Making the Invisible Tangible: Learning Biological Engineering in Kindergarten

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Abstract
In this paper we describe the motivation for and design of Garden G-nome, a reality-based interface for young children, which facilitates collaborative exploration of biological engineering. The research questions we explore focus on how reality-based interaction techniques can be applied to make the invisible tangible. Specifically, on how to design age-appropriate interfaces that engage very young children in scientific investigations.

Keywords
Collaborative learning, multi-touch, tabletop interaction, interfaces for learning

ACM Classification Keywords
H5.2 Information Interfaces and Presentation: User Interfaces

General Terms
Design, Human factors

Introduction
Over the past two decades, research on Human-Computer Interaction (HCI) generated a broad range of interaction styles that move beyond the desktop into new physical and social contexts. Often unified under the umbrella of Reality-based Interfaces (RBIs) [8], these emerging interaction styles leverage users'

existing knowledge and skills of interaction with the non-digital world. Such interfaces draw upon users understanding of naive physics, as well as on users' spatial, social and motor skills [8]. The idea of bridging the physical and the digital aligns with the notion of bridging concrete and abstract thinking. Thus, researchers exploring technologies to promote learning have also designed and studied RBIs (e.g. [3, 4, 5, 8]).

The need for RBIs is salient in early childhood education where children are likely to be transitioning between the Piagetian preoperational stage, when they are not yet able to conceptualize abstractly and need concrete physical objects, and the concrete operational stage, when they start to conceptualize abstractions. By basing interaction on pre-existing real world knowledge and skills, reality-based interfaces offer a concrete way to think about abstract phenomena. Research on tangible interaction shows that it facilitates kindergarteners to learn abstract concepts and computational skills [2,3].

Building on this work and motivated by the need to further engage children in science, technology, engineering, and math (STEM) [9], we are currently developing an RBI and curriculum for kindergarteners to explore biological engineering.

Combining Science and Technology

Our choice of biological engineering as a domain is motivated by the new ways this field combines science and technology to solve critical real-world problems. Kindergarten students are already exposed to biological engineering in their everyday life. For example, in the supermarket they encounter fruits and vegetables that are bigger and last longer than their natural counterparts because they were specifically designed so. However, the early childhood natural science curriculum does not include emerging domains of knowledge such as biological engineering that cut across disciplinary boundaries [9].

Learning abstract concepts in Kindergarten

Our choice of working with kindergartners is motivated by three different challenges. First, research has shown that kindergartners are able to understand abstract concepts that were previously thought to be too complex for their age if presented with a developmentally appropriate interface and curriculum [1,2,3]. Second, educational interventions that begin in early childhood are often associated with lower costs, and stronger more durable effects. Finally, in today's world, where science and technology are combined in new and creative ways, there is a need to re-envision what young children can and should be learning [9,10].

Emerging opportunities for design

The introduction and increasing availability of multi-touch high-resolution displays open the opportunity to design reality-based interfaces for children that combine displays of different scales (e.g. personal tablet computers and large tabletop displays) to mediate co-located collaboration in groups of different sizes. By allowing multiple users to simultaneously touch and manipulate representations of data, multi-touch displays make actions visible across users and provide multiple points of entry for an activity [6]. Wireless communication enables easy and intuitive transfer of data from one display to another, facilitating transition between individual or pair-based activities (e.g. using a tablet computer) to collaborative interaction in larger groups (using a tabletop computer). Digital objects on tabletop interfaces are typically rendered to look and behave like they operate under virtual laws of physics, while tangible objects are often also incorporated into the interaction making it easier for children to directly manipulate, both tangible and digital objects.

Figure 1, the digital lab notebook and a collection of scientific probes for measuring size, humidity, pH, and temperature.

Garden G-nome

We currently develop Garden G-nome, a reality-based interface that utilizes tangible and multi-touch interaction to allow children to explore and apply concepts of biological engineering. The system enables users to observe and measure plant parts, compare and contrast cells and genomes, and design and predict the traits of new vegetables. *The system consists of three parts: 1) digital lab notebooks, 2) tangible scientific probes, and 3) a digital lab workbench.*

The digital lab notebook (see figure 2) allows children to work together to collect and record heterogeneous information in the field. It is implemented on a Google Android-powered 7" tablet device. Using the notebook children can take photographs, draw sketches, and conduct measurements. The notebook manages the communication with a collection of *tangible scientific probes and provides real-time guidance* and feedback during measurements. It automatically records data received from the probes and presents it using icons and numbers. The notebook is also capable of transferring content to the *digital lab workbench*.

The tangible scientific probes *(see figure 1)* are instruments that measure a particular facet of the specimen under test, such as pH, temperature, size, and humidity. These devices communicate with the digital lab notebook through Bluetooth. Each device includes an indicator that provides instant feedback to the user conducting a measurement.

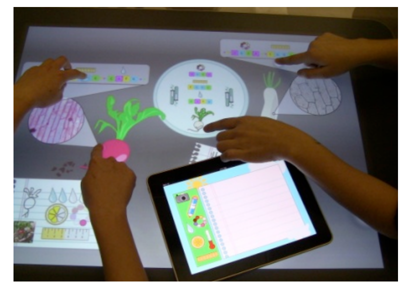

Figure 2, the digital lab workbench shows the DNA sequence of radishes which is divided into genes that control specific traits.

The *digital lab workbench (see figure 2) is implemented on the Microsoft Surface.* When a digital lab notebook is placed upon the workbench, its content 'spills' out onto the table. Users can then compare and relate information, relate cellular and molecular data to physical traits, and use molecular data to design and simulate new vegetables with desired traits.

Evaluation

To test the effectiveness of Garden G-nome in facilitating learning of biological engineering concepts in kindergarten, we will use both quantitative and qualitative measures and indicators, analyzing learning outcomes, levels of engagement, as well as the nature of discussion and collaboration within groups. We will evaluate the Garden G-nome with kindergarten students and teachers at both Wellesley's schools and at the Tufts Eliot Pearson Children's School.

While testing a preliminary prototype, a teacher gave us this feedback: "I have to say I'm kind of against computers in the classroom because our kids are so young you want them to learn about the social. Be hands-on, sort of the kind of physical things they do. But I'm totally following you on this. We've done things like this before where we have the kids observing something and writing down. And that's really hard for them. And this would give them success."

Summary

The goal of this research is to design, develop, and evaluate a reality-based interface for young children to facilitate collaborative exploration of biological engineering. The research questions focus on how RBI techniques can serve to make the invisible tangible. Specifically, how to design age-appropriate interfaces that engage very young children in scientific investigations? Outcomes of this project will contribute to several areas including tabletop and tangible human-computer interaction, human-computer interaction for children and early childhood education in STEM.

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