A Survey of Currently Used *C. elegans* Curricula

Morgan (1999) noted that "Many of the features that make *C. elegans* an excellent research organism—its small size, rapid life cycle, and ease of cultivation—also make it useful for undergraduate instruction, including courses in genetics, developmental biology, and molecular biology." While *C. elegans* is popularly used in research laboratories, its use is increasing in education. At the 12th *C. elegans* Meeting, a teaching workshop was held for educators who use *C. elegans* in their classrooms. During the meeting, the teachers exchanged their experiences, including how to invoke students' interest in science. A poster session was held after the teaching workshop, where educators displayed and discussed how they have incorporated *C. elegans* into their curricula. After the meeting, I met with most of these *C. elegans* educators, discussed how they used *C. elegans*, and obtained their permission to include descriptions of their use in my project. These descriptions follow this introduction.

C. elegans has been used as an educational tool in several disciplines. According to the disciplines and level of the courses, I will categorize the use of *C. elegans* below. First of all, the type of curriculum is divided into two categories, which include lecture/laboratory and courses with a research focus. For each of the disciplines, I have further categorized the courses as being introductory or advanced.

C. elegans in Lecture/Laboratory

Most of the educators use *C. elegans* in laboratory sessions that accompany a lecture course.

Introductory Biology

Example 1.

Dr. Stephanie Aamodt teaches an introductory biology course at Louisiana State University-Shreveport in the Department of Biological Science. Students in this course learn basic biological concepts and techniques. Due to the ease of cultivation and the availability of mutant worms, *C. elegans* is chosen as the experimental organism for students to work with. Students learn how to use microscopes, how to distinguish different sexes, how to characterize wild-type and mutant worms, and how to observe behaviors in different environments such as, those in which there are different chemical substances. By observing and examining wild-type and mutant worms, students can learn to size a worm, how worms move and how worms sense, how worms react to different chemical gradients, how mutant worms react differently from wild-type worms to stimuli, and realize how mutations can influence behaviors.

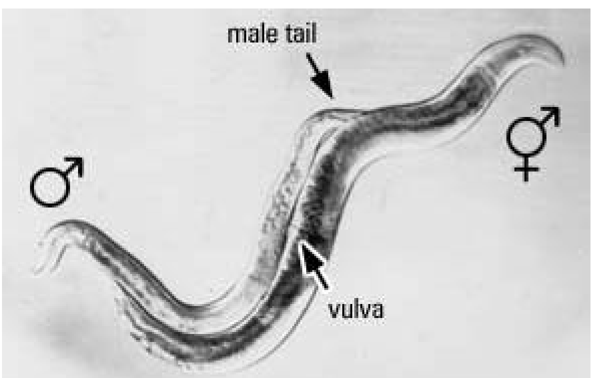
While using *C. elegans* as a model organism, Aamodt mentioned certain disadvantages of its use. Its small size makes it hard for beginning students to handle and manipulate. In addition, she points out that the currently used *C. elegans* databases (ACeDB: A *C. elegans* DataBase), which is used by researchers, is not student-friendly (Aamodt, 1999).

Example 2.

Dr. Elizabeth DeStasio teaches an introductory biology course at Lawrence University-Appleton in the Department of Biology. Students work as a team on a small project with the faculty. They learn general methods of scientific research, including hypothesis testing, data collection, and interpretation of results, and the importance of controls in a research project. The use of *C. elegans* provides students chances to practice scientific methodology. For example, students experiment with the motility of *C. elegans* by using wild-type and motional mutant worms. They measure and compare tail-beats/min of different worms. By doing this experiment, they learn the importance of controlling some variables (such as the sex of the worm) in order to get reliable data. Students also use *C. elegans* to observe how it reacts to chemical substances and whether it is able to learn. In this course, *C. elegans* acts as a model organism for students to learn basic biological concepts and experience the scientific research process (DeStasio, 1999).

Advanced Evolution

Dr. David Fitch offers a course, Principles of Evolution, for graduate students at New York University in the Department of Biology. *C. elegans* is used as part of the instructional material. Primarily, literature on the worm is used for students to discuss



concepts in evolution. For example, papers about heterochronic mutants of *C. elegans* are assigned for students to discuss how this might be used to explain macroevolutionary changes.

Another use of *C. elegans* in this evolution course is literature on its vulval development. The developmental process of vulva in *C. elegans* is especially suitable for the study of developmental genetics, because *C. elegans* is transparent, making the tracing of cell lineages possible. The mutant and wild-type phenotypes are easily observable as well. As it is feasible to trace *C. elegans*' vulval development, research literature produced from this development is widely available and is useful for students to study certain principles in both developmental genetics and evolution (Fitch, Hubbard, & Clark, 1999).

Advanced Genetics

This genetics course, designed by Dr. William Morgan at Wooster College, allows students to learn the principles and methodology of genetics, using *C. elegans* as an experimental model organism. *C. elegans* is used in the laboratory to engage students in solving genetic problems and exploring genetic concepts. Students study the properties of genes, such as how a mutated gene in a worm influences the worm's phenotype. Under Morgan's supervision, students design their own experiments to decide whether a specific mutation is dominant or recessive to the wild-type phenotype. By working on wild-type and mutated worms with known genetic backgrounds, they learn how to determine where an unknown mutated gene is located in the worm's chromosomes.

As Morgan mentioned, by working on *C. elegans*, students learn how to handle this powerful model organism that can be used in further studies, such as in developmental biology and molecular genetics. *C. elegans*' various mutants, such as motion defective worms, are good materials for students to learn how genes influence phenotype, such as behavior. Students not only learn genetic concepts, they practice the process of scientific investigation and become familiar with the techniques that are needed for advanced genetic studies.

Advanced Molecular Biology

Example 1.

Morgan not only uses *C. elegans* in teaching genetics, he also uses it in molecular biology as well. The laboratory section for his molecular biology course is a mini-project under Morgan's own research project which was granted by NIH and is mainly working on two genes - *kin15* and *kin16* that encode two tyrosine kinases. Students use *C. elegans* to practice powerful molecular biological techniques. For example, they perform PCR (a technique that enables researchers to amplify a small amount of DNA into detectable amounts) to select desired mutants (Morgan, 1999a; Morgan, 1999b).

Example 2.

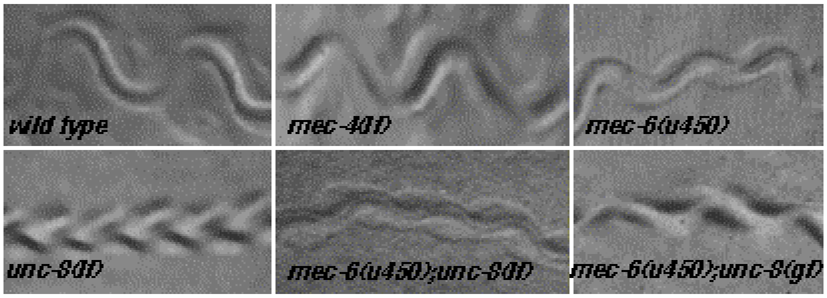
This course is a "molecular methods lab" conducted by Dr. James Lissemore at John Carroll University. It focuses on exposing students to advanced molecular biology techniques. *C. elegans* is used as an experimental material for students to practice different advanced molecular methods, such as PCR. Its importance is that it can be used to expose the difference between alleles of the same gene. For example, if a gene with a mutated allele will result in certain kinds of diseases, PCR can be used to screen whether certain individuals have this mutated gene. As it is a powerful and commonly used tool, ability to perform this technique is necessary for students in molecular biology. In this laboratory, *C. elegans* is used as an experimental system, much like *E. coli*. Students extracted genomic DNA from wild-type and mutant worms, (e.g. mutation in *unc-93* gene) respectively. They then use these extracted genomic DNA to perform/practice PCR and see whether the *unc-93* gene is deleted in any of these worms. PCR results are represented as different DNA band patterns on an agarose gel, which is then stained with a fluorescent dye to show the bands. By comparing the differences among resulting patterns from different mutants, students are able to acknowledge the power of PCR. Usually students are able to perform this experiment and obtain the expected results (Lissemore, Lackner, & Fedoriw, 1999).

Advanced Molecular Genetics

This is a National Science Foundation (NSF) funded course taught by Dr. Bruce Wightman at Muhlenberg College. Students design their own projects, and are exposed to inquiry-based learning. In this course, *C. elegans* serves as an experimental organism for students to learn molecular genetics. The project they are working on is to learn DNA cloning by using *C. elegans*. Thanks to the completion of *C. elegans*' genome sequence and its availability on the world wide web, students search the genome database on the web and find a gene of interest to work on for the whole semester. By working on cloning a gene of interest in *C. elegans*, students learn various techniques and practice research methodology, including the design of an experiment. For example, they start with the search of a gene of interest for assessing the function of this gene. Along with the scientific learning process, they also learn powerful techniques, such as PCR (Wightman, 1999).

Advanced Physiology

In this physiological laboratory, taught by Dr. Taylor Allen at Oberlin College in the Department of Biology, *C. elegans* is used to enhance the concepts students learned and involve them in experimental design. Dr. Allen mentioned that the reason he picked *C. elegans* for students to work with is because of the large numbers of available mutants. It is easy to find motional defective worms to be used in muscle physiological experiments. For example, the phenotype of worms with a selected missense mutation in the *unc-54* gene has a limp paralyzed phenotype, yet the worms' muscle structure is not destroyed.



This figure shows one wild type (in upper left corner) and 5 locomotion defect worms. As you can see, the moving patten of mutants is different from wild type.This is to show how locomotion defect can affect worms' motion.

As this is an open-ended physiological laboratory, students are involved in designing their own experiments. They use wild-type and mutant worms to measure muscular performance, using tail-beats/min. By observing and doing these experiments, they come to realize the relationship between muscle structure and muscle function. For example, by comparing wild-type to mutants, students realize that to possess the same muscle structure does not mean the muscles will perform the same function equally. Furthermore, students can apply this understanding to some human diseases, such as certain human heart diseases and muscular dystrophy.

By using *C. elegans* in this open-ended physiological experiment, students gain both understandings of certain physiological concepts and techniques that can be used in tackling other physiological problems, as well as an in-depth understanding of scientific methodology (Sulcove & Allen, 1999).

C. elegans in Courses with Research Focus

Introductory Genetics

The "Project Lab", which is a research-intensive course, offered by Dr. Leilani Miller at Santa Clara University and is funded by NSF for five years. The purpose of this course is to bring students to a research laboratory and have them experience real life research problems. Part of the aim is to retain students in the biological sciences and enhance their critical thinking via the Project Lab training.

The goal of the project is to study/isolate genes that affect the cell fate in the process of *C. elegans*' vulval development. *C. elegans* is an excellent choice as the mutants are easily visualized and the vulva is not required for viability. The working objectives for each year are connected to the previous year and the upcoming year in terms of the data and materials developed. For example, in the first year, students select mutants that are defective in vulval development, then use PCR to decide which chromosome the mutated gene is located on and to characterize the gene in terms of its dominance or recessiveness. The research findings will be used by students enrolled in the following year.

While working on *C. elegans*, students learn basic biology, advanced molecular and genetic experimental techniques, such as how to handle worms, how to perform PCR, and how to clone genes of interest. They learn biological concepts and experience what real life research problems are and how to solve these problems as well (Miller, 1999).

Advanced Molecular Biology

The course is offered by Dr. Joe Pelliccia at Bates College. It is a research & seminar course which mainly provides students the experience of doing research, like graduate students do, by using *C. elegans*. The research question students work on is whether the *mut-2* gene influences meiotic recombination during meiosis. By working as a group on a project using *C. elegans*, students also experience, to a certain degree, how *C. elegans* researchers work. For example, a *C. elegans* database (ACeDB) hosted on several web sites is where researchers usually search for gene sequences or particular publications. Students are required to be able to use this resource to search and measure the map distance between genes of interest. Students attend journal clubs routinely to gain up-to-date information about *C. elegans*. They also learn basic techniques, such as how to handle and experiment with *C. elegans*. These techniques then can be used in more advanced biology courses. At the end of the semester, students are supposed to compile their findings, write a scientific article, and have the article published in a newsletter of the worm community, the "Worm Breeders Gazette."

In sum, as shown above, *C. elegans* is been used in both lecture and laboratory as a model organism. It has been used in various disciplines, such as genetics, molecular genetics and molecular biology. From its use in teaching, we can see the wealth of resources used from research laboratory to education, such as the use of mutant worms and powerful techniques like PCR. By using *C. elegans* in classrooms, educators hope their students not only learn biological concepts but also the process of scientific investigation and the advanced techniques/tools that will be needed for further study in science.

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