# Biosphera: A Prototype Design for Learning about Multivariate Systems

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## Abstract

This paper presents a prototype learning environment for children to create their own knowledge about multivariate systems. We developed a virtual world linked to a tabletop–sized physical dome in which children experiment with environmental parameters affecting plant growth. A key concern of the design was giving children control of the temporal domain, allowing for the playful exploration of cause-and-effect relationships. We show how this resulted in a tool in which children may create, exhibit and reflect upon their own knowledge by challenging and exploring their conceptions of variable interaction.

## Keywords

Constructionism, Multivariate Systems, Learning Technologies, Design for Learning, Physical Interface, Virtual World.

## 1 Introduction

We live in a complex world. To understand it, we need to be fluent with the inter–relationships, patterns and concepts that occur in decentralized, dynamic and multivariate systems. Many emerging phenomena can be understood in these terms: for example, traffic patterns, economic markets and population growth. Often building this understanding is not easy, as many of the underlying concepts are counter–intuitive and people have a natural tendency to think in a "centralized" manner. An important challenge is to design new and innovative learning environments that help people, and in particular children, understand these underlying concepts.

At Media Lab Europe, we are developing *Biosphera*, a learning environment to enable a personally meaningful and highly satisfactory experimentation with dynamic, decentralized systems. Specifically, Biosphera enables scientific inquiry through physical and virtual representations designed to empower exploration, creation and reflection around the learning experience. We situate children's experimentation in the biological world using plants. Primarily this is because they are an exemplar of a multivariate system that children find easily accessible. The variables of our system are the environmental factors affecting plant growth, where the behavior of the overall system emerges from the interactions among the constituent factors. Note that we are not concerned with children's understanding of plant biology, such as the origin of plants, concepts of growth and the relationship between plants and seeds. Such questions were the focus of our previous work [8].

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|---|---|
| **Learning Setting** | Informal |
| **Target Audience** | Children (8-12) |
| **Learning Type** | Constructionist |

Table 1: Our Design Space

## 1.1 Design Space

Our learning setting is an informal one, centered on clubhouses and museums, and aimed at creating novel and unique learning situations. Biosphera is designed to facilitate self–paced learning structured around an open–ended time frame. Our target users are primarily children between the ages of 8–12. Outside of the fixed and structured classroom setting, we hope to connect users who are normally separated by institutional or community conventions, thus engendering successful learning partnerships which may not otherwise occur.

We work in the Papertian [11] tradition of constructionist learning environments in which users actively build personally meaningful knowledge by creating and manipulating "objects to think with". Our approach emphasizes learning and does not use the "computer as tutor" model. In this way, we avoid the generally fixed program of instruction associated with such programs. We take advantage of the computer's ability to generate many alternatives enabling explorations of multivariate changes as they occur over time. Significantly, we maintain constructionist principals by aiding the child in forming scenarios to answer questions that occur as s/he interacts with the Biosphera. Table 1 summarizes our design space.

In common with ecological thinking [12], our learning environment responses to local, not centrally planned, conditions and produces new solutions adapted to these new conditions. A key point is that these conditions develop over time; there are no predefined solutions. We believe that giving children the opportunity to explore their concepts of multivariate systems through interaction and understanding of the decentralized, biological world, can be useful in building a cross-fertilization of ideas in other domains, such as communication/network systems, economics and mathematical modeling.

## 1.2 Related Research

A number of research works have addressed children's understanding of multivariate systems. Resnick has developed a number of environments for children to challenge the centralized mindset. Starlogo [9] is a programmable modeling environment for exploring the workings of decentralized, massively parallel systems and can model many real–life phenomena, such as bird flocks or ant colonies.

Netlogo [18] is an extension to Starlogo which among other enhancements adds the ability to perform participatory simulations using networked handheld devices.

Strohecker et al. [1, 2, 3] have developed the "Magix" series of playful learning environments to explore emergent phenomena through constructive–dialogic forms of interaction. Here learners' moves alternated with computer moves so that the interactions resembled turn–taking in a dialog.

Keselman and Kuhn [7] describe a software-based system to enhance children's understanding of multivariable causality. Their findings suggest that children perceive a variable as causal, in one instance, and non–causal in another, depending on the situation. The software they designed presented a situation in which children had to explicitly differentiate between the variables they considered to be causal and non-causal. We want to argue that a multiple framework can be used by children depending on the perceptual raw data the learner has available at any point in time [16].

Another interesting study explained how children may acquire a domain–general processing strategy called Control of Variables Strategy (CVS) [5], in which the learner should change one variable at a time, keeping all others equal. While worthwhile results were obtained, this method cannot be applied in our situation (as several variables can be changed simultaneously) or in situations where is not possible to maintain all but one of the variables at a fixed value.

## 2 Design of the Biosphera Learning Environment

We designed the Biosphera as an “object to think with” [11]. It has two main, inter–linked components, a physical dome and a virtual world. This design strategy of utilizing multiple representations provides a way “in” for people with different thinking styles, and allows learners to deepen their understanding of the phenomenon under study. We believe that the use of a physical component can strengthen the formation of mental models of multivariate systems. Indeed, the use of physical manipulatives has been very successful in the area of mathematical learning and has been shown to increase achievement [14].

### 2.1 Physical World Design

In conceiving this design, the physical component was required to house, and allow children to experiment with, the biological world under examination. The physical component we constructed was a tabletop-sized, Plexiglas, transparent dome. It constituted the physical interface, as shown in Figure 1. This dome is fully equipped with light, heat and humidity sensors to monitor the changing environmental conditions. To modify the conditions, the dome is equipped with fibre-optic lighting, heaters, fans, and a small irrigation system. We designed the dome as a shell to separate the space in which the plant lives from the external world. In this way, it is possible to modify environmental conditions within a closed system, free from external disturbance. Naturally, the user can access the internal part of the dome should the need arise. Of course, this must occur before running any experiments, so as to maintain the integrity of the results acquired.

Plants have long been a source for children to learn about biological ideas such as growth, flowering and photosynthesis. It seems natural to leverage children’s affection for them in the design of our learning environment. Thus, we chose them as a component of our transitional object[1] which children could identify with when thinking about multivariate systems. Indeed, just as patterns and shapes could be designed when programming the LOGO turtle, so the interaction between environment factors in the Biosphera affects the plants physical condition. It exemplifies the emergent, inter-related, phenomenon resulting from the child’s control of the dome’s environmental factors. That is to say, the child can witness and learn from the plant’s health and its progress over time. The particular outcome (e.g. the rate of plant growth, whether the plant flowers or withers etc.) is a direct result of the child’s actions.

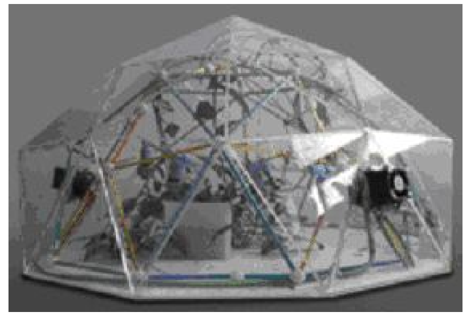

Figure 1: Biosphera’s physical dome.

The natural world provides materials and situations in which children can develop their intuitions through experimentation. Nevertheless, the focus and power of of these materials can be augmented through purposeful intervention. Designed artifacts and environments can make experiments possible for which the natural resources available are not fully sufficient. Thus, a second component of the Biosphera design is a graphical, virtual world, running on a PC and connected to the physical dome. A significant attribute of our design is that it is highly visual in nature. In common with many others (e.g. [4]) we believe visual information represents a powerful mechanism for understanding the world.

[1] A transitional object is one that acts as a carrier of powerful ideas and is easy to relate to. For example, in *Mindstroms*, Papert presented the gears of his childhood.

## 2.2 Virtual World Design

Our design for the virtual world emphasized creating and contemplating the relationships that occur between variables. In common with other microworld designs, our design focuses on the core characteristics of a phenomenon [10], in our case light, temperature, humidity and time.

Primarily, the virtual world was designed to overcome some constraints associated with the physical dome, in particular, those associated with time. In our case, we designed the Biosphera's virtual world to enable children to construct and develop a number of scenarios, envisaged as their own "plant movies". These movie stories evolve over a time frame chosen by the child and may be saved for future work and/or exhibition.

The movies stories created with Biosphera represent a compelling personal story of the life of the learner's plant. They may follow non-linear paths of interaction, and test multiple possible futures and time–lines in their "plant story". This gives the learner the possibility to test a certain environmental conditions and observe the corresponding results. Testing many hypotheses gives the child the chance, for example, to access the single factor responsible for a certain result or to reverse certain prior assumptions. From the learning perspective, it was important that emergent effects were easily generated by constructive interaction.

Once the learner has contemplated and reflected upon their choices and perhaps shared their plant movies with others, they can decide whether or not to apply their changes in the physical dome. This opens an avenue of discovery to a comparative framework between the "real–world" of the physical plant and the knowledge created while actively interacting with the virtual plant.

## 2.3 Simulation versus Representation

An important distinction to be made regarding the design of the virtual world is between simulation and representation. In our vision, science education must pass through reality, and reality must be the witness and the meter to judge the accuracy of our model. We want to use sensor readings to incorporate something of the physical world into our virtual world, so that we are not simulating but representing reality. Model and phenomena must be kept together.

Beyond the seduction of simulations [15], we believe that virtual representations are powerful environments, able to give great insights about the real world, as long as they remain closely defined by the physical world. With our design choice the user can assess the error associated with the model simply by visually evaluating the goodness of the virtual representation against the real plant when the two are aligned. We believe that the ability to compare is a powerful approach to learning underlying models as it allows the child to overcome black box assumptions [13].

# 3 Modes of Interaction

Figure 2 shows our initial design prototype for the virtual world. It was written in Java, runs on Pentium III laptop and reads the environmental conditions in the physical dome via a Tower [6] interface. When interacting with the virtual world, the goal is for the learner to build a particular ecosystem and investigate its affect on the virtual plant.

The virtual world interface consists of a virtual plant animation window, the current date, simulation parameter buttons and time line, simulation movie buttons and a frame for showing the current conditions in the physical dome.

The virtual world has two modes of investigation. In the first, the virtual world opens by presenting a building area at the bottom of the screen where constructive interaction occurred using the *simulation parameters* panel. Here the learner can chose the combination of variables and, significantly, for how long to apply them in the virtual world. Once this is done the plant begins to grow and the learner can create and explore the future "life story" of the plant.

The learner is free to select and save them for later contemplation and continued exploration by using the *load* and *save* movie buttons. This gives the

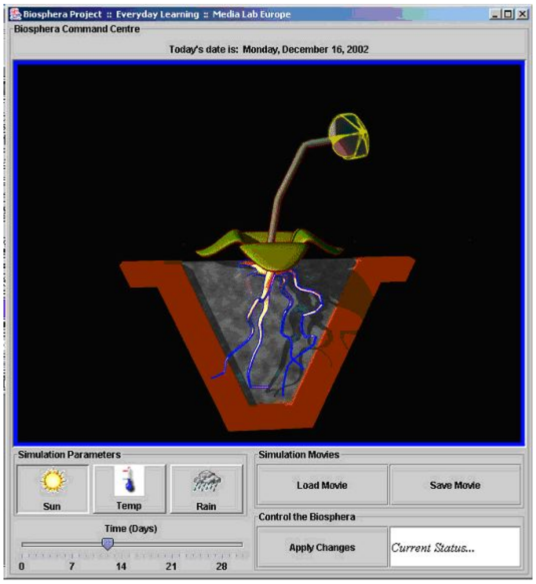


Figure 2: Biosphera's Virtual World.

learner the opportunity to think about different perspectives as the story unfolds, rather than having to adhere to a predefined plan.

The second mode of investigation allows the learner to interact with the physical world of the Biosphera. Once the learner is happy with their level of exploration and about their knowledge of the interaction between parameters affecting the plant's growth, s/he can decide to apply to the changes to the enclosed physical dome containing a real plant. Once this is done the system logs the changes occurring in the dome which the learner can then study. In this way the Biosphera provides the learner with a means of undertaking a *comparative* investigation between the "plant movie" and the growth of the real plant.

By interacting with the Biosphera in the manner outlined above, the child is actively creating his/her own knowledge about the relationship between variables in a complex system. They are acting as *bricoleurs* [17], developing robust concepts about multivariate systems. By encouraging the use of multiple avenues of investigation we hope to lay the foundation to support the study of more advanced, formal scientific concepts.

# 4 Conclusions & Future Work

This paper presented a prototype learning environment for exploring the underlying concepts associated with dynamic, multivariate systems. Biosphera supported learning through an exploratory, comparative framework. The working prototype we presented here promoted personally meaningful knowledge creation. A key aspect of the design was the use of physical and virtual avenues of discovery. In this way, the learner was free to interact with the system, following non-linear paths of interaction, and testing multiple possible futures in the their "plant story".

In terms of future work, we are concentrating on the development of the virtual world. We are currently in the process of running a number of collaborative design workshops with children. We wish to take into account their ideas and opinions to build upon our initial designs. We hope that this will lead to new designs that are useful, attuned to and supportive of children's learning needs. In the longer term, we wish to further investigate the collaborative learning paradigm by using multiple Biospheras in diverse geographical locations.

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