increasingly complex objectives in a logical, stepwise progression. {I copied this from one of my text- either SEPA grant or Potter’s past paper with flies}

The concepts and activities highlighted in this educational module are aligned with NGSS (NGSS; Achieve, Inc., 2013) and the NHES (2007) and address concepts in biology, mathematics, physics, and chemistry, as well as engineering design. The combinations of the proposed modules cover the three-dimensionality of NGSS (i.e., Scientific and Engineering Practices, Crosscutting Concepts, and Disciplinary Core Ideas) using authentic science investigations.

**Student assessment**

 In assessing student learning and the practically of the conducting the various components in implementation of the full module undergraduate college freshman group of students volunteered as non-identifiable individual participants. They provided feedback in a a pre- and post-survey on concepts related to diet and health as well as in the use of pedagogical tools such as models was implemented. They also worked through each module after taking the pre-survey. After completing the modules and sharing out amongst the entire class the various findings the students took a post survey. The responses on the surveys were analyzed and compiled as presented in the Appendix.

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Students over the years who helped develop these aspects of this module in various ways.LaShay Byrd, Jenni Ho, Ruth Sifuma, Brecken  Overly, Hunter Maxwell & Crysta Meekins, Brittany Slabach, Alex Stanback, Maddie  Stanback, Emma  Rotkis, Clare Cole, Kay Johnson, Samantha Danyi, Sushovan Dixit, Madan Subheeswar, Gaayathri Veeraragavan, Suraj Rama, Angel Ho, and Samuel Potter. Teachers who have helped develop the content are: Kim Zeidler-Watters and Diane Johnson.

**Appendix**

*NGSS Middle School Connections to the Module*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Performance Expectation | Science & Engineering Practices | Disciplinary Core Ideas | Cross Cutting Concepts | Mathematics |
| MS-LS1-5 | Developing and Using ModelsConstructing Explanations and Designing SolutionsEngaging in Argument from EvidenceObtaining, Evaluating, and Communicating InformationScientific Knowledge is Based on Empirical Evidence | LS1.B: Growth and Development of Organisms | Cause and EffectScientific Knowledge Assumes an Order and Consistency in Natural Systems | Model with mathematics. *(MS-LS3-2)*6.SP.B.46.SP.B.5 |
| MS-LS2-1 |  | LS2.A: Interdependent Relationships in EcosystemsLS2.C: Ecosystem Dynamics, Functioning, and Resilience | Cause and EffectStability and ChangeScientific Knowledge Assumes an Order and Consistency in Natural Systems |

Summary of NGSS Secondary Connections to Modules

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Performance Expectation | Science & Engineering Practices | Disciplinary Core Ideas | Cross Cutting Concepts | Mathematics |
| HS-LS2-1. | Developing and Using ModelsConstructing Explanations and Designing SolutionsEngaging in Argument from EvidenceObtaining, Evaluating, and Communicating InformationScientific Knowledge is Based on Empirical Evidence | LS2.A: Interdependent Relationships in Ecosystems | Cause and EffectScale, Proportion, and Quantity | MP.2 Reason AbstractlyMP.4 Model with MathematicsHSN.Q.A.3Choose level of accuracy  |
| HS-LS2-2. | LS2.A: Interdependent Relationships in Ecosystems | Cause and EffectStability and ChangeScientific Knowledge Assumes an Order and Consistency in Natural Systems |
| HS-LS2-6. | LS2.C: Ecosystem Dynamics, Functioning, and ResilienceLS4.C: AdaptationLS4.D: Biodiversity and Humans |

There are various NGSS this model align to: Biology-systems,

Engineering-modeling and design (Next Generation Science Standards, 2013; SS Lead States. 2013.)

The disciplinary core ideas in middle school will be reinforced in high school

with this diet and development model. A number of disciplinary core ideas will align as well to these exercises, such as MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem

High school:

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

HS-LS2-2 Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

HS-LS2-8. Evaluate the evidence for the role of group behavior on individual and species’ chances to survive and reproduce.

HS-LS1-3 From Molecules to Organisms: Structures and Processes

 LS1.A: Structure and Function

HS-LS2-1 Ecosystems: Interactions, Energy, and Dynamics

 LS2.A: Interdependent Relationships in Ecosystems

HS-LS2-2 Ecosystems: Interactions, Energy, and Dynamics

 LS2.A: Interdependent Relationships in Ecosystems

 LS2.C: Ecosystem Dynamics, Functioning, and Resilience

HS-LS2-6 Ecosystems: Interactions, Energy, and Dynamics

 LS2.C: Ecosystem Dynamics, Functioning, and Resilience

Mathematics -

MP.4 Model with mathematics. (MS-LS2-5)

6.RP.A.3 Use ratio and rate reasoning to solve real-world and mathematical problems. (MS-LS2-5)

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**Appendices**

*Include addresses of suppliers, instructions for the preparation of media and*

*chemicals, rearing of animals, growing of plants, and any other special instructions and*

*information.*

1. List of supplies and suppliers for this exercise.

 TBA, This will be forth coming as I am also checking on prices to list.

2. To maintain adult flies for breeding and rearing. Cornmeal-molasses-agar culture for Drosophila

water 420 ml .

agar 4.5 gm

unsulfured molasses 60 ml

cornmeal 49 gm

brewer’s yeast 6.5 gm

cold water 145 ml

propionic acid 3.4 ml

Mix and boil water and agar 3–5 minutes.Add unsulfured molasses and heat to boiling again. Mix together cornmeal, brewer’s yeast, and cold water in a separate container until all lumps are removed. Add cornmeal-yeast mixture to molasses-agar mixture.

Boil 5 minutes, stirring constantly. Cool mixture to 60°C. Add propionic acid (as mold inhibitor). Pour culture medium 1-inch deep into sterile culture jars with sterile plugs. Add a sprinkle of active baker’s yeast (from a salt shaker) to each jar before adding flies.

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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; Taniguchi and Moore, 2014),

This unit contains pedagogical support to assist teachers with facilitating open inquiry to acquire new knowledge (Abrams et al., 2007; Appleton, 1995; Nadelson, 2009).