Biocomplexity in the High School Classroom

By Michael Sinclair[1], Kalamazoo Area Math & Science Center - Helene Dauerty, Elkhart Central High School - Tom Finke, Trinity School at Greenlawn

It's early May and your students have just finished taking the Advanced Placement® Biology examination. There are two or three weeks left in the school year and the question is: What to teach? More of the same? Something new? How about a short, exploratory topic beyond high school biology? In this paper, we suggest the newly emerging field of biocomplexity.

Biocomplexity is the study of the structures and behaviors that arise from the interaction of biological entities such as molecules, cells, or organisms. While physical and chemical processes give rise to a great variety of spatial and temporal structures, the complexity of even the simplest biological phenomena is infinitely richer[2]. Over the past decade, much of the focus of biocomplexity research has been on the development of mathematical and computer models which carefully replicate the known characteristics of a cell or a biological organism[3-4]. At a variety of colleges and universities, mathematicians, biologists, physicists, biochemists, and computer scientists are working on developing techniques based on mathematical methods, probability theory and stochastic processes coupled with computer modeling for the study of biological problems.

As part of this interdisciplinary approach, and in conjunction with the National Science Foundation's Research Experience for Teachers program at the University of Notre Dame, we have developed a web-based modeling environment designed to introduce high school students and teachers to the field of biocomplexity, familiarize them with related research currently underway, and – most importantly – incorporate an integrated approach to learning the prerequisite knowledge necessary for examining mathematical and computational biology at the cutting edge. The site – located at www.nd.edu/~tutorial – is a basic and straightforward introduction to modeling and biocomplexity.

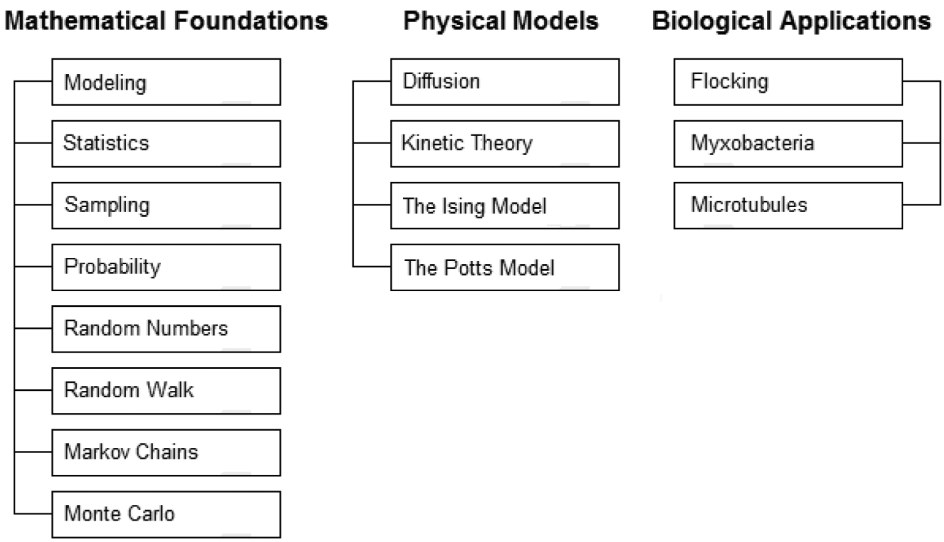
A concerted effort was made throughout the development of the online tutorials to make them user friendly, clearly written with many examples, and – most especially – highly interactive. In addition, we focused on developing a comprehensive site, which was aimed specifically for use in the high school classroom applicable to the students' academic level. We intended for our tutorial to be a solid introduction to biocomplexity with a carefully developed survey of the pertinent mathematical and computational concepts and tools commonly used in the field. Finally, we wanted students to interactively examine various mathematical and physical models illustrating the behavior of specific biological systems.

This modeling environment was specifically designed and formatted in such a way that it could be readily linked into the corresponding mathematics and life sciences courses; the tutorials can be used as a supplemental topic for AP Statistics or AP Biology. We also see it as the foundation for "doing" basic research at the high school level.

Design and structure

The end configuration of our web-based tutorial incorporates a three-strand approach; one strand focusing on the mathematics necessary to explore the second track, the second strand being an overview of the basic physical models used to explore the ▶

Fig. 1. Three strand tutorial approach.



third strand, and the third strand examining the biological behavior currently under investigation These are shown in Figure 1.

A variety of computer modeling programs are used throughout all three strands, including NetLogo™, MatLab™, and CompuCell3D™. However, the majority of the simulations were developed using NetLogo, primarily because the program is easy to use, free (an especially important factor for teachers given the current fiscal restrictions faced by educators today), and easily downloadable directly from the NetLogo homepage at http://ccl.northwestern.edu/netlogo. The programming language is simple, user-friendly, and extremely robust. NetLogo also has a strong educators and users support group5. Finally, all the basic simulations are embedded in the tutorial itself.

The high school teachers developed modeling tools and wrote tutorials with guidance from researchers currently working in the field. Each tutorial dealt with key concepts necessary to examine biocomplexity behavior within the limitations of the available background of the students. They all followed a straightforward and readily recognizable format; an introduction to the topic under investigation with examples, then a computer-driven model (with the ability for students to modify initial parameters), and ending with links to additional resources

Completion of all the web tutorials would give students a reasonably comprehensive overview of biocomplexity and also allow teachers to evaluate their knowledge and progress through the material.

Tutorial format

The modeling environment is best appreciated by using it. However, screenshots and brief explanation of each section can be used to convey key aspects of the tutorial. We use the structure of the interface shown in Figure 2 below as the basis for the tutorials. The Navigation Wheel links the four parts of each tutorial topic: **How it works, Activities, Quick links,** and **What's next.**

In **How it works**, an overview of the given topic is presented. This section describes

Fig. 2. Screenshot of Modeling Myxobacteria tutorial opening page.

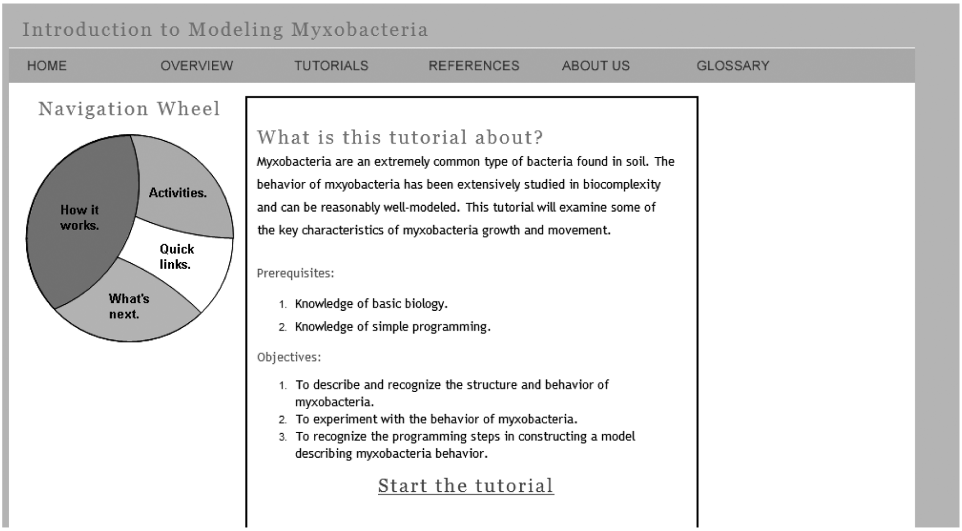
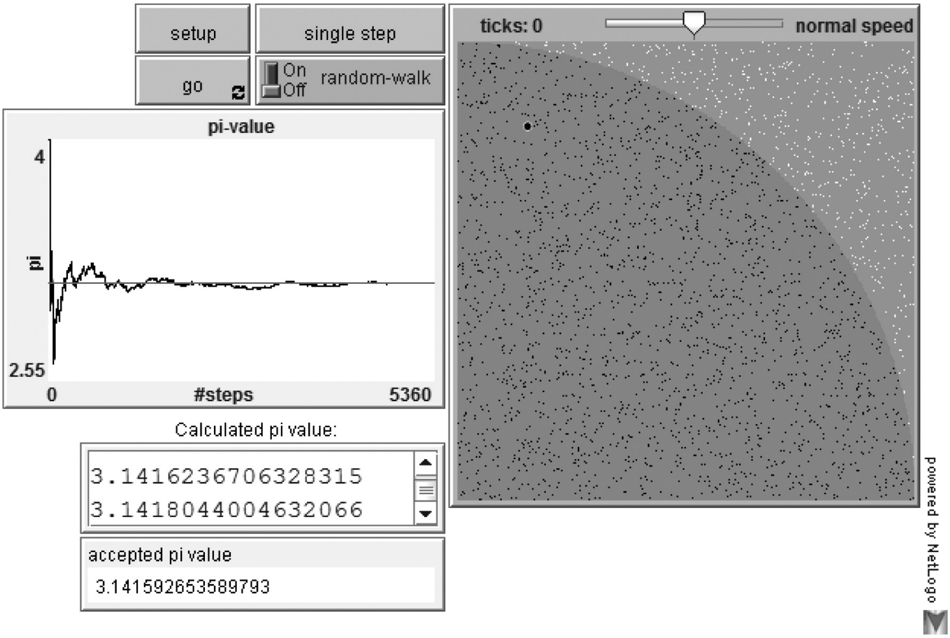


Fig. 3. Screenshot of beginning of the Introduction to Microtubules tutorial How it works section

the basic theory and concepts in this tutorial, how the computer model works, and outlines several examples and activities. Some of the topics also include a short summary explaining how the model is used in studying biological behavior. For the more advanced tutorials, it was assumed that students will have worked through previous material so there is little or no review. For example, see Figure 3.

The **Activities** section actually allows students to interactively test the model; this is where the applets for the various simula- ▶

Fig. 5. Screenshot from the Monte Carlo tutorial.



tions are located. Several of the programs have parameters which can be changed so students have the opportunity to work through a series of models. Students are encouraged to try to do as many as possible as each trial will illustrate more about how the topic works.

Note that all of the models have been simplified so that students are able to handle the level of expertise needed to at least recognize the cogent aspects of the science and mathematics behind topics given.

The **Quick links** section has direct links to similar sites that describe extensions to the area of interest as well as a list of resources (such as books, articles, etc.) available to the student. In addition, this also takes students to a complete glossary of all the key terms found in the tutorials. Finally, the **What's next** section directs students to the next tutorial topic. They may also chose to "leap past" any given tutorial area and examine other topics as they see fit.

Future Work

Early reviews by students and teachers have generally been positive, but a more extensive evaluation will be performed this upcoming academic year. We are also planning a workshop for high school mathematics and science teachers as well. The next major step in this project will be to create several more tutorials, including cellular automata, population dynamics, limb formation, and blood clotting. We also plan on developing and incorporating a series of evaluative tools for the classroom.

The collaborative approach in developing an integrated and interdisciplinary program along with extensive opportunities to explore the connections between mathematics and biology through a web-based environment are the next major phases in the long-term reform of the secondary school curriculum. It's time to take the plunge and check out biocomplexity at www.nd.edu/~tutorial.

References

1. Kling, J (2004). Mathematics in Biology: The Mathematical Biology Job Market. Science's Next Wave. Online: nextwave.sciencemag.org.
2. Chaturvedi, R., C. Huang, B. Kazmierczak, T. Schneider, J. A. Izaguirre, T. Glimm, H.G.E. Hentschel, J. A. Glazier, S. A. Newman, M. Alber (2005), On Multiscale Approaches to 3-Dimensional Modeling of Morphogenesis, Journal of the Royal Society Interface 2 3, pp. 237-253.
3. Gregoretti, I., Margolin, G., Alber, M., & Goodson, H. (2006). Modeling microtubule dynamic instability, Journal of Cell Science 119 (22) pp. 4781-4788.
4. Wilensky, U. (1999). NetLogo. Center for Connected Learning and Computer-Based Modeling. Northwestern University, Evanston, IL. Online: ccl.northwestern.edu/netlogo.

About the Authors

- **Michael Sinclair** – Kalamazoo Area Mathematics & Science Center, 600 West Vine, Suite 400, Kalamazoo, MI 49008, msinclair@kamsc.k12.mi.us