**Final Report
Exploratorium
Exploring the Gene: Interactive Exhibits on Genetics and the Human Genome
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Project Summary

Under funding by the United States Department of Energy, the Exploratorium has substantially completed the prototype development of four exhibits on the nature of DNA and genetics, and substantially completed the production of finished exhibits based on these prototypes. Over the next two months, we anticipate completion of the various elements, with a corresponding evaluation of their pedagogic effectiveness in communicating molecular biology and genetic principles. Individually these genetic exhibits have been designed to elucidate specific themes, such as, the molecular properties of DNA, the encoding of genetic information, the expression of genetic information, and technological manipulation. The exhibits are titled **Dancing DNA**, **Marching Bands**, **Protein Production Line**, and **Genetic Playbook**. Specific exhibit projects are detailed below.

In all the exhibits we have sought to draw a relationship between the nature of DNA and its expression in organisms. For most visitors, DNA exists as an invisible abstract molecule with marginal connections to their lives, while organisms exist as a familiar tangible entities. Inclusion of this broad thematic connection provides the crucial bridge between the abstract principles and the real world, and serves to underpin scientific, medical, and public interest in the topic.

Development of the individual exhibits has taken longer than anticipated because of technical problems and the complexity of the project. In particular, **Protein Production Line** has taken more time than originally anticipated. I feel that the overwhelmingly popular appeal of the puzzle aspect of this exhibit to visitors of all ages, in conjunction with the fundamental understanding the model can convey, warrants significant attention. If this simple model of how DNA encodes for a protein functions as intended for a majority of our visitors, a significant educational goal will have been attained. The cabinetry for **Dancing DNA** nears completion with all prototype work completed. **Genetic Playbook** is functional now and approaches a fully operational status with an anticipated extended period of protocol modification and further specimen selection. **Marching Bands** still undergoes some testing but primarily awaits the construction of a cabinet. In Exploratorium tradition, all of the exhibits will continue to undergo evaluation and refinement over the next few years with intensive attention during the next year as we complete an additional eight exhibits on genetics and bioethics, and prepare for a major public exhibition on these topics in the spring of 1995.

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Specific Exhibits

Dancing DNA

Dancing DNA allows visitors to observe and manipulate individual fluorescently stained molecules of DNA. The individual components of the exhibit consist of a fluorescent microscope and video camera, and a joystick-controlled electric field. The remarkable observation of an individual molecule of DNA arises from molecular properties of the molecule which allow it to be stained with a number of readily available fluorescent dyes. These dyes when stimulated with appropriate frequencies of light, glow brightly to reveal the long, skinny, springy DNA molecules visible at 1,000 times magnification. Additionally, because the molecules of DNA have an inherent negative electrical charge, they may be manipulated with an electrical field. The negative DNA molecules are attracted to the positive electrode.

At the exhibit we have used both of these characteristics to demonstrate the movement of molecules of DNA through a thin agarose gel. The gel serves both as a transparent matrix for the DNA and as a partial mechanical barrier to its migration. The electrically induced migration of DNA through an agarose matrix constitutes a commonly utilized laboratory technique for the separation of DNA molecules by size, and their subsequent sequencing. Interestingly, observation of the motion of the molecules through the gel reveals an irregular serpentine movement, which at time closely imitates the movement of an inchworm caterpillar.

Through **Dancing DNA** we have aimed at demonstrating several features about the DNA molecule. First, the tiny molecule has a long skinny shape. Second, DNA has an inherent electrical charge which allows for simple manipulation. And third, DNA's electrically driven migration through a gel matrix allows for specific size separation of different length molecules. All of these features are key components of various scientific techniques that have been utilized in forming our current understanding of DNA. The exhibit nears completion with on-floor testing and evaluation scheduled for June.

As an enhancement to this exhibit, we plan on developing a computer simulation modelling the serpentine effect of DNA moving through a gel, called **Stimulated Movement**. This exhibit has been funded by the E. L. Wiegand Foundation and the United States Department of Energy, Office of Health and Environmental Research, which is supporting the development of eight additional exhibits on genetics and bioethics.

Marching Bands

Marching Bands demonstrates the separation of differently sized pieces of DNA through the use of an agarose gel and an electrical field at normal gel box sizes (a nominal 8 X 6 inches). This exhibit allows exploration of the technological applications

of the properties shown in **Dancing DNA**. Gel separation of DNA by size forms the basis for all currently available DNA sequencing procedures. At the exhibit, visitors observe the gel box, power supply, and the separating bands of differently sized pieces of DNA as they move through the agarose. Observation of the DNA occurs under ultraviolet light. To aid in the observation of the migration of the DNA bands, a grid of lines is placed below the gel box.

The final exhibit will have an enclosed dark space and visitor-activated ultraviolet light. Since our early prototyping work, described in the last progress report, we have purchased equipment, run several tests, and conducted further formative evaluation sessions with staff. Daniel Mirel, Ph.D., at the University of California at San Francisco, has consulted on some aspects of the project and been helpful in developing protocols for display. Our progress on the final exhibit has simply been slower than anticipated because of staff commitments to other projects. We expect completion of this project in mid-July.

Protein Production Line

Protein Production Line allows visitors to work through the steps involved in decoding the genetic information contained in DNA and converting this information into useful protein molecules. This exhibit essentially mimics the processes found in almost every cell of every organism and serves as the very foundation of life. The exhibit is a large-scale model of a short length of double-stranded DNA, complete with base pairs, which forms something akin to a bacterial plasmid. The belt of DNA rides on rollers, and in one portion the two strands separate, so that the information contained in the DNA may be transcribed to messenger RNA(mRNA). At this section, in the "nucleus" of our imaginary cell, loose pieces of mRNA bases are provided for transcription. Once visitors have transcribed the DNA, they move the mRNA to the "cytoplasmic" section of the table. In this section, amino acid residue "molecules" correspond to the specific three letter mRNA code found in the genetic alphabet. The DNA belt and puzzle pieces are contained on a 14-foot long doglegged table. Visitors carry out the actual work at the exhibit, filling the role of various enzymes: unraveling the DNA as DNA heliase, transcribing the DNA as RNA polymerase, and synthesizing the amino acid sequence as a functional ribosome.

The mechanical mechanism, puzzle pieces, and preliminary graphics were thoroughly tested and evaluated on visitors over an eight-month period (November 92 to June 93). At the conclusion of the evaluation period, a series of design review meetings resulted in the redesign and fabrication of mechanical components, puzzle assembly areas, surfaces materials, and graphical presentation.

As part of the initial formative development of **Protein Production Line**, high school biology teacher suggestions were incorporated into the design process and the exhibit received high marks as a teaching aid and a useful tool in laboratory workshops. When

placed on the museum floor for unaided visitor use, however, the exhibit proved less comprehensible. Though very popular with all age levels, almost no one operated it as intended. From observations, most visitors (93%) did not seem to understand anything of the steps of transcription and translation. The small percentage of visitors (7%) that did use the exhibit as intended, often turned out to be biologists. As such, the exhibit proved to be a predictor of educational background rather than a good teaching device. This result lead to a host of recommended changes.

In response to the problems identified in this formative evaluation, we sought to de-emphasize the role of written explanations in the graphics presentation and instead focused heavily on diagrams and photographic images which highlight the connection between the mechanical operation of the puzzle and analogous cellular processes. Through extensive research we located a series of strikingly beautiful electron micrographs, courteously provided by Drs. Oscar Miller and Ann Beyer at the University of Virginia, which have been incorporated as part of the graphics.

Our primary objective in creating **Protein Production Line** has been to accessibly demonstrate the steps involved in the conversion of information contained in the sequence of DNA bases into useful proteins. The key steps in this conversion are transcription and translation. As of this report, the exhibit has been on the exhibit floor for five months since its redesign and will be finally evaluated in the near future.

Genetic Playbook

Genetic Playbook seeks to display the expression of various specific genes found in *Brachydanio rerio*, commonly know as zebra fish. Zebra fish are a small, horizontally striped tropical fish that readily breed in captivity and produce easily collectible and observable eggs. The zebra fish's short generation time and translucent eggs have made it an ideal candidate for genetic observation and discovery. The fish has recently become the focus of intense scientific interest as a powerful new genetics tool. At the exhibit we display both embryos and adults.

One millimeter in diameter zebra fish eggs containing embryos at four stages of development are displayed at 20 times magnification using a modified optical comparator. At this magnification one can see the gross features of the developing embryo, such as the eyes, heart, mouth, nervous system, notochord, and skeletal muscles. As with all organisms, the genes which control the development and maintenance of the various body components are expressed at specific times during the organism's development and life. At the zebra fish exhibit, amidst the thrill of seeing a developing fish embryo, visitors can easily observe the expression of the genes which control the pigmentation. In the wild type fish this gene creates the striped adult fish appearance. Expression occurs between 24 and 30 hours of development as dark spots on the surface of the embryo. In the mutant albino form of zebra fish the pigmentation development fails to occur, resulting in a unpigmented fish. As the exhibit progresses,

we plan to use various other interesting mutations (in ground-breaking work more than 1,000 different mutations have recently been created and cataloged at the Max Planck Institute in Germany) as well as graphically depict the mapping of the zebra fish's genome.

To provide a continuous supply of embryos, as well as display adult zebra fish, we have constructed an 18-tank zebra fish "embryo factory." This recirculating aquarium system has been adapted from the system developed in Charles Kimmel's lab at the University of Oregon. Our system, when in full production, should efficiently produce a continuous supply of Zebra fish embryos for public display. Zebra fish mate approximately one hour after the first morning light. To provide a continuous supply of embryos at different stages of development, we have adjusted light-dark cycles of fishes so that only four tanks are available for public viewing during normal museum hours.

Our primary objective at **Genetic Playbook** has been to demonstrate genetic expression in a model organism. At the exhibit, visitors are able to make the simple but profound connection that offspring have the traits of their parents, that development involves a specifically timed set of genetic instructions, and that by manipulating the organism's genes, one can produce different results in the organism. As the genome of the fish becomes more completely determined, visitors will also be able to observe the genotypic and phenotypic connection. As of the writing of this report, the optical comparator portion of the exhibit is undergoing final construction and the breeding colony of Zebra fish partially functions.

Evaluation

We have engaged the services of Inverness Research Associates, Inverness, California to conduct limited formative evaluation and a more complete summative evaluation on the genetics exhibits. Their formative evaluation serves to both supplement and confirm our ongoing, in-house evaluation. The summative evaluation will be conducted over the summer months and the results of this evaluation will be forwarded to the Department of Energy as soon as they are completed. It should be noted that we have worked extensively with both high school teachers and visitors in the exhibit development process. Graphical presentation of genetic concepts has proved to be particularly difficult when compared to larger scale, physically observable phenomena, and because of this we have focused intensively on reviewing and revising sign text.

The Exploratorium

The Exploratorium is a museum dedicated to public understanding of science, art, technology, and human perception. Last year more than 629,000 visitors came to the museum, including 69,000 students on school field trips. Since its founding in 1969, by the physicist and educator Frank Oppenheimer, it has pioneered the role of museums as active teaching centers by developing interactive exhibits, publications, videotapes, workshops, and teacher training. Each year 550 teachers K-12 receive intensive

professional development classes, and 1,500 alumni participate in workshops. The basis of all these activities is the collection of 670 interactive exhibits developed at the museum. Museums around the world request reproductions of exhibits developed at the Exploratorium

Future Genetics Projects

The Exploratorium is now planning a major public exhibition on genetics for spring 1995. The exhibition will present basic genetic science as well as facets of current research in local and national laboratories. In addition, the exhibition will introduce for consideration some of the health issues and social impacts that genetic engineering and the Human Genome Project will have on people's lives. The exhibition, with 22 hands-on exhibits (including the four developed under this grant) in a 7,000 square-foot exhibit space, demonstrations, special events, films, and a lecture series, will run at the Exploratorium for three months. The project is designed to help teachers, students, and the general public explore the science of genetics and the new scientific discoveries being made by the Human Genome Project. We anticipate that at least 180,000 people will see the exhibition. In response to the need expressed by high school biology teachers for activities and materials on genetics, the Exploratorium's Center for Teaching and Learning (CTL) will present special weekend workshops for teachers and work with Genentech's Access Excellence.

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