ACTIVITY: *Drosophila*

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Section

i. Overview

Students learn and apply the principles of Mendelian inheritance by experimentation with the fruit fly *Drosophila melanogaster*. Students make hypotheses for monohybrid, dihybrid and sex-linked traits and test their hypotheses by selecting fruit flies with different visible mutations, mating them, and analyzing the phenotypic ratios of the offspring. Students record their observations into an online notebook and write an online lab report.

ii. Learning Objectives

1. Formulate hypotheses
2. Design experiments
3. Analyze and interpret data

iii. Prior knowledge needed

- Basic terminology and principles of Mendelian genetics, including recessive, dominant, and sex-linked inheritance
- Formation of gametes by meiosis
- The laws of segregation and independent assortment
- Predicting the results of monohybrid and dihybrid crosses by constructing a Punnett square
- How genetic mutations can produce changes in phenotype
- Chi-square statistical analysis

iv. Expected Learning Outcomes

- Demonstrate the meaning of dominant and recessive traits and the genetic principles of segregation and independent assortment.
- Demonstrate the implications of sex-linked traits for heredity (optional).
- Demonstrate genetic linkage and recombination (optional).
- Demonstrate a chi-square analysis.
- Reach conclusions regarding the principles of genetic inheritance

v. Estimated Time

Teacher Preparation

15 minutes	Previewing the activity
10 minutes	Registering a Teacher Account and setting up a class
20 minutes	Editing and activating the report guide and rubric
40 minutes	Online assessment (grading the report)

Class Time *(if students have Internet access outside the classroom, they can work on their own time)*

30 minutes	Minimum amount of time to become familiar with the activity
60-180 minutes	Working on experiments and composing report
30 minutes	Online assessment quiz

vi. Alignment to Standards

National Science Education Standards

A – Science as Inquiry (Grades 9-12)

Abilities necessary to do scientific inquiry:

- Identify questions and concepts that guide scientific investigations
- Design and conduct scientific investigations
- Use technology and mathematics to improve investigations and communications
- Formulate and revise scientific explanations and models using logic and evidence
- Recognize and analyze alternative explanations and models
- Communicate and defend a scientific argument

C2 – Life Science

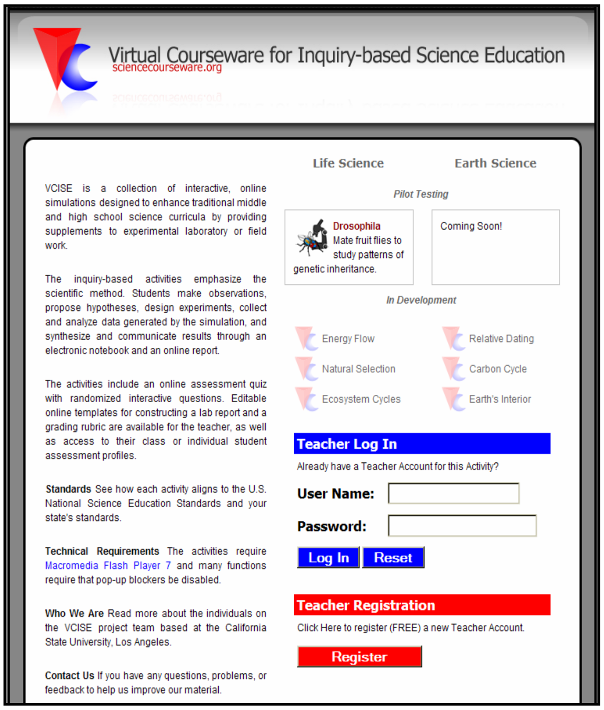
- Molecular basis of heredity

State Standards

Access the alignment of this activity to your state's standards by selecting your state at:
http://ScienceCourseware.org/vcise/standards

1. Introduction

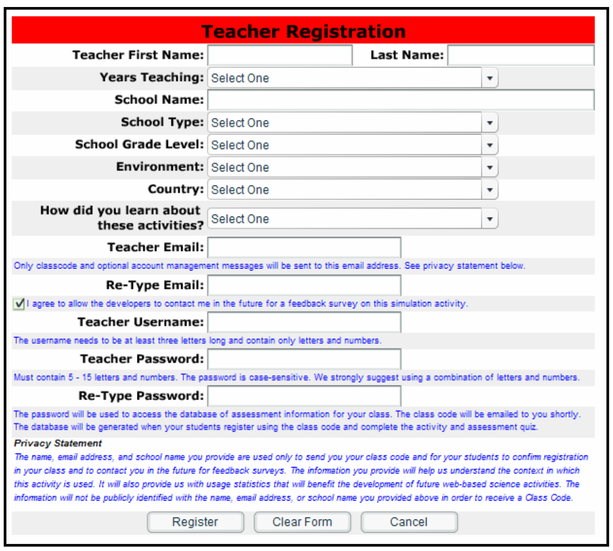
Drosophila is an interactive simulation activity that enhances the traditional fruit fly laboratory experience. The experience takes place in a virtual environment where students have an unlimited ability to design experiments and analyze patterns of genetic inheritance to discover the principles of genetics. The *Drosophila* application presents students with a "virtual lab bench" where they can order fruit fly mutants from a web merchant, mate the flies in an incubator, anesthetize flies for observation, examine flies under a microscope, and analyze the data from offspring to determine patterns of inheritance.



This application allows students to learn principles of genetic inheritance (e.g. dominant versus recessive traits, sex-linkage, etc.) by designing, conducting, and analyzing the results from their own experiments or by repeating classic experiments by pioneers in genetic research. As students work through the assignments, they can capture and save data and figures into their online notebook, and will be able to write their own notes online in their virtual laboratory notebook. Students also learn to organize results into a scientific report that can be graded on-line by their teachers.

The activities include an online assessment quiz that consists of randomized interactive questions. The students' answers are graded automatically and stored in a database server hosted by our institution, and a printable Certificate of Completion is issued for each student. The instructor has the option of editing the templates for the grading rubric and guiding questions for the laboratory report. The instructor has access to individual student and class results. A learning objectives report allows the instructor to quickly gauge how well the key concepts were understood.

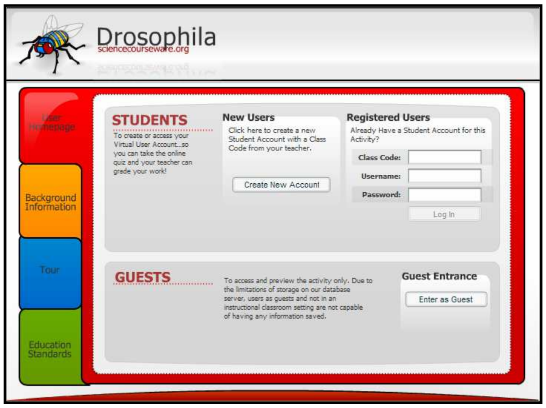
2. Teacher Registration and Workspace Guide



See the Teacher Registration and Workspace Guide for setting up and using a Teacher Account available on the VCISE homepage at: http://ScienceCourseware.org/vcise/trwg.html

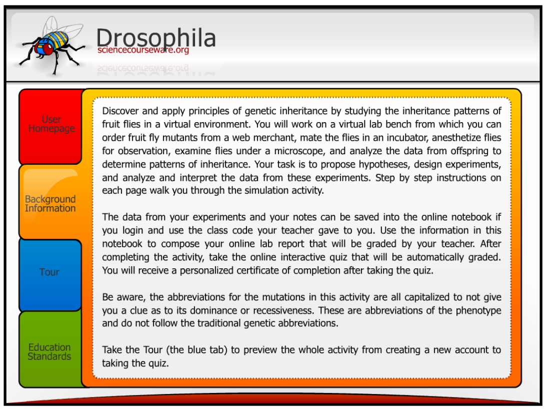
Includes directions on adding classes, editing the templates for the Report and Rubric, reviewing student performance with the online assessment tools, and accessing the Teacher Manual for the any of the VCISE activities.

3. Activity Entry Page

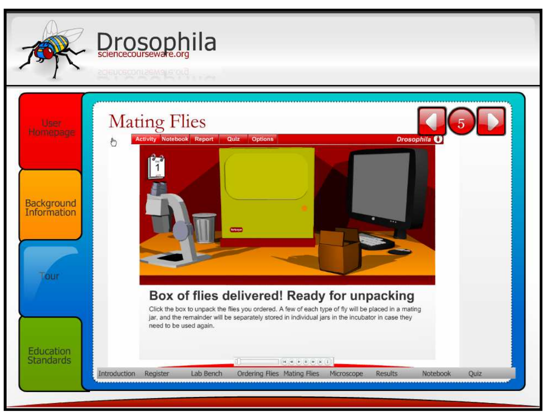


The entry page for *Drosophila* is found directly at: http://ScienceCourseware.org/vcise/drosophila/

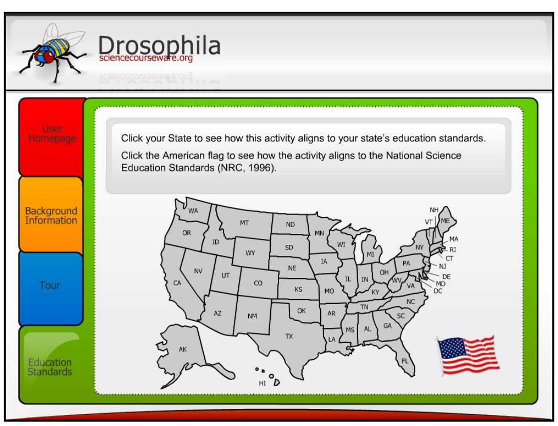
In the User Homepage tab (red), the student user creates a new account by clicking on the "Create New Account" button. The student enters the Class Code (generated when a teacher registers and sets up a class account), their name, username, and password to create their student account. Once a Username is created, the activity is accessed by entering the information in the "Registered Users" section.



The Background Information tab (orange) provides a brief overview on what the student should expect in the activity.



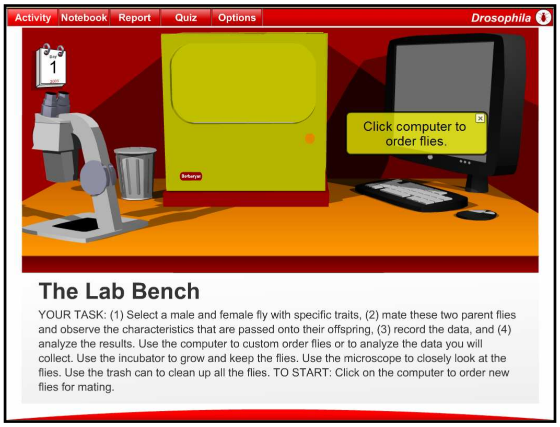
The Tour tab (blue) provides an animated demonstration of the whole activity. This Teacher Manual for the activity is based on that demo. Preview the Tour yourself, and encourage your students to take to the Tour before doing the activity.



The Education Standards tab (green) provides links to this activity's alignment to state and National Science Content Standards.

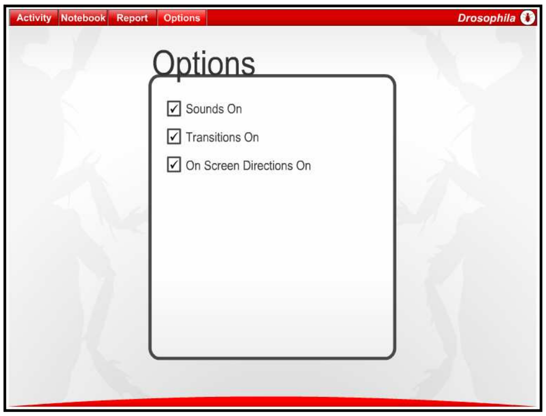
4. Starting the Activity

Once a student logs in as a registered user, the Lab Bench becomes the starting screen of the *Drosophila* activity.



The tabs on the top menu bar indicate different parts of the activity package:

- The Activity tab shows the Lab Bench screen.
- Images and tables from the activity can be added into the Notebook. The Notebook tab gives students access to their lab notes.
- Once the Report is activated, the Report tab guides the student in writing an online lab report on his or her experiments.
- Once the Quiz is activated, students can use this tab to take an interactive and randomized assessment quiz.



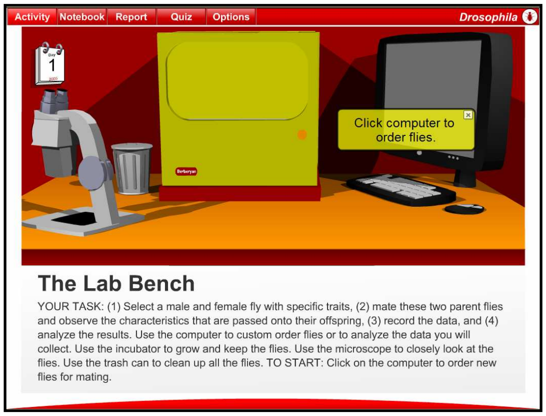
- In the Options tab, the sounds, transitions, or the on screen directions can be turned off or on. The transitions can be turned off to save time after the students understand what occurs in between two steps of the simulation. The On Screen Directions are step-by-step directions highlighted in yellow boxes that can also be closed on individual pages.

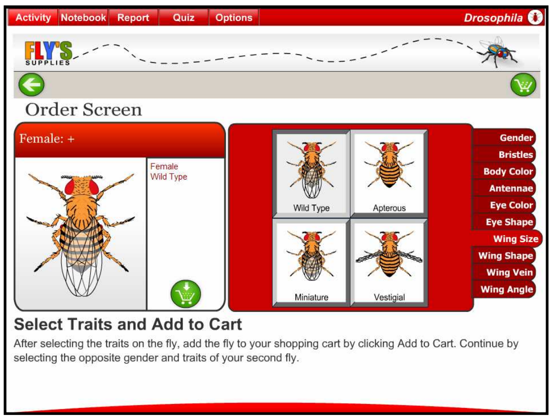
5. Ordering Flies

In general, the student:

(1) selects a male and female fly with specific traits,
(2) mates these two parent flies,
(3) observes and records the characteristics that are passed onto their offspring, and
(4) analyzes the results and provides a hypothesis based on the outcome of the experiments.

The computer in the virtual lab bench allows the student to custom order flies or to analyze the data that is collected. The icon for ordering flies leads to the store front page where flies can be customized for a particular experiment.



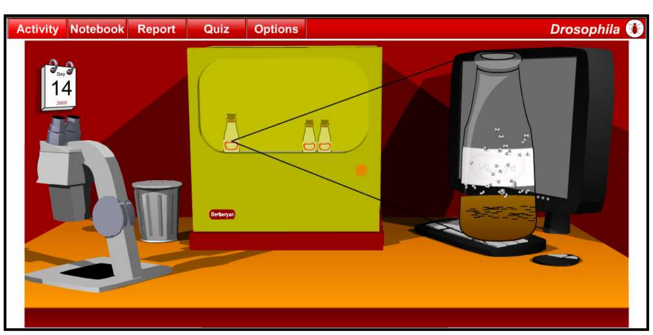


On the Fly's Supplies Order Screen, the fly being customized is in the view on the left half of the screen along with a listing of its characteristics. Up to three traits may be selected in this application. The tabs on the far right of the screen have possible choices for gender and the wild-type or 29 mutant traits in nine different categories listed as: Bristles, Body Color, Antennae, Eye Color, Eye Shape, Wing Size, Wing Shape, Wing Vein, and Wing Angle.

To promote inquiry-based learning, students do not have access to the detailed information on these mutations shown in Table 1 of the Appendix. Therefore, the abbreviations for the mutations in this activity are capitalized to hide any clue as to its dominance or recessiveness. **Special emphasis should be made so that students understand that it is not the traditional genetic abbreviation, but rather just an abbreviation of the phenotype**.

At the most basic level, students choose one mutation and cross it with a fly having the wild-type version. For example, a female with vestigial wings and a wild-type male are ordered and added to the Shopping Cart. At Checkout, these images of these flies can be recorded directly into the online notebook when the alert box appears.

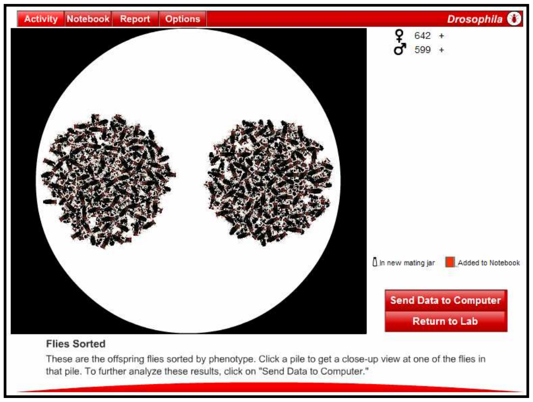
6. Mating Flies



The flies are shipped to the lab bench, unpacked, added to a mating jar, and placed in the incubator to start mating. The first generation (F1) of offspring develop.

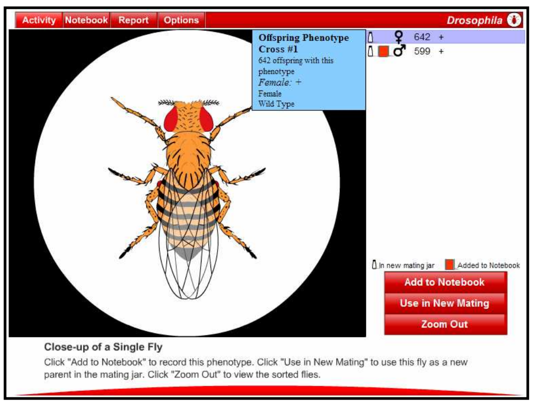
An animation shows that the offspring are anesthetized by ether in preparation for viewing under the microscope.

7. Using the Microscope



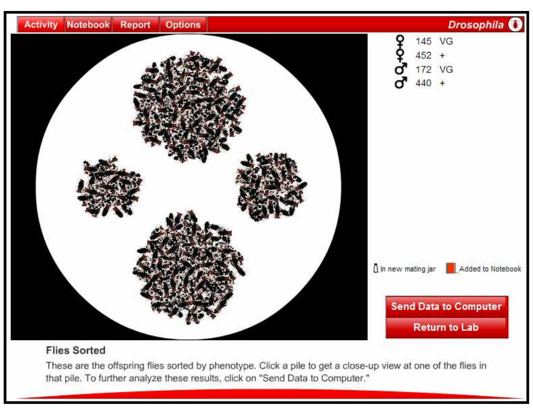
The flies are automatically sorted based on their appearance, that is, their phenotype.

In the Microscope View, the data listed on the upper right of the screen includes the gender, count, and phenotype of each pile. Rolling over a pile with the mouse cursor reveals the same information. This data can be sent to the computer by clicking on "Send Data to Computer." This is how students save their experimental results for analysis later. Clicking on a pile zooms the view on one of the flies in a pile.



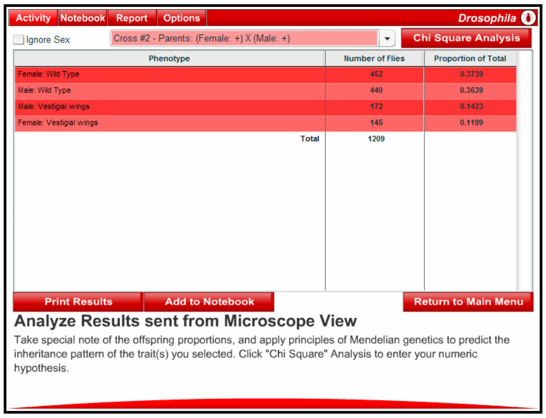
In the zoomed-in view of one fly, several options are available:

- "Add to Notebook" saves the image and phenotype of the fly into the online notebook.
- "Use in New Mating" uses this particular fly in another mating. Offspring from this mating, or a new fly from the store can be used for the next mating.
- "Zoom Out" returns to the microscope view with the sorted piles.



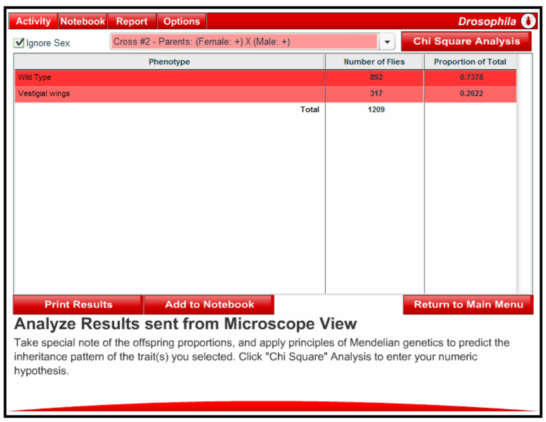
In this example, both male and female offspring showing a wild-type phenotype are used in a new mating, Cross #2. The mating jar appears when "Return to Lab" is clicked, and the development process produces the next generation of offspring (F2 generation). Returning to the microscope view, the F2 generation is now sorted into four piles and the data (gender, count, and phenotype) are listed in the upper right section.
Clicking "Send Data to Computer" transfers the data from the microscope view into the analysis view of the computer screen.

8. Analyzing Data



The purpose of the data analysis view is for the student to determine the pattern of inheritance based on the experimental results. In analyzing the empirical data generated, the student will apply principles of genetic inheritance to make a hypothesis of the resulting offspring ratios.

Data sets from multiple crosses are numbered and can be accessed from the pull down menu on top of the table. The gender, phenotype, number of flies, and the proportion of the total population are listed in a tabular format.

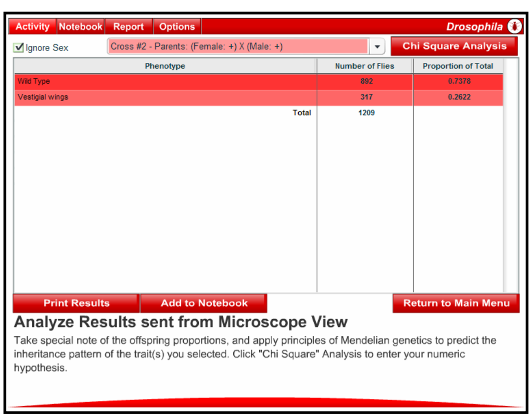


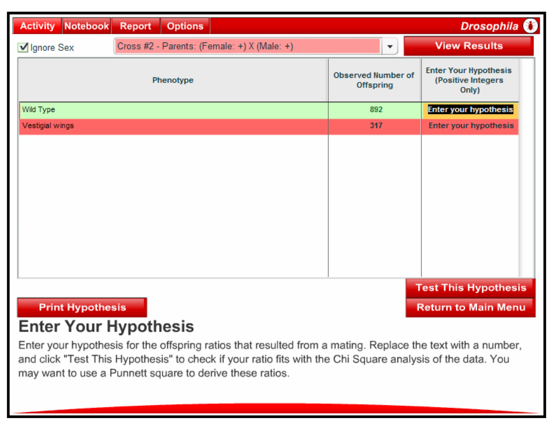
Checking the “Ignore Sex” box will combine the males and females of one phenotype together. This can simplify the analysis of matings in which the mutations are autosomal, and thus, gender has no effect on the inheritance pattern. *For advanced classes studying sex-linked traits, see Appendix.*

Clicking the “Add to Notebook” will enter the table of results into the lab notes.

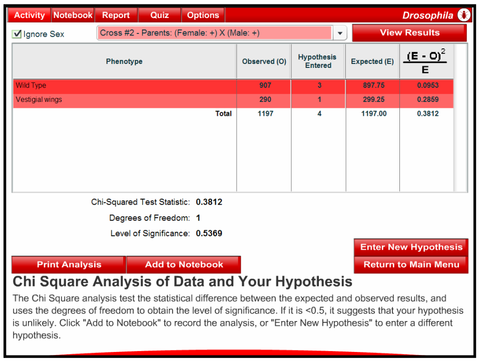
9. Entering a Numerical Hypothesis

The “Chi Square Analysis” button prompts the student to enter a numerical hypothesis for the offspring ratios that resulted from a mating. These ratios are usually derived by performing a Punnett square analysis of the parents’ genotypes. Students enter a hypothesized ratio (positive integers).





Clicking on “Test This Hypothesis” checks if the ratio fits using a chi square analysis of the data.



The chi square test statistic, the degrees of freedom, and the level of significance are automatically calculated. Based on these results, the student needs to determine their hypothesis is acceptable.

A level of significance equal to or less than 0.05 suggests that the hypothesis is unlikely. The student may enter a new hypothesis by clicking on “Enter New Hypothesis.” Clicking “Add to Notebook” records the analysis into the student’s lab notes.

9a. Chi-square Test

A chi-square analysis is a statistical test that measures how well a suggested numerical hypothesis compares to the observed results. In other words, do the observed results reflect acceptable differences from the expected values? The actual offspring numbers that result from the mating are compared to expected values based on the student’s hypotheses for the ratios among the different types of offspring.

For example, based on some genetic mechanism that you are proposing, you believe that there should be a 4 to 1 ratio of wild type flies to flies with paisley eyes. Of course, the ratio won't be exactly 4 to 1; one has to allow for random error. The question is: do the results differ "significantly" from a 4 to 1 ratio? To put it differently, if the 4 to 1 ratio is true, what is the probability that you would get deviations from a 4 to 1 ratio that are as large (or larger) than the deviations which you observe in the data? Statisticians call this probability the "level of significance."

So how do you calculate the level of significance? Statisticians have derived a test statistic called "chi-square" that can be used compute the level of significance. The chi-square test statistic measures the deviations of the observed values from the "expected values" that you would get if your hypothesis is true.

The formula for calculating the chi-square (χ^2) test statistic is:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

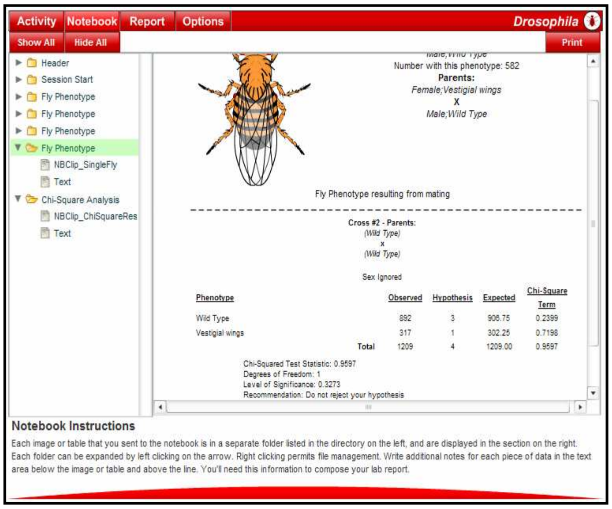
In this formula, you take observed number for each phenotype, O_i, subtract the expected number, E_i, square the difference, and divide the squared difference by the expected number. You sum the chi-squared terms for all of the phenotypes to obtain your test statistic.

If the squared deviations between the observed and expected values are small (i.e., the observed and expected values are similar), the test statistic will be small. Thus, the data support the hypothesis. On the other hand, if the squared deviations between the observed and expected values are large, the test statistic will be large and, thus, there is a smaller probability that the hypothesis is true. This will lead to small values for the level of significance, and a hypothesis that should be rejected.

The test statistic can be compared with a theoretical probability distribution to obtain the level of significance. This probability distribution depends on the "degrees of freedom" which equals number of phenotypic groups used in the calculation minus one. The *Drosophila* program automatically calculates the level of significance.

If the level of significance is large, there is a good chance (high probability) that the deviations from your hypothesis are simply due to random error. In other words, there is no evidence to reject your hypothesis. The hypothesis fits the data. On the other hand if the level of significance is small (less than 0.05), it is unlikely (low probability) that the deviations from your hypothesis are due to random error alone. Therefore, your hypothesis is probably wrong. In other words, if there is a less than a 5% chance that the deviations from your hypothesis are due to random error, then you should reject your hypothesis. Your hypothesis is inconsistent with the data. A new ratio based on a different genetic hypothesis should be entered.

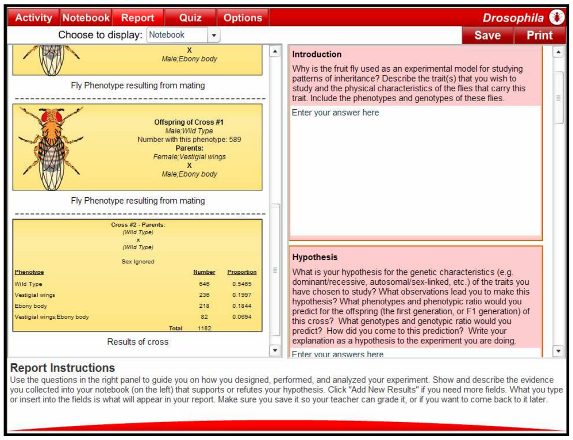
10. Recording into the Notebook

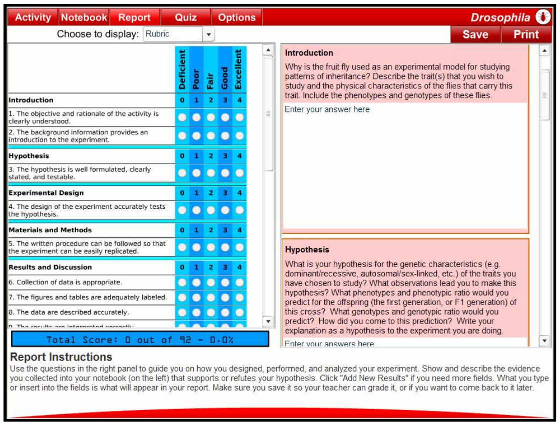


An online notebook is available. The student records images and data from experiments throughout the activity. In the Fly's Supplies ordering screen, there is a check box in an alert panel that has "Also add flies to the notebook" as the default during the order confirmation process. Additionally, there are "Add to Notebook" buttons in the microscope and "Analyze Results" views.

These data are added into the Notebook section of the activity as separate folders in the view on the left panel. The data are fully displayed in the section on the right. Each folder can be expanded by left clicking on the arrow. Right clicking allows file management. Additional notes for each piece of data can be typed in the text area below the images or tables. The students will use the information recorded in their notebooks to compose the lab report.

11. Composing a Report



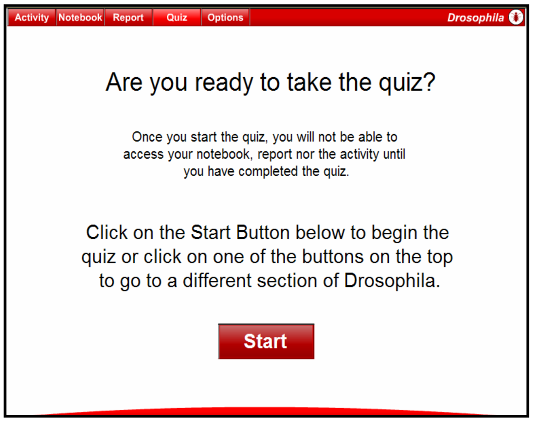


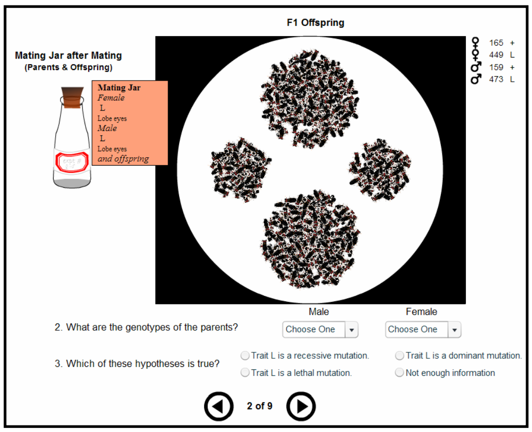
From the Report tab in the activity, students use the questions in the right panel to guide them on how they designed, performed, and analyzed their experiment. The evidence should have been collected during the activity and recorded into their notebook, which is now shown on the left panel. By using the pull down menu on top of the left panel, students are able to toggle to a view of the rubric the teacher has activated. In addition to the guiding questions in the report, the rubric will assist the students in composing their lab report. The objectives in the rubric can be edited by the teacher. However, this must be completed prior to activating it for your students from the Teacher Workspace.

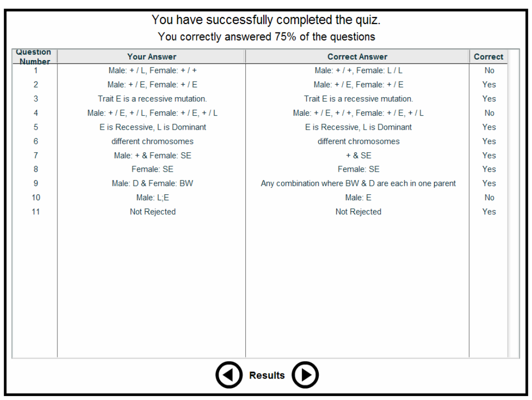
If more fields for entering results are needed in the report, students can click "Add New Results." Only what is typed or inserted into the blank fields is what will appear in the report, which should be saved into the activity's server database for editing at a later time or for grading by the teacher. Each student's notebook and report can be accessed in the Assessment tab of the Teacher Workspace section.

The text in the pink area of the Report guide in the right panel can be edited by the teacher. However, this must be completed prior to activating it for your students from the Teacher Workspace. The text in the Report guide will not be included in the Student Report file. Only what is typed or inserted into the blank fields by the student is what will appear in the student's printed and/or saved report.

12. Taking the Quiz






You have successfully completed the quiz.
You correctly answered 75% of the questions

Question Number	Your Answer	Correct Answer	Correct
1	Male: + / L, Female: + / +	Male: + / +, Female: L / L	No
2	Male: + / E, Female: + / E	Male: + / E, Female: + / E	Yes
3	Trait E is a recessive mutation.	Trait E is a recessive mutation.	Yes
4	Male: + / E, + / L, Female: + / E, + / L	Male: + / E, + / +, Female: + / E, + / L	No
5	E is Recessive, L is Dominant	E is Recessive, L is Dominant	Yes
6	different chromosomes	different chromosomes	Yes
7	Male: + & Female: SE	+ & SE	Yes
8	Female: SE	Female: SE	Yes
9	Male: D & Female: BW	Any combination where BW & D are each in one parent	Yes
10	Male: L;E	Male: E	No
11	Not Rejected	Not Rejected	Yes

Results

Once the Quiz is activated from the Teacher Workspace, it will be accessible to your students in that particular class. For the *Drosophila* activity, there are two possible quizzes: one that includes 12 basic questions on monohybrid and dihybrid crosses, and another that has six additional questions related to sex-linkage. Select the appropriate one for your particular class in your Teacher Account page.

Once a student starts the quiz, the notebook, report, and activity will not be accessible until the quiz is completed. Questions are located at the bottom of the screen. They are randomized and unique each time the quiz is taken. The graphical set up of the problem is viewed above the question and takes familiar elements of the activity. The arrow controls at the bottom of the page allows the student to go forward to the next question or reverse to review a previous question.

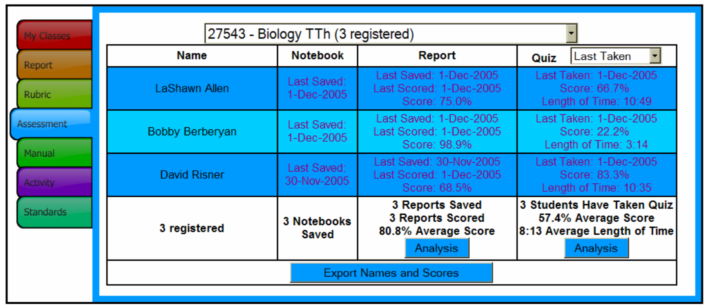
All the answers are submitted into the server database only at the end of quiz. An alert panel reminds the student that the answers can not be changed after clicking on the "Yes" button to finish the quiz.

When the student confirms his or her completion of the quiz, it is automatically scored and a table compares the student answers with the correct answers. The student may go back to review the quiz questions, but will not be able to change his or her answers. Moreover, since the quiz is randomized with multiple combinations of possibilities, this is the only time that the student would be able to review his or her particular set of quiz questions. The percentage score and each individual response by the student are recorded into the Assessment tool in the Teacher Account pages.

Finally, a personalized Certificate of Completion is available to the student after the quiz has been completed. The certificate can be printed by clicking the "Print" button or saved by right clicking on the certificate image (PC).

13. Assessment Results

See the Teacher Registration and Workspace Guide for reviewing student performance with the online assessment tools available on the VCISE homepage at: http://ScienceCourseware.org/vcise/trwg.html



14. Suggested Assignments

<u>Basic Level</u>

Assignment 1: Study the inheritance patterns of mutations from the list of autosomal mutations (excludes sex-linked and lethal mutations).

(a) Students should try reciprocal crosses (female mutant vs. male wild type and female wild type vs. male mutant).

(b) Students should try a test cross for recessive traits. Mate an F1 wild type to a homozygous recessive mutant from the store.

(c) Students should cross an F1 x F1 to get an F2 generation. This should demonstrate a 3:1 Mendelian ratio.

(d) *Optional:* Students can test the 3:1 ratio by using a chi-square analysis.

Autosomal Mutation	Standard Notation	VCISE Notation	Dominant / Recessive
Apterous	*ap*	AP	recessive
Black body	*b*	BL	recessive
Brown eyes	*bw*	BW	recessive
Curved wings	*c*	C	recessive
Dumpy wings	*dp*	DP	recessive
Ebony body	*e*	E	recessive
Eyeless eyes	*ey*	EY	recessive
Lobe eyes	*L*	L	dominant
Purple eyes	*pr*	PR	recessive
Radius incompletus	*ri*	RI	recessive
Sepia eyes	*se*	SE	recessive
Spineless bristles	*ss*	SS	recessive
Shaven bristles	*sv*	SV	recessive
Vestigial wings	*vg*	VG	recessive

Assignment 2: Select any two traits on two different chromosomes and study their inheritance patterns (excludes sex-linked and lethal mutations).

(a) Students should try reciprocal crosses:
- i. female with mutant A vs. male with mutant B
- ii. female with mutant B vs. male mutant A

(b) Students should cross an F1 offspring with another F1 offspring to generate an F2 generation. This should demonstrate a 9:3:3:1 Mendelian ratio.

(c) *Optional:* Students can test the 9:3:3:1 ratio by using a chi-square analysis.

Chromosome	Autosomal Mutation	Standard Notation	VCISE Notation	Dominant / Recessive
II	Dumpy Wings	*dp*	DP	recessive
	Black Body	*b*	BL	recessive
	Purple Eyes	*pr*	PR	recessive
	Apterous	*ap*	AP	recessive
	Vestigial Wings	*vg*	VG	recessive
	Lobe Eyes	*L*	L	dominant
	Curved Wings	*c*	C	recessive
	Brown Eyes	*bw*	BW	recessive
III	Sepia Eyes	*se*	SE	recessive
	Radius Incompletus	*ri*	RI	recessive
	Spineless Bristles	*ss*	SS	recessive
	Ebony Body	*e*	E	recessive
IV	Eyeless	*ey*	EY	recessive
	Shaven Bristles	*sv*	SV	recessive

<u>Advanced Level:</u> For classes studying linkage, sex-linkage, and lethal traits

Assignment 3: From the table in Assignment 2, select two traits on the same chromosome and study their inheritance patterns (excludes sex-linked and lethal mutations). Also see the Appendix in Section 15 for a pictorial genetic distance map.

(a) Students should cross a double mutant with a wild type. Best examples from which to choose are traits that are less than 20 map units apart.

For example: F1 cross

dp || dp X + || +
b || b X + || +

If crossing over does not occur in the F1 generation (also known as a non-recombinant event), an F2 mating produces a traditional Mendelian 3:1 ratio as demonstrated in the figure below.

However, if crossing over (CO) occurs in the F1 generation, then an F2 mating will produce an offspring ratio different than that of the traditional Mendelian ratio as demonstrated in the figure below.

nonrecombinant events
(non-crossing over) "NCO"

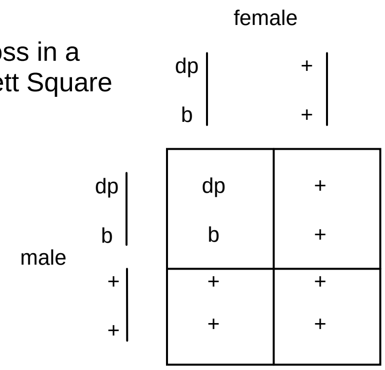
F2 cross

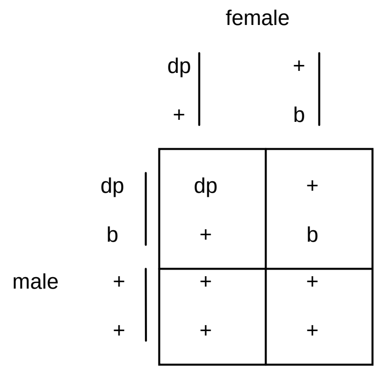
female: dp || + / b || + X male: dp || + / b || +

Crossing Over *(in Drosophila, occurs only in females)*

female: dp || + / + || b X male: dp || + / b || +

F2 cross in a Punnett Square



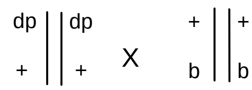


There is a 3:1 phenotypic ratio of the wild type to the *dp b* mutant offspring.

There is a 2:1:1 phenotypic ratio of the wild type to the *dp* mutant and to the *b* mutant offspring.

(b) Students should select and cross different mutations on different parents.

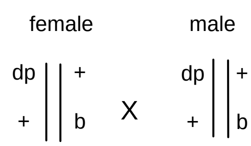
For example: F1 cross

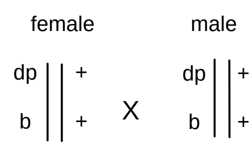


If crossing over does not occur in the F1 generation (also known as a non-recombinant event), an F2 mating produces a 2:1:1 offspring ratio as demonstrated in the figure below.

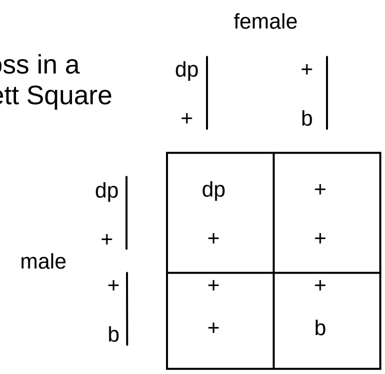
However, if crossing over (CO) occurs in the F1 generation, then an F2 mating produces a 3:1 offspring ratio as demonstrated in the figure below.

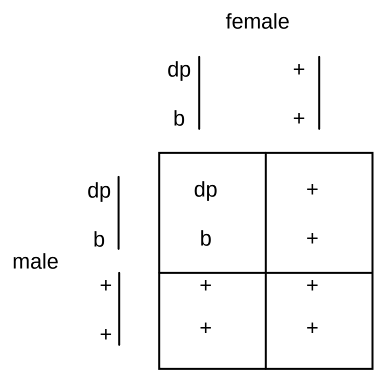
F2 cross





F2 cross in a Punnett Square



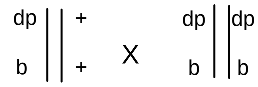


There is a 2:1:1 phenotypic ratio of the wild type to the *dp* mutant and to the *b* mutant offspring.

There is a 3:1 phenotypic ratio of the wild type to the *dp b* mutant offspring.

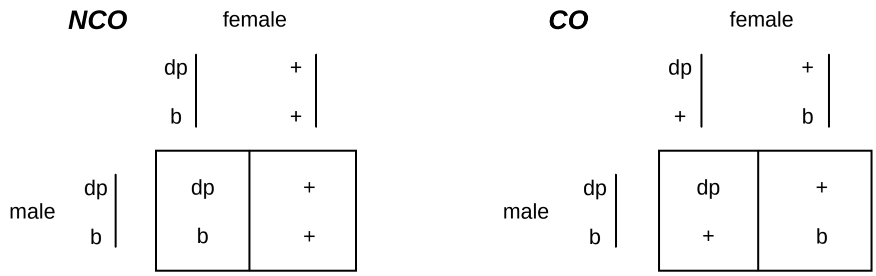
Take note: because of linkage of the genes on the same chromosome, the above dihybrid crosses do not produce the typical 9:3:3:1 Mendelian ratio.

(c) Estimate the map distance by test crossing an F1 female to a double homozygote recessive.



If crossing over does not occur, the offspring will have the parental phenotypes.

If crossing over occurs, the offspring are considered as recombinants. The frequency of recombinants is equivalent to the map distance of the two genes.



Parental types **Recombinants**

Assignment 4: In addition to autosomes, genes are found on the sex chromosome (I-X). The pattern of inheritance in these cases is different. These traits are considered as "sex-linked." The table below and in the Appendix of Section 15 lists the traits that are found on the sex chromosome.

(a) Students should try reciprocal crosses (female wild type vs. male mutant and female mutant vs. male wild type).

Sex Chromosome	Mutation	Standard Notation	VCISE Notation	Dominant / Recessive
I-X	Yellow Body	*y*	Y	recessive
	White Eyes	*w*	W	recessive
	Crossveinless	*cv*	CV	recessive
	Singed Bristles	*sn*	SN	recessive
	Tan Body	*t*	T	recessive
	Miniature Wings	*m*	M	recessive
	Sable Body	*s*	S	recessive
	Scalloped Wings	*sd*	SD	recessive
	Forked Bristles	*f*	F	recessive
	Bar Eyes	*B*	B	dominant

Parental: X^+X^+ x X^wY X^wX^w x X^+Y

F1: X^+X^w x X^+Y 100% + (wild type) X^+X^w x X^wY females +, males w

F2:

	X^+	X^w	
X^+	+	+	female
Y	+	w	male

	X^+	X^w	
X^w	+	w	female
Y	+	w	male

Phenotypic ratios 2 : 1 : 1
female + : male + : male w

1 : 1 : 1 : 1
female + : female w : male + : male w

Assignment 5: Mate two flies from the store that both have lethal mutations.
i. Note that the wild type phenotype is obtained. Therefore, the store flies must be heterozygous.
ii. There is a 2:1 ratio of mutant to wild type because homozygous mutant flies die.

Chromosome	Lethal Mutation	Standard Notation	VCISE Notation	Dominant / Recessive
II	Star Eyes	*S*	SS	dominant
	Curly Wings	*Cy*	CY	dominant
III	Dichaete Wings	*D*	D	dominant
	Aristapedia	*Ar*	AR	dominant
	Stubble Bristles	*Sb*	SB	dominant

15. Appendix

The first column gives the name of the mutation followed by its standard genetic abbreviation. The next column gives the abbreviation used by this *Drosophila* application, which is capitalized to hide any clue as to its dominance or recessiveness. This nondescript, capitalized abbreviation is used throughout the on-line activity. **Special emphasis should be made so that students understand that it is not the traditional genetic abbreviation, but rather just an abbreviation of the phenotype**. The next column gives the chromosome number. Chromosome I-X is the sex chromosome.

For advanced classes, the map distance is indicated in the next column and in the genetic map of mutations in the figure below the table. The last two columns indicate whether the mutation is dominant or recessive and whether or not it is lethal when homozygous (Biology Labs On-Line, 2001).

Mutation	Standard Notation	VFL Notation	Chromo-some No.	Map Distance	Dominant / Recessive	Lethal
Apterous	*ap*	AP	II	55.2	recessive	no
Aristapedia	*Ar*	AR	III	47.5	dominant	yes
Bar eyes	*B*	B	I-X	57.0	dominant	no
Black body	*b*	BL	II	48.5	recessive	no
Brown eyes	*bw*	BW	II	104.5	recessive	no
Curved wings	*c*	C	II	75.5	recessive	no
Crossveinless wings	*cv*	CV	I-X	13.7	recessive	no
Curly wings	*Cy*	CY	II	6.1	dominant	yes
Dichaete wings	*D*	D	III	41.0	dominant	yes
Dumpy wings	*dp*	DP	II	13.0	recessive	no
Ebony body	*e*	E	III	70.7	recessive	no
Eyeless eyes	*ey*	EY	IV	2.0	recessive	no
Forked bristles	*f*	F	I-X	56.7	recessive	no
Lobe eyes	*L*	L	II	72.0	dominant	no
Miniature wings	*m*	M	I-X	36.1	recessive	no
Purple eyes	*pr*	PR	II	54.5	recessive	no
Radius incompletus	*ri*	RI	III	47.0	recessive	no
Sable body	*s*	S	I-X	43.0	recessive	no
Stubble bristles	*Sb*	SB	III	58.2	dominant	yes
Scalloped wings	*sd*	SD	I-X	51.5	recessive	no
Sepia eyes	*se*	SE	III	26.0	recessive	no
Singed bristles	*sn*	SN	I-X	21.0	recessive	no
Spineless bristles	*ss*	SS	III	58.5	recessive	no
Star Eyes	*S*	ST	II	1.3	dominant	yes
Shaven bristles	*sv*	SV	IV	3.0	recessive	no
Tan body	*t*	T	I-X	27.5	recessive	no
Vestigial wings	*vg*	VG	II	67.0	recessive	no
White eyes	*w*	W	I-X	1.5	recessive	no
Yellow body	*y*	Y	I-X	0.0	recessive	no

Genetic map of the mutations in *Drosophila*.