META!BLAST: AN INTERACTIVE LEARNING ENVIRONMENT FOR INFORMAL SCIENCE EDUCATION

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ABSTRACT

Subcellular phenomena are highly dynamic, exquisitely beautiful, complex, and multidimensional, but occur at scales that cannot be directly observed. The interactive computer game Meta!Blast (metablast.org) is designed by a team of artists, scientists, and museologists to engender public engagment and participation in science. Our working hypothesis is that 4D (3 spatial dimensions + time) interactive learning environments such as Meta!Blast can increase public understanding and appreciation of scientific phenomena. Science City, Kolkata, India, piloted Meta!Blast use as an interactive exhibit in their nanoscience área, which is primarily dedicated to school children visits. An evaluation of 50 high school students indicated that understanding of basic concepts of cell and metabolic biology increased an average of 32% ($p<0.05$) after exposure to Meta!Blast.

KEYWORDS: computer game, biology, interactive,

INTRODUCTION

Science is multidimensional, which is part of the reason that it is often difficult for the public to grasp. Understanding multidimensional concepts can create a scaffold to enable a deep and expanding understanding of science. One of the most difficult challenges in learning biology is in comprehending the structure and function of cells and molecules, which occur across three-dimensional space and at different size and time scales. Yet public understanding of such highly abstract concepts is essential for society to attain the level of science literacy needed for informed decisions on public policy, and to enable participation of talented individuals, regardless of background, in the modern workforce. Even those educators who deeply understand the concepts are at a loss for immersing and engaging the public. 4D interventions (three spatial dimensions + time) have the potential to merge interactivity and (virtual) movement in space/scale and across time to provide new opportunities for students to comprehend the relationships among the life and physical sciences. Computer games are a familiar medium to many youths, and one that they relish; thus this medium may provide a key approach to learning science concepts (Aldric, 2005; Call et al., 2006). We know the importance of hands-on experience, but given the limitations of hands-on experiences of nano-scale phenomena, perhaps virtual environments can overcome these limitations and enable higher levels of learning.

RESULTS

A learning environment created across disciplinary boundaries. The Meta!Blast team of faculty and students includes artists, scientists, biology educators, museologists, specialists in pedagogy and assessment, artists, and computer scientists, all with the common goal of creating an interactive learning environment that enriches understanding of complex concepts in biology. One goal is to integrate new discovery as development of the game procedes. For example, as illustrated in Hur et al. (2013), new databases and analyses software are being developed by computational biologists to store and analyse massive information on gene, RNA and protein sequences, and small biomolecule structures. Based on this emerging área of research, we have developed a minigame on DNA/RNA sequence for Meta!Blast, and are expanding this game to incorporate concepts of metabolic networks.

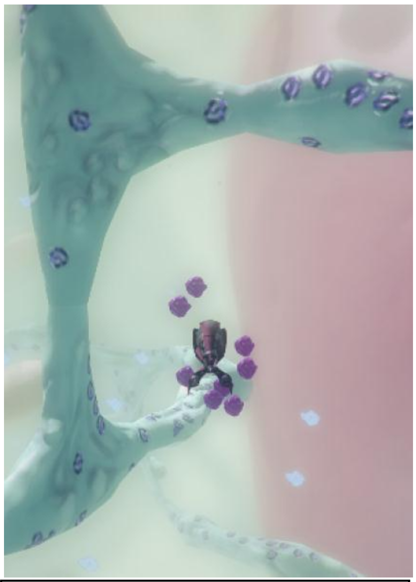


Figure 1. Inside the Meta!Blast cell. This screen shot from the computer game shows the player's bioship navigating past endoplasmic reticulum, studded with the ribosomal protein manufacturing machinery.

Art in the Meta!Blast computer game. Visualizations of the cellular world have existed since the 1600s when Robert Hooke first saw living cells through a microscope. Meta!Blast provides an original take on this fascinating environment. Envisioning a dynamic, ever-changing cell that reflects current scientific understanding is a challenge (Schneller et al., 2012). Concept art provides an initial way to define the atmosphere and lighting of Meta!Blast's photosynthetic cell and molecular scenes, and demonstrating what is possible. Our goal is to depict the liveliness of the cell, rather than the static diagrams or simplified cartoons often seen in books. Due to the minimal level of pigment in most structures and proteins of the cell, our artists had to be a bit more creative, yet still remain conservative with the color palette (Fig. 1). We chose something less saturated to avoid looking too stylized. Another challenge was determining the effects of light at such a small spatial scale. Doing so allowed us to develop our own unique view of the microscopic world, while remaining scientifically accurate as far as is known. For highly detailed organic forms such as the surface of cellular organelles or proteins, a specialized application is used; it involves taking a standard polygonal mesh and using digital brushes to establish shape, form, and fine details, with a graphics tablet used in order to achieve an analog feel. This provides a contrast with programs that rely on pushing and pulling faces and vertices with a mouse. 3D modeling software can handle meshes up to a few million faces-- digital sculptures often have tens of millions of faces-- while allowing the artist to smoothly interact with the brushes. However, all of this detail cannot be placed directly into the game, because it would require a tremendous time to render during gameplay. Thus, to simplify the forms such that game play is sufficiently quick, we combine traditional 3D modeling techniques with advanced texture maps that simulate high-resolution details (Fig.1).

Fig 2. Existing Meta!Blast learning environemt. Movement of the ubiquitin ligase proteins towards the bioship is controlled by the "pursue" steering behavior of the plug-in for Artificial Intelligence in 3D developed by Masters student PJ Campbell. If the student does not "escape, she/he is proteolysed.

Supplementary materials. To best engage the public, and to allow accessibility to the many locations world-wide that do not have sufficient

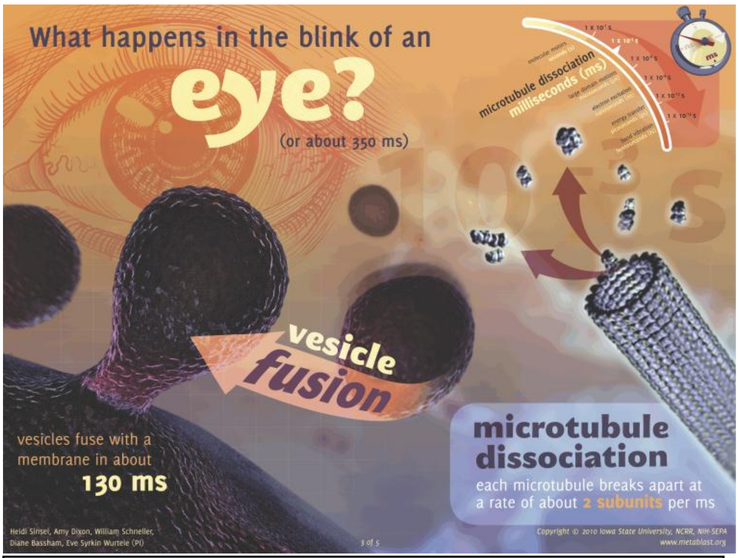


Figure 3. One in the series of Meta!Blast Time posters. These posters illustrate the speeds at which biological events occur.

computer or internet access, we have created a set of posters that supplement the scientific concepts of Meta!Blast (Fig. 3). **Scientific Accuracy.** To ensure the science is accurate according to current scientific understanding, and our representations and models are as authentic as technology will allow, our team at any time includes 2-4 research scientists (these might include, e.g., cell biologists, molecular biologist, biochemists, agronomists, physicists). Under their guidance, the team draws from original research and uses data from microscopic imaging techniques such as transmission electron micrographs (TEMs), scanning electron micrographs (SEMs), confocal micrographs and electron tomography to model the overall 3D structures of organelles and to shape the details of the cell environment, cellular function, and the game itself. The global database for molecular structures, the RCSB Protein Data Bank (PDB) (www.rcsb.org), is the source of the structural data for proteins and molecules in the Meta!Blast environment. The world of Meta!Blast is set inside a spongy mesophyll cell of a soybean leaf, and our resources and references are always filtered by relevance and similarity to the biology specific to *Glycine max*.

Figure 4. Screenshot of the Meta!Blast laboratory. The game starts in this lab.

Technical innovation*:* Creation of an Artificial Intelligence plug-in. In order to create realistic motion in a virtual environment, artificial intelligence (AI) methods are required. Meta!Blast represents a particular challenge, because unlike most other games, the *gameplay itself occurs in three dimensions.* To enable directed behavior of cellular structures in 3D, we have created an AI based on steering behaviors and octrees (Schneller et al., 2012; Fig. 2).

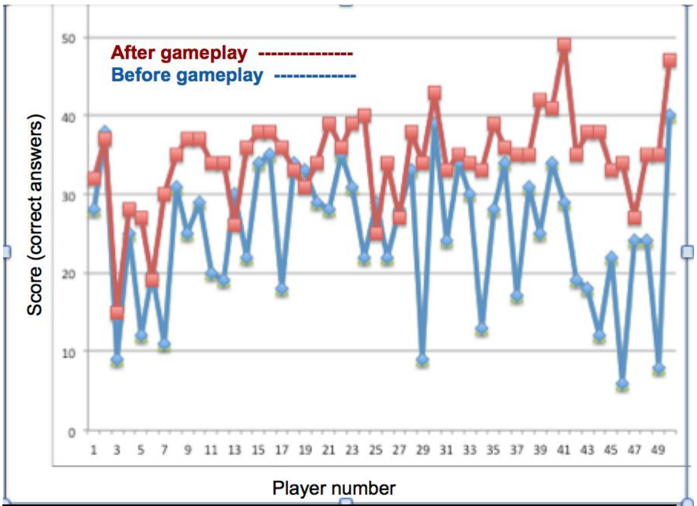


Figure 5. Formative evaluation of 50 high school student at Science City shows significant increase in learning following exposure to the Meta!Blast exhibit. Blue squares represents student scores before playing Meta!Blast. Red squares represents scores of the same students after playing Meta!Blast

Meta!Blast at museums: formative evaluation. The Meta!Blast posters, and more recently the Meta!Blast computer game, have been displayed at 16 science centers in India and the USA. In addition, Meta!Blast has been presented as interactive demos at over 30 science fairs, and schools.

The 2012 release of Meta!Blast was piloted as an interactive exhibit in several science museums in India. A formative evaluation was conducted at Science City, Kolkata. The largest of the National Council of Science Museums (NCSM) science centers, Science City has an estimated 1.5 million visitors each year. The NSCM science museums and smaller regional and local science centers are located throughout India. These science centers have a major program in which school classes visit the museum with their teachers and are guided in this experience by a trained curator; additional mobile units reach schools in rural areas. An emphasis is placed on identifying and encouraging gifted children, regardless of background. In the present evaluation, evaluation, 50 students from high schools in Kolkata were tested with a set of questions focused on basic concepts of cell and metabolic biology. The test was conducted before and after each student's exposure to the Meta!Blast learning environment.

Sample question (50 questions total):

When a mesophyll leaf cell is very young and small, it looks much paler. Why was this?

1. *The cell had little chlorophyll*
2. *The cell had a very thick wall*
3. *The cell was white*
4. *The mitochondria were larger*
5. *The cell was filled with pigment*

Student scores following a single exposure to Meta!Blast increased by an average of 32% ($p<0.05$).

The survey also contained set of questions designed to understand how the students were able to navigate the mechanics of using the Meta!Blast computer game. By using this portion of the evaluation, the museum and exhibit development teams were sable to

Figure 6. High school teachers play Meta!Blast in Science City. Though not "gamers" and a bit reluctant at first, these teachers caught on quickly.

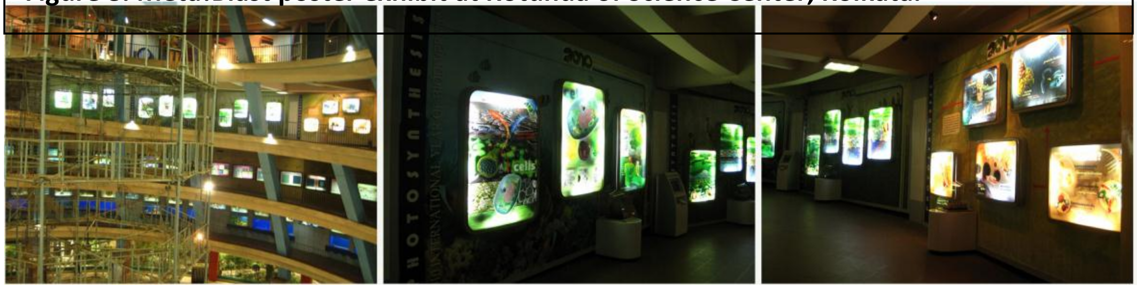
see what aspects of Meta!Blast could be made more effective. The results indicated the major challenge the students experienced was ease of use of the game controls. The Meta!Blast team is in the process of improving this aspect of the game. An anecdotal incident from directly after the installation of the computer game: a high school student ran up to the developer and said, "I used to think cells were boring. Thank you for making Meta!Blast, because now I really like them and want to learn more about them".

Figure 7. Gifted high school students from Ames, IA, USA (l) and Hyderabad, India (r) playing Meta!Blast

Recommendations for use of Meta!Blast as a teaching tool. Meta!Blast posters should be displayed in museums in proper sequence. The associated educators guides to the posters should be printed in the form of brochures. Brochures should be read by curators, and taught to all educational assistants. After explanation, brochures can also be given to teachers as handouts to be taken back to schools. Science City has displayed the posters using very simple but effective *supporting explanation*. This could provide a role model for other museums. It is an highly effective technique for display of the poster material.

The Meta!Blast computer game can be used as a exhibit in museums as a single player, large-screen or in a multiplayer format. Trials in a variety of public settings in the U.S. and India, including Science City, indicate that one particularly effective set up for student learning is to place three computers with modern graphics cards (detailed information on computer requirements is at metablast.org), and internet access (if possible), exhibit in proximity and at angles to one another. Curators or teachers moderate three to 4 players position themselves at each of the 3 computers. The students on each team collaborate with each other. The teams compete to achieve the

Figure 8. Meta!Blast poster exhibit at Rotunda of Science Center, Kolkata.



highest score in a given time (from 10 to 30 minutes, depending on context).

CONCLUSION

Meta!Blast represents an innovative 4D approach to engaging the public in cell and molecular biology. The application combines biology and art in an interactive 4D computer game. Formative evaluation of a Meta!Blast exhibit with high school students indicates that it represents a novel method for engaging the public that can be used effectively by museums for science education. Meta!Blast will capture the imagination of children, and stimulate them to take up careers in the basic and applied biosciences The approach could be applied to other aspects of STEM education content.

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