

## Designing and Implementing Virtual Courseware to Promote Inquiry-based Learning

### Robert A. Desharnais

Professor, Department of Biological Sciences  
and Director, Virtual Courseware Project  
California State University, Los Angeles  
Los Angeles, CA 90032-8201 USA  
[rdeshar@calstatela.edu](mailto:rdeshar@calstatela.edu)

### Melvin Limson

K-12 Education Programs Coordinator  
American Physiological Society  
Bethesda, MD 20814-3991 USA  
[mlimson@the-aps.org](mailto:mlimson@the-aps.org)

### Abstract

Web-based learning objects continue to evolve as technological advances enhance our ability to create and share high-quality learning resources. An important class of learning objects are simulations intended to supplement traditional science instruction. After several years of experience in this endeavor, the Virtual Courseware Project has arrived at a set of ten design principles that it uses to guide its development of new web-based learning activities. These guiding principles place an emphasis on educational standards, open-ended inquiry-based learning, scientific methodology, critical thinking, and an intuitive and interactive user interface that includes linear tours, assessment tools, and documentation. These design principles are exemplified in *Drosophila*, an activity for learning the genetics of inheritance.

**Keywords:** inquiry-based learning, learning object design, science simulations, Virtual Courseware, web-based learning objects

### Introduction

Science instructors seek engaging, effective, and inquiry-based activities that are convenient to implement in their classrooms (Flick and Bell, 2000; National Research Council, 2000). While the Web provides a vast resource of declarative information (some of it multimedia), far less common are Web sites where instructors can obtain effective inquiry-based tools for teaching science. The Virtual Courseware Project at California State University, Los Angeles addresses this need through the development and implementation of interactive, web-based simulation activities that emphasize the scientific methods of inquiry: making observations, formulating hypotheses, designing experiments, collecting and analyzing data, and arriving at conclusions based on these analyses. By augmenting traditional instruction with simulations, science educators provide a more engaging learning experience that emphasizes science as a process rather than a collection of knowledge to be assimilated (Linn, Davis, and Bell, 2004).

The creation of effective inquiry-based learning objects requires careful thought and planning (Edelson, Gordin, and Pea, 1999). The purpose of this paper is to outline a set of design principles that can be used in the development of "Virtual Courseware" and to provide an example of how these principles have been implemented in the Virtual Courseware Project simulations. The next section provides a brief history of the Virtual Courseware Project which began in the late 1980's. The following section summarizes the design principles that have developed from nearly twenty years of experience in the creation of

educational software. This is followed by a description of the most recently developed Virtual Courseware activity that exhibits these design principles. The paper ends with a brief conclusion.

### **Historical Background of the Virtual Courseware Project**

The Virtual Courseware Project has its beginning in 1988 when Apple CEO Steve Jobs introduced his groundbreaking NeXT computers for higher education. (For an overview of NeXT and additional references, go to <http://en.wikipedia.org/wiki/NeXT>.) Over the next several years California State University at Los Angeles established a computer classroom of 20 NeXT workstations and developed a variety of NeXTSTEP applications for use in science classes. These activities were supported by three major grants from the National Science Foundation (NSF) with matching funds from the California State University (CSU). These applications were disseminated freely over the web and were used by most institutions of higher education with significant NeXT computer installations.

In the early 1990's the emergence of the World-Wide-Web provided a new opportunity for the use and dissemination of instructional technology. In 1995 a NeXTSTEP application called Virtual FlyLab was converted into a web-based simulation called Virtual FlyLab. Soon after its release in June 1995, it became a popular tool for genetics instructors worldwide, with over 665,000 students using Virtual FlyLab to conduct over 5 million genetic crosses. In June of 1996 the release of Virtual Earthquake was met with similar success with over 1.5 million "certificates of completion" issued to date. It was clear there was a large demand for inquiry-based science education activities and that the Web was an effective means of dissemination.

The success of Virtual FlyLab led to development of Biology Labs On-Line ([BiologyLabsOnline.com](http://BiologyLabsOnline.com)), a commercial partnership between the CSU Center for Distributed Learning and the publisher Benjamin Cummings. This subscription web site offers 12 biology simulations on a variety of topics for a modest price (\$5.25/year/applet). Since its availability in 2002, students have purchased over 500,000 applet subscriptions. Hundreds of colleges and universities use these learning tools.

These initial efforts blossomed into the "Virtual Courseware Project" ([ScienceCourseware.org](http://ScienceCourseware.org)). Two suites of activities have been developed and released. Geology Labs On-Line contains the activities Virtual Earthquake, Virtual Dating, and Virtual River. The second subproject, Virtual Courseware for Earth and Environmental Sciences consists of Earthquake and Global Warming. The latter subproject includes assessment tools for instructors who register their classes. Students are presented with a randomized quiz and the results are graded automatically and made available to the instructor. Over 7,000 classes are now registered in the user database. All of the projects hosted by ScienceCourseware.org are available to students and instructors at no cost.

One of the most remarkable revelations has been the interest among K-12 teachers. Approximately 75% of Virtual Courseware users are from high schools and middle schools. In 2004, the Virtual Courseware Project was awarded a grant from the NSF to develop web-based simulations that target secondary school learners. This has led to the development of another suite of activities called Virtual Courseware for Inquiry-based Science Education (VCISE). The first product, Drosophila, provides high school students with a "virtual lab bench" where they can conduct experiments to learn the genetic principles of inheritance. It also provides teachers with online tools for assessing their students. Administrators and teachers in the Los Angeles Unified School District have been involved in developing and field testing this software.

As the technical capabilities of the Web browsers have evolved, so have the Virtual Courseware Project methods and applications. Technologies such as Java, Macromedia Flash, and server-side databases provide new opportunities to enrich the learning experience. But finally, the most critical element in the success of Virtual Courseware lies in its ability to engage students in the process of science. The next section outlines the design principles that can help make this happen.

### **Design Principles**

The strategy in the development of Virtual Courseware can be summarized by ten guiding design principles. These principles have evolved from user feedback, focus groups of teachers involved in the

software design, and classroom field tests. While some of these design principles apply to simulations developed for the sciences, others are generic and should be considered when authoring learning objects for any field. The highlights of each principle are described below.

(1) Align to learning standards or objectives

Learning objectives are defined at the conception of an activity. The curriculum development model used in the design of Virtual Courseware is grounded in the Understanding by Design framework by Wiggins and McTighe (2005). The instructional design is "backwards" in the sense that it begins with the identification of desired learning outcomes, proceeds to the identification of acceptable evidence for an assessment that learning has occurred, and concludes with the actual creation of the learning object. For Virtual Courseware material designed for pre-college science students, both state and U.S. National Science Education Standards are used to guide and align the activities to appropriate science teaching standards and objectives. Teacher focus groups are used to ensure the learning activity is at an appropriate grade level for its intended audience and that the learning activity will complement the existing curriculum.

(2) Make the software web-based and easily accessible

Technical problems can be a significant obstacle for educators in accepting and adopting web-based learning resources (Rogers, 2000; Pajo & Wallace, 2001). Virtual Courseware is produced to be compatible with the most commonly used Web browsers by using widely available browser technologies. These include server-side databases, JavaScript, Java applets, and Macromedia Flash. The latter two technologies allow the use of animations to depict scientific processes and permit a rich and intuitive user interface. In compliance with Section 508 of the American Disabilities Act, the most recent suite of activities includes keyboard shortcuts for non-mouse users, allows unlimited magnification of screen images, and displays text in way that is compatible with screen readers.

(3) Design with the three "i's" in mind: interactive, intuitive, and inquiry-based

Interactive features are built into the design of Virtual Courseware to engage students and allow exploration, the initial two phases of Bybee's "Five E's" pedagogical model (Bybee, 1997). The activity simulates a virtual laboratory environment, allowing students to manipulate on-screen objects. This level of engagement is designed to keep the student on task and focused on the learning experience. The interactivity in Virtual Courseware resembles that found in computer games, yet the feedback and responses are balanced with an element of guided inquiry. A printable certificate of completion is awarded to students who successfully complete the experiments and the quiz, and has proven to be an effective incentive.

The user interface that Virtual Courseware strategically exploits is graphical representations of real world objects. This increases the intuitive appeal of the activity and helps create an "authentic learning environment" (Herrington and Oliver, 2000). The challenge is to create an appropriate level of authenticity without overwhelming students with mundane details or tedious and repetitive actions that have little learning value. An effective compromise is to engineer an intuitive interactive virtual environment that provides students the freedom to explore, yet limits their possible choices. This follows the instructional strategy of guided inquiry (National Research Council, 2000).

Inquiry-oriented teaching and active learning are cornerstones of the National Science Education Standards and reform-minded science teacher preparation programs (National Research Council, 1996, 2001). Virtual Courseware promotes inquiry-based learning by emphasizing the way scientists do science (Design Principle 4 below). Guided inquiry is achieved by allowing student-centered exploration within the constraints of the teacher- and material-directed instruction. The goal of this strategy is to provide an inquiry-based learning experience that has positive effects on cognitive achievement, process skills, and attitudes towards science (National Research Council, 2000).

(4) Reinforce scientific methodology and critical thinking skills

The National Science Education Standards emphasize the “processes of science” as part of a student’s understanding of scientific inquiry (National Research Council, 1996). The scientific method plays a major role in the Virtual Courseware Project’s philosophy of “learn by doing.” Students make observations, propose hypotheses, design experiments, collect and analyze data generated by the software, and organize and communicate their results through an electronic journal and an online report. This comprehensive approach in performing virtual scientific experiments reinforces the processes necessary to improve critical thinking.

(5) Create open-ended simulations with linear demonstration tours

Well-designed open-ended learning environments can be effective means of inquiry-based science education (Edelson, 1998). Virtual courseware allows students to explore a seemingly unlimited number of experimental situations through its programming and variability of scenarios. The inquiry-based approach does not follow a traditional “cook book” laboratory procedure with fixed data. Rather, the simulations create an open-ended environment where students can choose to explore different aspects of a scientific topic with potentially multiple outcomes. However, field tests of Virtual Courseware have revealed that students often undergo an initial period of confusion when presented with these types of open-ended virtual environments. Therefore, at the suggestion of teachers, the latest Virtual Courseware activities include linear tours with animated demonstrations that provide an overall introduction to the activity. In these tours, an entire experiment or procedure is presented step by step as an example of the work that will be encountered in the simulation. These tours help orient students to the activity, decrease the anxiety associated with the use of new technology, and often generate excitement when students realize that they may have fun while learning.

(6) Use randomization algorithms that simulate experimental error

Experimental error is a ubiquitous feature of empirically-derived experimental data. This error may arise through the imprecision of the experimental methods (measurement error) and/or through the collection of a finite number of observations of an inherently noisy process (sampling error). Randomization algorithms are used in Virtual Courseware to simulate experimental variation to make the virtual learning environment as authentic as possible. This allows each student to generate and work with a unique experimental data set. It also provides an opportunity to teach students about experimental error and the role of statistics in scientific research. An additional benefit is that it discourages cheating since each student or workgroup bases their analyses and conclusions on a different data set.

(7) Provide mechanisms that allow students to record and save experimental results

One of the challenges of using the Web to deliver learning objects is that each “web transaction” is independent. This makes it difficult to preserve the history of a user’s session on the web. Adding to this problem are the security features built into Web browsers that, by default, prevent saving to or reading from the user’s hard drive. Virtual Courseware uses a user account and server-side database model to enable the recording of observations, data, and results. This is manifested as a built-in electronic notebook or journal. Students use this data to compose an online laboratory report for the experimental activity. Thus, the online user interface exhibits the entire process of science from discovery, to analysis, to reporting. One advantage of this paradigm is that, since all user results reside on the server, the data follows the student from school to home to library. Furthermore, collaborative groups have access to the same information and can build upon the same results. Another advantage is that it also provides a mechanism by which teachers can access students’ portfolios online for the purposes of assessment (Design Principle 8 below).

(8) Incorporate assessment tools

Assessment is critical for understanding the effects of technological tools on student learning (Pellegino, Chudowsky, and Glaser, 2001). For this reason, Virtual Courseware includes assessment tools that teachers can use to gauge the performance of their students. Instructors can access the lab notebooks or journals that students generate during the course of their investigations. Teachers can also view their

students' reports and evaluate these reports using a grading rubric. The activities include an online quiz that consists of randomized interactive questions. The questions take elements of the activity and address the intended learning objectives. The students' answers are graded automatically and stored in the server database, and a printable certificate of completion is issued for each student. Instructors can access individual student and class results, allowing them to quickly gauge how well the key concepts were understood.

(9) Allow customization by instructors

Every classroom situation is unique. In developing instructional tools, especially with teachers of secondary science, one attractive feature is the ability to adapt components of an activity to make them appropriate for different levels or populations of learners. The most recent Virtual Courseware user interface gives teachers the ability to choose quiz options and grading policies, modify the student report templates, create multiple versions of the guiding questions for students, and modify grading rubrics for their students' laboratory reports. Furthermore, the teacher has the ability to set up and manage multiple classes with the differentiated material. These capabilities are provided by using a password-protected "teacher workspace" which is tied to each teacher's account.

(10) Provide online help for students and supporting documentation for instructors

Open-ended learning environments can be a challenge for students because they require sophisticated levels of cognitive functioning (Land 2000). Designers need to consider the embedding of "scaffolds" that guide learner investigations so that students can connect what they are doing with their prior knowledge (Land, 2000). Three key features of Virtual Courseware that address this principle are the inclusion of graphical on-screen prompts, detailed context-sensitive instructions for students, and supporting teacher material. The latter describes the activity in detail, includes suggestions for classroom assignments, and provides additional scientific background information. The instructional guides are available directly within the application and as a printable portable document format file (PDF).

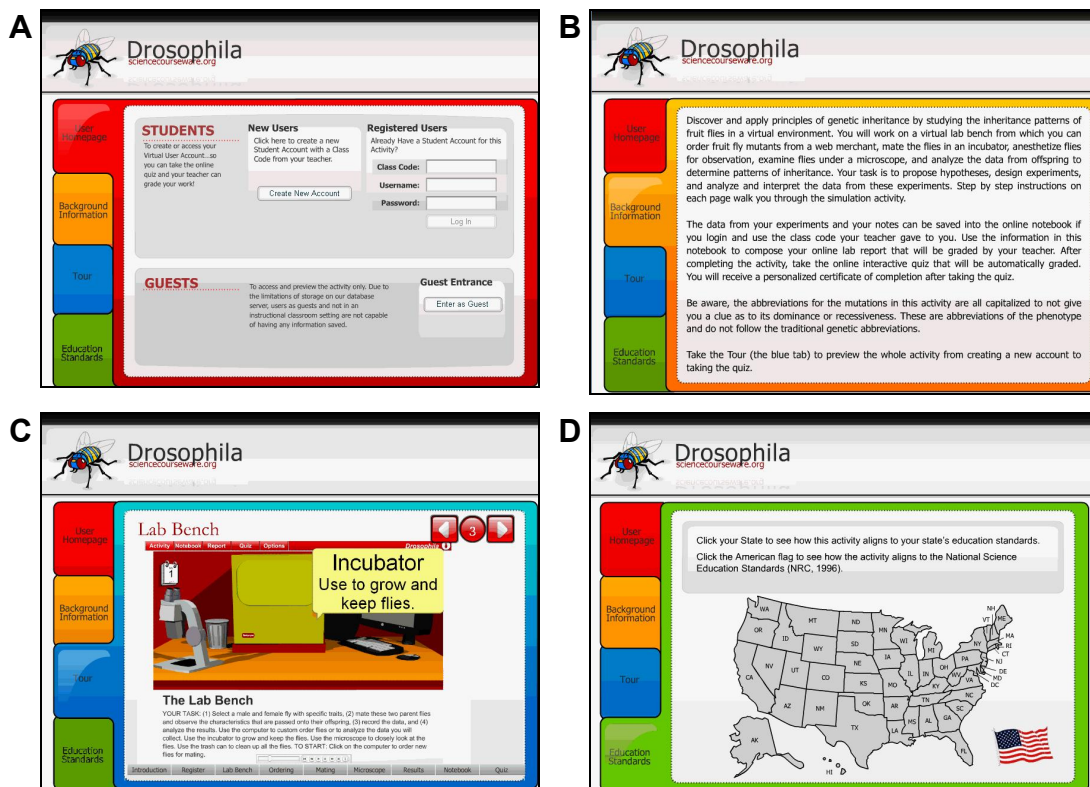
### **An Example of Virtual Courseware: The Drosophila Activity**

The design principles listed above evolved from the development of interactive and inquiry-based activities in the Virtual Courseware Project over its history (all accessible at the project's homepage: <http://www.ScienceCourseware.org>). The simulations were created to enhance traditional earth, environmental, or life science curricula and to provide a supplement to experimental laboratory or field work. The Drosophila activity is one example that addresses all ten guiding principles and is described here.

Drosophila (<http://ScienceCourseware.org/vcise/drosophila/>) is an interactive simulation created to support genetics instruction in secondary schools. Students use Drosophila to discover the principles of genetic inheritance by performing mating experiments with fruit flies. The activity addresses several National Science Education Standards at both the middle and high school levels (National Research Council, 1996). Teachers and students can see the explicit alignment on the website. The content targets the standards for scientific inquiry and the molecular basis of heredity. These learning standards and objectives were first identified in the initial phase of development for this activity (Principle 1).

The Drosophila activity was designed using Macromedia Flash and runs within any web browser that supports the Flash plug-in (Principle 2). Moreover, keyboard short-cuts have been designed to assist in the navigation of the website, if necessary. Throughout the activity, visual graphics (colors and animations) are complemented with brief or detailed text to address multiple styles of learning. The entry page for Drosophila begins on the user homepage tab in which the student user creates a new account by clicking on the "Create New Account" button (Fig. 1A). 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 (Fig. 1B) provides a brief overview on what the student should expect in the activity. The tour tab (Fig. 1C) provides an animated linear

demonstration of the activity (Principle 5). The education standards tab (Fig. 1D) shows how the *Drosophila* activity aligns to state and National Science Education Standards (Principle 1).

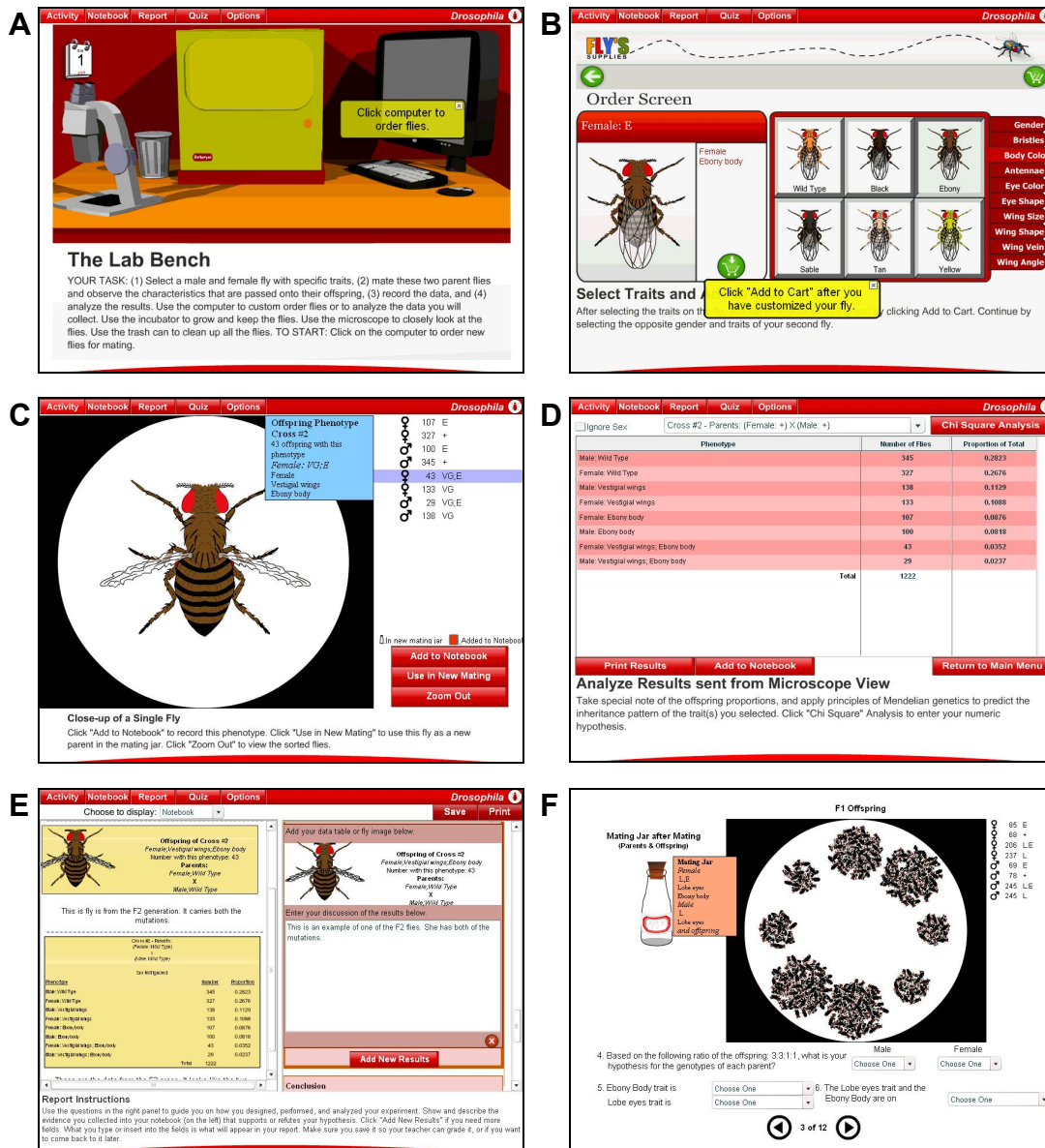


**Figure 1.** The student entry point for *Drosophila* has four tabs: (A) a user homepage where students can create a new account or log into an existing account (guest access is also allowed), (B) a brief background information page that describes the activity, (C) an animated tour with controls for pausing, rewinding, or jumping to different parts of the activity, and (D) a clickable map that provides access to the science content standards of each state and the national standards and shows how the *Drosophila* activity aligns to those standards.

The overarching theme in designing and developing an engaging web-based activity focuses on interactivity, intuitiveness, and inquiry (Principle 3). The user interface mimics real life situations in the process of experimentation, including instruments for performing the experiment and tools for documenting the experiment. After logging on, the student sees a lab bench with the equipment necessary to perform the fruit fly experiments (Fig. 2A). In a typical experiment, the student selects a male and female fly with specific traits, mates the two parent flies, observes and records the characteristics that are passed onto their offspring, and analyzes the results. Offspring from one cross can also be mated to produce a second generation. The computer in the lab bench allows the student to custom order flies or to analyze the data that is collected. This process of scientific experimentation provides an environment that reinforces scientific methodology and critical thinking skills for the student (Principle 4).

Designing an experiment begins with the “Fly’s Supplies” screen (Fig. 2B). The fly being customized is in the view on the left half of the screen along with a listing of its characteristics. Visible mutations are chosen from a tabbed catalog on the right. Up to three traits may be selected for any single experiment. Possible choices include thirty traits in different categories: gender, bristles, body color, antennae, eye color, eye shape, wing size, wing shape, wing vein, and wing angle. Thousands of experimental combinations are possible allowing for open-ended inquiry (Principle 5). At “checkout time,” images of these flies can be saved directly into the online notebook. The next steps occur at the lab bench (Fig. 2A). The customized flies are shipped, unpacked, added to a mating jar, and placed in the incubator to initiate

mating. An animation shows the development of flies through a normal life cycle. Another animation shows the offspring flies being anesthetized with ether in preparation for viewing under the microscope. Data collection occurs in the microscope view (Fig. 2C). The flies can be automatically sorted based on their phenotype. A table in the upper right of the screen lists the gender, count, and phenotype of each group of flies. Students send their data to the computer for later analysis. Clicking on a fly pile zooms the view to a single fly. The fly image can be saved into the online notebook and later added to a student's report. *Drosophila* allows multiple generations. A zoomed fly in the microscope can be chosen for a new mating. If a test cross is desired, a new fly from the store can be also used for a mating with the offspring fly. Multiple generations allow a student to see experimental examples of classic Mendelian genetic ratios.



**Figure 2.** Views from the *Drosophila* activity: (A) the laboratory bench showing the microscope, incubator and computer, (B) the “fly store” where students custom order flies for experiments, (C) a view within the microscope of an offspring fly, (D) a data table showing the results of an experiment, (E) the report view showing a student’s laboratory notes on the left side and the report they are writing on the right side, and (F) one of the questions in the interactive assessment quiz.

Data analysis occurs in the computer view (Fig. 2D). Data transferred from the microscope appear in tabular form. Virtual Courseware uses randomization algorithms that simulate experimental error (Principle 6). Thus, no two students will obtain data that are exactly the same. Students can propose a numerical hypothesis for the expected ratio of the different fly phenotypes and see how well their hypothesis matches the data. A chi-square statistical analysis is also an option. All data tables and analyses can be saved in the online notebook (Principle 7).

Throughout the activity, images, data, and notes are added into the notebook and can be viewed under the notebook tab (Fig. 2E). Once the report is activated by the teacher, the report tab guides the student in writing an online lab report (Fig. 2E). The student can move a copy of any fly image or data table from their notebook into the report. After the teacher has activated the quiz, students can use the quiz tab to answer a series of interactive and randomized questions which are similar to the tasks they perform with the activity (Fig. 2F). This quiz is graded automatically and the student gets a certificate of completion together with a report on their quiz results. The quiz can be repeated as often as a student wishes, but the teacher chooses a policy of whether or not to accept the first quiz, last quiz, or highest score. All three components (notebook, report, and quiz) are assessment tools that can be used by the teacher (Principle 8). In the options tab, the sounds, transitions, or the on-screen directions for the activity can be turned off or on.

The latest Virtual Courseware introduces a section for instructors called the “teacher workspace” (Fig. 3). This section permits teachers to create, customize, and manage multiple and/or differentiated classes (Principle 9). Teachers first register by completing a brief online form for general demographic information. Teachers then use the workspace to establish classes (Fig. 3A). Each class is associated with a class code that the teacher shares with their students. The students use the class code when they set up their account thus giving the teacher access to their assessment results. Teachers can create a set of customized report templates (instructions to the student) and associate the different report templates with different classes (Fig 3B). Likewise, teachers can create customized versions of the rubric they use to grade the report and associate the different rubrics with different classes (Fig 3C).

Through the assessment tab, the teacher can access student and class results, allowing them to quickly gauge how well the key concepts were understood (Fig 3D). Teachers can also use the assessment tab to view student notebooks and grade student reports using the associated rubric (Fig. 3E). The Teacher Workspace also provides access to a printable teacher’s manual (Fig. 3F) that includes instructions on using the activity with students, suggested student assignments, and additional background information for more advanced lessons (Principle 10).

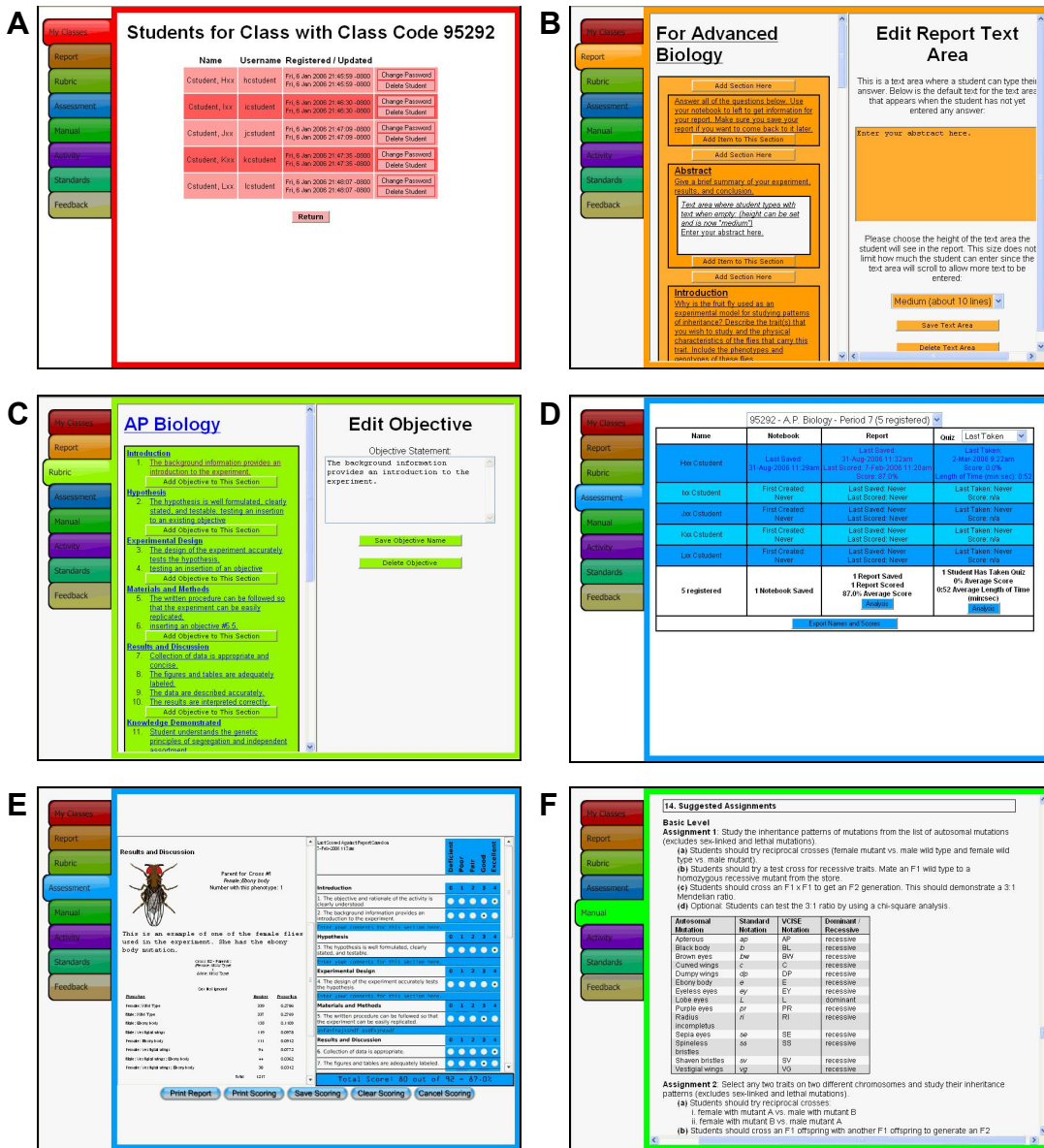
## Conclusion

Web-based simulations can be a convenient and effective means of infusing more inquiry-based learning into the science curriculum. When creating learning objects for this purpose, care must be taken to address learning standards, provide an engaging and open-ended learning experience, reinforce scientific methodology and critical thinking skills, and include opportunities for assessment. The design principles recommended in this paper can help achieve these goals.

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**Figure 3.** Views from the teacher workspace for *Drosophila*: (A) a list of registered students in one of the teacher's classes that is using *Drosophila*, (B) the report editor for customizing instructions to students, (C) rubric editor for customizing the rubric used to grade reports, (D) the assessment view for the quiz and report, (E) the assessment view for grading student reports using the rubric, and (F) an online view of the teacher manual.

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