

Interaction Design Institute Ivrea

Thesis report

16 - May - 2005

Eco-Pods

Tangible user interfaces for learning systems thinking

Erez Kikin-Gil

e.kikin-gil@interaction-ivrea.it

<http://people.interaction-ivrea.it/e.kikin-gil>

Thesis Committee

Simona Maschi

Thesis Coordinator

Massimo Banzi

Primary Advisor

Philip Tabor

Secondary Advisor

Christine Truc Modica

External Advisor

Gillian Crampton Smith

Director and Chair of Examiners

Eco-Pods

Tangible user interfaces for learning systems thinking

Erez Kikin-Gil

Abstract

This thesis explores how tangible user interfaces can help children learn systems thinking. "Tangible user interfaces" (TUIs) typically use manipulable objects, rather than keyboard and mouse, to interact with software operations. Systems thinking is a holistic way of looking at the world. To learn systems thinking at an early age offers children new perspectives on the world. My design methodology comprised a sequence of prototype games, each followed by user testing. From my exploration, I can conclude that, with proposed tangible interfaces such as the Power Eco-Pod, children can learn systems thinking at an early age.

Table of Contents

1. INTRODUCTION	4
2. BACKGROUND	6
Educational theory and its history	6
Systems theory and its history	12
Children and time	14
Related work	15
3. CONCEPT	19
4. DESIGN AND IMPLEMENTATION	20
Light Wall	21
Eco-Sim	24
Mini Eco-Pods	30
Power Eco-Pods	35
5. ECONOMIC STUDY	45
6. CONCLUSION: FINAL EVALUATION AND ANALYSIS	50
7. SOURCES	51

Acknowledgment

I would like to thank the following people:

Massimo Banzi for teaching me physical computing

Philip Tabor for his irreplaceable guidance

Gillian Crampton Smith for helping me when I needed

Daniela Bauducco and Louise Judge for giving from their experience

Andy Davidson that helped me to refine my thoughts

Gianluca and Francesco from studio Ape

Nathan Shedroff for his sharp ideas

Jan Christoph Zoels and Simona Maschi that encouraged me to design for people (also known as users)

Christine Truc Modica for her kind support

Ruth, Tom, Andrea, Jen, Patray, Anurag, Nick, Christian and

Nathan for their valuable advices all along the way

Yaniv Steiner the **InstantSOUP** master

Special thanks to **Vittoria Burton** from Alce Rosso Servizi Educativi, for opening a door for me to the magical world of children and to Patrizia Lo Cigno that helped me understand them.

This work would not be completed without the help of the children from the primary school in Banchette, Piedmont, Italy

Done with **InstantSOUP** and **Wiring**

1. Introduction

My thesis explores how manipulable objects in the context of games can help children learn systems thinking. Inspired by existing methods that use playful activities and tangible devices to teach logical and mathematical operations, I designed a series of games that utilize tangible interfaces in a playful learning experience.

A “tangible user interface” (TUI) typically uses manipulable objects, rather than keyboard and mouse, to interact with software operations. The main feature of TUIs is their ability to represent and control digital information in a physical manner, mediating computational operation in a fashion that is not identified usually as computer-based.

Systems thinking is a holistic way of looking at the world. It looks at the world as an assemblage of interrelated components comprising a unified whole. The relationship of elements in the system facilitates the flow of data, matter or energy between them. Learning systems thinking at an early age offers children new perspectives on the world, and develops the cognitive skills needed to organize, represent and interpret how the world works.

My design methodology comprised a sequence of prototype games, each followed by user testing. In each design session I started from an initial aim that derived from my research or previous exploration, designed and built a functional prototype, tested it with users, and drew conclusions that led me to the next stage.

An adult can have a wonderful imagination, expressive powers and tools that allow them create amazing things. However, adult cognitive abilities are different than children abilities. To understand what will appeal to children, how children perceive things and what does not work, one should test their ideas at first hand. In my thesis, I tried to let children guide my design process. I have done that with the games, drawing books and computerized prototypes that they played with. The path I took led me to

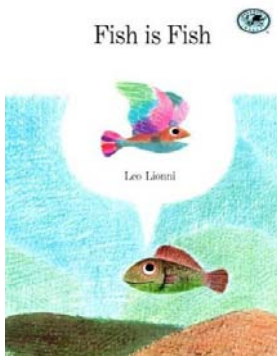
successfully design the Power Eco-Pod, a TUI-controlled system that mimics nature and allows children to learn through play the core principles of systems thinking.

2. Background

Educational theory and its history

Learning

Let him know nothing because you have told him, but because he has learnt it for himself. Let him not be taught science, let him invent it. If ever you substitute in his mind authority for reason, he will cease to reason; he will be a mere plaything of other people's opinion (Rousseau).



In *Fish Is a Fish*, Leo Lionni writes about a curious fish. The fish approaches the tadpole and asks him to explore the land, once he grows into a frog. The tadpole grows and sets off for the land. After he returns, he meets the fish and describes the sights he has seen. He describes people, cars, cows and birds. As the fish keeps listening, he imagines this wonderful land. In his imagination he pictures fishes with fins so big that they can fly, or walk on land.

The way people acquire new information has a great impact on the meaning they produce from it. As people learn new information, they refer to their pre-existing knowledge in their attempt to create meaning. Immanuel Kant first introduced this idea and claimed that knowledge is dependent on both environment and innate knowledge. This interaction creates mental structures that are the interpretation of experiences.

Jean Piaget advanced an information acquisition theory called *constructivism*. He suggests that people develop conceptual models as a method to understand the world; they interpret events through the creation of abstract models. This cognitive structure, also known as a *schema*, is active and constantly changing in response to interaction with the world.

In their *information acquisition* process, people adapt information, by assimilating it or accommodating it. *Assimilation* suggests the interpretation of new information according to

existing conceptual models, whereas *accommodation* suggests the change of an existing conceptual model to fit the new information. As result, people might misunderstand information that does not fit an existing conceptual model, as they construct for it a new one.

One of the implications of constructivism was the role of prior knowledge in the learning process. It became clear that to gain effective learning it is necessary to associate new information with prior knowledge. Such prior knowledge can vary from the use of page layout (title and heading) to clear verbal instructions, familiar environment, and the use of models and familiar scenarios instead of abstract figures.

The active learner

The constructivist approach promoted the role of the individual in the learning process, but active learning was not a new idea. The concept that through direct engagement comes true meaning can be traced in the writings of Rousseau, Friedrich Froebel, Maria Montessori, and others. They all believed that to understand complex ideas one should be in direct engagement with the world.

In his main work *Die Menschenerziehung* [On the education of man], Froebel writes on the need of humankind for guidance in order to be able to represent the divine inner law. In the *Kindergarten*, which Froebel developed in 1837, he provided guidance based on direct engagement with objects and nature. His Kindergarten was the first environment designed to fit children's scale. In it, children could develop their motor and social skills. Froebel believed that through activity children would gain powers that would carry them from one developmental stage to the other.

Montessori, the first woman in Italy to finish medical school, followed Froebel in her educational method. Working at the Casa dei Bambini in the slums of Rome in 1907 allowed her to give scientific and practical essence to Froebel's "education of man". Much like Froebel and the Swiss humanitarian Johann Pestalozzi, Montessori believed that education is a tool for individual fulfilment. In her mind, children's direct engagement with the

environment allows the cultivation of moral, emotional, physical and spiritual entities. Montessori designed a dedicated environment, developmental curriculum, and didactic learning materials, to achieve that.

Montessori promoted children's exercise in daily living (*exercices de la vie pratique*) in a scaled-down environment. Living in the house meant children coping with real tasks such as serving warm meals to their peers or managing and participating in cleaning tables after eating. This exercise aimed to give them challenges which teach them self-determination and self-realization.

Children's engagement with real-life tasks was a stage in Montessori's "method". After a child had gained focus and self-control, he or she would proceed to the following stage, from the education of the senses to the education of the intellect. The goal in Montessori's method was to let children learn how to deal with problems rather than providing a solution.

Believing in the individual perspective of the human being, Piaget suggested the concept of the child as a "lone scientist", an idea that was also promoted by Seymour Papert in his theory, *constructionism*. Papert's theory emphasized the role of the individual in the constructivist process and suggested that by actively constructing models in real life, people can build accurate conceptual models of the world. This recursive interaction places the learner as an active participant in the learning system.

Manipulable objects in learning

Using manipulable object to convey abstract ideas, as Papert suggested, can be seen in the writing of John Locke on construction sets, such as alphabet blocks, in the 17th century. In the 19th century, Froebel designed a set of manipulable objects, "gifts", which children used to explore the shape, dimension and size of objects and the relationship between them.

Montessori provided children with didactic material aimed to arouse their interest in exploring their senses. Children would

develop their fine motor abilities as well as an understanding of the different values of form, such as width, height and depth, and learn to compare items. By feel and touch, children would learn to differentiate between objects:

The didactic material, in fact, does not offer to the child the "content" of the mind, but the order for that "content". It causes him to distinguish identities from differences, extreme difference from fine gradation and to classify, under conception of quality and of quantity, the most varying sensations appertaining to the surface, color, dimensions form and sound (Montessori, 137).

The use of manipulable objects was a preparation for advanced learning in language and arithmetic. In the language-acquisition stage, children could use the same principles they had learned, such as delicate motor capabilities and hand-eye coordination, to recognize the different letters. In arithmetic, children learned about quantity, scale, size, height and width, using manipulable objects.

Children's use of manipulable objects can help them understand abstract concepts. Robert Hartshorn provides sources to support the idea. He refers to Suydam and Higgins which determined that mathematical achievement increases when manipulables are used. Hartshorn cites research by Evelyn Sowell which found that manipulables could be effective with kindergarten through post-secondary students. Hartshorn also quotes James Heddens, which says that even if children can solve a given problem at the concrete level, they may not be able to solve the same problem at the abstract level.

Sohee Kim brings three areas in math learning where manipulables are effective:

- Concrete application (manipulating physical objects to represent mathematics problems)
- Semiconcrete application (drawing pictures to represent the problems)

- Abstract application (writing mathematical equations to represent problems)

She points out that manipulables allow individuals to develop a clearer understanding of a problem and enhance their reasoning skills.

Learning with others

Lev Vygotsky also promoted the idea that our environment plays an important part in the learning process. He suggested that not only the concrete environment but also tools of culture and social interaction could help in developing better conceptual models. He suggested that cultural tools, such as spoken and written language, rituals, and systems of scientific concepts, could carry messages and induce changes in children's mode of thought. They allow them to govern their own mental functions and extend their cognitive capabilities. He believed that when individuals engage in social interaction they can develop mentally better than doing so alone. He called this gap, between the child's capability to learn alone and the ability to learn with an adult or other more capable peers, the *Zone of Proximal Development (ZPD)*.

Much like Vygotsky, Jerome Bruner believed in the importance of social interaction and environment in the child's development. He believed that individuals use peer support as scaffolding. Because of social interactions with others, students process their ideas and elaborate them as they try to communicate them. During this act of communication, they learn about their peers' views and reflect on their own ideas (Ormrod 232).

Play

Vygotsky writes in *Mind and Society*:

In play the child creates the structure meaning/object, in which the semantic aspect – the meaning of the word, the meaning of the thing – dominates and determines his behavior. To a certain extent meaning is freed from the object with which it was directly fused before.

In his *Play and its Role in the Mental Development of the Child*, Vygotsky points to play as the liberator from concrete thinking. In play, children not only construct the meaning/object connection, but reconstruct it as they will. Freeing the meaning from the object allows conceptual thinking, which allows the use of representation. This freedom enables children to assign word meanings to an object. For example, the word "horse" can be assigned to a broomstick.

Play has been the focus of major key figures in education and developmental psychology. Piaget and Vygotsky linked symbolic play with language and literacy and developing skill in representation and transformation (Barbara et al).

Providing playful environments and activities to motivate learning can be seen in the works of Froebel, Pestalozzi and Montessori, in the form of materials such as the building blocks, button-up frames and other toys, and activities such as imitating-life sessions, and sing-along.

Although the zone of proximal development generally refers to other individuals as facilitators in the child's growth, Vygotsky also points to play as a facilitator, which allowing children to challenge themselves willingly:

Play also creates the zone of proximal development of the child. In play, a child is always above his average age, above his daily behavior; in play, it is as though he were a head taller than himself. As in the focus of a magnifying glass, play contains all developmental tendencies in a condensed form; in play it is as though the child were trying to jump above the level of his normal behavior (Vygotsky).

Allowing the child to embrace challenges takes an important role in Montessori's Method. In her silence lesson, children take control of their movements; hold their arms and legs still in such a way that they make no sound. An act, which in other contexts would have another meaning, is transformed into a playful activity

that children gladly take part in and benefit from even outside the realm of the game.

Systems theory and its history

In 1928, Ludwig von Bertalanffy proposed to look at biological systems in a holistic perspective. He suggested that understanding the interrelationships between systems provides a better perspective, and even a unique understanding, of the system, one that cannot be produced by the traditional scientific way.

Unlike the traditional scientific approach, which aims to reduce each object to its core components and then analyze them (reductionism), the *holistic* approach (Greek *holos* = whole) suggests that the properties of a system cannot be determined by analysis alone, but rather by understanding the context and relationship of the system. Von Bertalanffy's theory started from biology but quickly moved to the study areas of psychology and ecology, economics, social sciences and even quantum theory:

It is necessary to study not only parts and processes in isolation, but also to solve the decisive problems found in organization and order unifying them, resulting from dynamic interaction of parts, and making the behavior of the parts different when studied in isolation or within the whole (Bertalanffy).

Systems theory looks at systems as an assemblage of interrelated components comprising a unified whole. The relationship of elements in the system facilitates the flow of data, matter or energy between them. Stephen W. Littlejohn identifies four elements that constitute a system:

- First are the objects – the parts, elements or variables within the system. These may be physical or abstract or both, depending on the nature of the system.
- Second, a system consists of attributes – the qualities or properties of the system and its properties.

- Third, a system has internal relationships among its objects. This characteristic is a crucial aspect [of systems].
- Fourth, systems also possess an environment. They do not exist in a vacuum but are affected by their surroundings. (qtd. in Salen and Zimmerman, 51).

Understanding systems allows individuals to generate deeper meaning for the environment they are living in. In his article, "Seeing the Big Picture", Neil McClelland suggests that as individuals understand the world in a holistic way, they can differentiate the cause of a problem from the symptoms that follow it. As systems thinking deals with understanding situations over time, it allows understandings that surpass a superficial snapshot. In viewing snapshots, momentary dominant elements can prevent one from viewing other elements that have much more influence on the system over time.

Barry Richmond suggests that as one attempts to solve one global problem, like world hunger or poverty, one must take in consideration the other effects of that solution. However, he points out, our capability to understand the interconnectedness has not kept pace with the complexity we are facing. This calls for systems thinking capability which allows "tightening of the links between the various physical and social subsystems that make up our reality". Richmond sees visualizing the systems as an important path towards identifying the different relations between the system's elements. Understanding positive and negative feedback loops and simulating their effect over time allows one to predict the outcome of the system structure.

Peter Senge, in *The Fifth Discipline*, writes on the invisible fabrics of interrelated actions that take effect only after years. He promotes the use of systems thinking within companies as it allows seeing patterns of change instead of focusing on snapshots of isolated parts of the system. He suggests that by providing a

conceptual framework, individuals can make these patterns clearer and help them understand how to change them.

Jay W. Forrester, the founder of systems dynamics, points out that unlike the direct cause and effect cycles individuals usually encounter in their life, in complex systems the cause is usually remote in distance as well as in time. The cause, which originated the problem at hand, is different from the apparent symptoms.

Visualizing the pattern of relationships is considered a core tool to systems thinking. Fritjof Capra, physicist and systems theorist, suggests that to study systems one should map and visualize them. Contextualized learning is commonly used as a learning method: bead stringing, pattern identification games, and problem solving through pattern recognition "which helps individuals develop their inductive reasoning and problem solving skills" (Kim 44). Kim continues:

Pattern recognition is reported as a critical problem solving skill across grade levels in NCTM's Standards for School Mathematics (1989). The Standards suggest that, "in grade 5-8, the mathematics curriculum should include exploration of patterns and functions so that individuals can analyze a wide variety of patterns" (p.98). In the Illinois Learning Standards for Mathematics (1997), two goals are dedicated to the mastery of skills involving pattern recognition (i.e., State Goal 8 & 9, 22-23).

Schools are using nature as a contextual ground to teach children systems thinking principles. The ecosystem is a familiar example for children to learn about systems relationships and allows them order to identify and map the patterns within this system.

Children and time

Andrea: Mom, when will I be like you and father?

Daniela: What do you mean, son?

Andrea: When will I be tall and strong as you are, mom?

Will I wake up one day and be bigger?

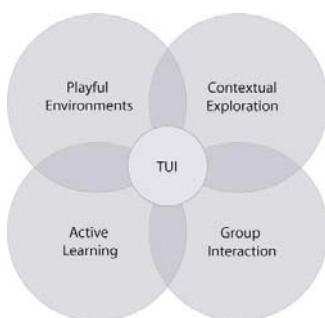
Andrea, five and a half, asks his mother something that adults usually conceive of as a naive question. As adults can think in abstract terms, they place events within time patterns. This allows them to understand the relations between different event, cause and effect cycles and observe gradual changes. Children's capability to do so happens only at the age of 10. Only at this age do children report the future distances of holidays as numbers of months rather than categorical terms: for example, "soon" or "not for a long time" (Friedman). To understand a system in a holistic way one should have the ability to think of it in terms of relationships that change over time and influence the system's parts. According to Friedman,

Young children cannot reconstruct the months, seasons, or years when remembered events occurred. The ability to reconstruct the month or season of a remembered event improves substantially between five and eight years of age. It is striking, though, that most children cannot use this information to determine which of two events a longer time ago was until about age 10.

It takes many years for children to learn about conventional time patterns, such as seasons and months, and to be able to use their mental representations of these time patterns in flexible ways.

Related work

My project involves many areas and as such was influenced by previous works. The research on Tangible Bits, Topobo and Tangible Programming Bricks (described below) showed how the physical world can represent, control or contain digital information, and be influenced by it. The Ambient Wood project showed how outdoor learning experience could be made possible with advanced technology. The Tamagotchi life-simulation game demonstrates



which children toys are relevant and Systems block coupled systems thinking with tangible interface.

Inspired by these works, my process led to the design of games that use tangible interfaces to teach systems thinking at an early age. My project shares the approach that to use the concrete allows one to overcome the difficulty of understanding the abstract. My project also relies on the understanding that contextual learning is highly beneficial in the learning process. Both, combined with playful environments and peer interaction, allow me to offer a new playful experience for the learning of systems thinking.

Computer-based simulations

Nancy Roberts reported that children at the age of 10 and 11 can learn the concepts of systems thinking with the aid of computer simulation software such as Stella, a screen-based software which allows users to create systems mapping. After the construction act, students assign variables to the elements based on systems dynamics principles. The constructed system is a dynamic one, which contains feedback loops and time delay and other systems dynamics factors.



Systems block

Oren Zuckerman and Mitchel Resnick's "Systems block" allows children to construct systems in a physical way, which allows fifth-grade students to experience systems dynamics concepts such as feedback loops, exponential change, stock and flows. Their project attempted to bring a constructivist value to the act of learning systems thinking. This project concentrated on learning systems dynamics through hands-on modeling and simulation of physical objects. Children view the images attached to the systems block, construct a mental model of the system and manipulate the inflow or outflow of the system to manipulate it. They could also connect a cable in order to explore negative or positive feedback.

Ambient Wood: Demonstration of a Digitally Enhanced Field Trip for Schoolchildren



This project, by Cliff Randell, Ted Phelps and Yvonne Rogers, allows children to use probing devices, PDAs and a WiFi network in their explorations of ecological systems. This playful learning outdoor environment allows children aged 11-12 to collect and listen to imaginative sounds representing, for instance, photosynthesis and plant respiration; to probe and automatically log environmental conditions; and use the WiFi network to interact using virtual cards and sounds.



Tangible Programming Bricks

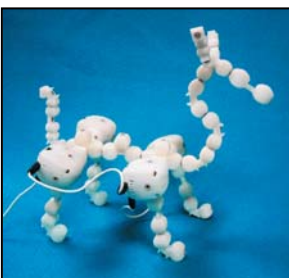
The Tangible Programming Bricks by Tim McNerney explore aspects of tangible programming, in order to provide an even lower threshold to programming language.

Tamagotchi Plus



BanDai released recently a new version of the familiar Tamagotchi. The new version introduces a social element to the simulation of a pet. With an embedded infrared communication the virtual pet can communicate with other pets, play games, give gifts and have "babies". (tamagotchiconnection.com)

Curlybot and Topobo



Topobo construction kit allowed learners to construct 3D robotic creatures and physically program their movements, using a playback mechanism to merge the conventional construction kits with tangible interfaces.

Curlybot also provided the user with an intuitive interface which allowed recorded play back of movements with its embedded kinetic memory system.

Tangible Bits

This research, by Hiroshi Ishii and Brygg Ullmer, explored the seamless integration of the digital and physical and in particular interactive surfaces, seamless coupling of graspable objects with the digital information and ambient media; the use of ambient media such as sound, light, airflow, and water movement for background interfaces with cyberspace at the periphery of human perception.

3. Concept

The goal of my thesis is to explore the use of tangible user interfaces (TUIs) for early learning of systems thinking. Tangible user interfaces usually use manipulable objects to control software operations. Systems thinking is a discipline which looks at the world holistically. To learn systems thinking at an early age offers children new perspectives on the world and develops the cognitive skills needed to organize, represent and interpret how the world works. My hypothesis is that through interaction with tangible user interfaces in a playful manner, children of 4-6 could internalize core systems thinking concepts, such as feedback loop, interconnectedness and change over time.

4. Design and implementation

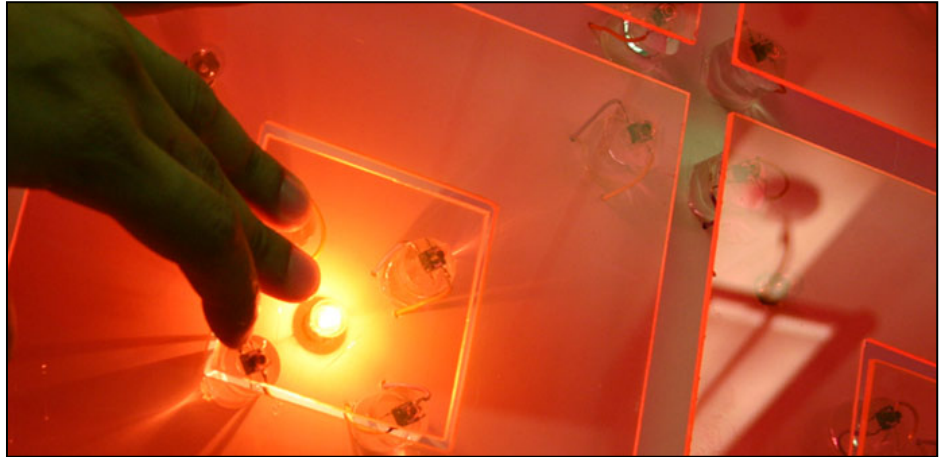
This thesis is comprised of three small explorations: the Light Wall, the Eco-Sim and the Mini Eco-Pods, which led me to the design of the Power Eco-Pod. Starting from a constructivist approach, I have designed the Light Wall and Eco-Sim games. In both, children can construct process within a system. By doing so, they experience at first hand core principles of systems thinking, such as stock and flow, interconnectedness, and change over time.

Following these exploration I have designed the Mini Eco-Pods, which allows children to monitor their class garden and learn how the different natural elements influence it, and each other, over time.

The final exploration was the Power Eco-Pods. This project was inspired by nature, as a contextual ground for learning systems thinking. It allowed children to take the role of natural elements and internalize systems thinking concepts through play with tangible interfaces.

My explorations aim to provide children with an intuitive way to learn in a playful environment with their peers. I have targeted my exploration towards young learners, of 4-6, and designed it for their capabilities at that age.

Light Wall

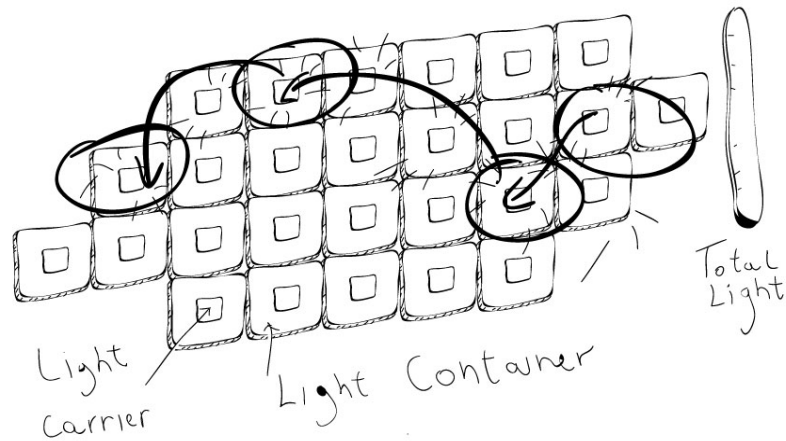


Light Wall

Overview

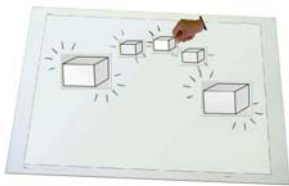
The Light-Wall project allows children to explore core concepts in systems thinking. It uses a representation of connected water containers to mimic the systems thinking process. In this representation, water containers stand for stocks and the tubes that connect them stand for flows. Stocks and flows are systems thinking building blocks. The stocks represent the value of an entity at a certain time while the tubes stand for flow value, the rate of change.

By connecting the water containers with the tubes, one can see how their value changes over time. By using different connections length, direction and quantity, one observes how the systems structure constantly changes, and explores systems thinking at first hand. The Light Wall use light tiles to represent the water container. Each tile is divided into two parts, an inner and an outer one. The tile parts are sensitive to pressure and change their light intensity according to it. The outer tile represents light containers (stocks) while the inner tile represents light tubes (flows).



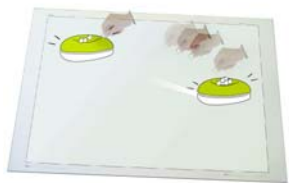
Light Wall process

In Light Wall, children “deposit” a certain amount of light in containers (stocks) by pressing on an outer tile for a certain time. Then they can structure paths (flows) between two containers. They can assign how much light flows in each path by pressing for longer or shorter on the inner tile. Then they can specify how long it takes the light to move from one container to the other, by structuring the path. As the child connects more and more tiles, it becomes more and more challenging to maintain the flow of light in equilibrium.



Design process

The Light Wall design takes its inspiration from the constructivist approach, especially the use of abstract objects to create concrete meaning. From the start, the design focused on finding a way that will convey the act of placing energy or matter in a container, channeling it to another container, and showing interrelations as they change. By this, children could learn about systems and change in a holistic way. They could explore and construct changing structures in an engaging way and gain insights from their peers.



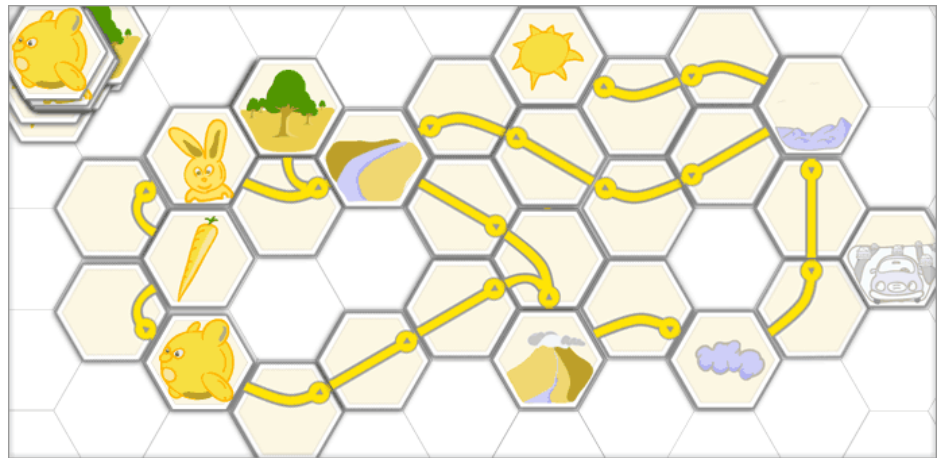
The design process started with animation prototypes that I presented to my colleagues. I gained several insights from this review. One was that a narrative that would allow children to construct a proper mental model of the process should accompany the use of abstract form. Using several abstract forms to convey

different meanings could help users associate the right objects with the right task. This differentiation within the unified language I designed could help users to construct better mappings of the process. Providing basic layout could help in the preliminary stages of the game.

Conclusions

The work on the Light Wall took three weeks. In this time, I was able to create a working prototype and present it to my peers. From the reactions I received from both peers and education specialists, I concluded that the ability to visualize paths within the systems is a promising start. On the other hand, the use of abstract form made it difficult for users to create appropriate mental models of systems thinking. Another insight was that the outputs, whether light or other sensorial stimuli, should not be subtle as the environment "noise", such as distracting light, sound or movement, tend to dominate it.

Eco-Sim



User testing in a local primary school

Overview

Eco-Sim is a board game that simulates ecological systems in a physical form. I designed it as a prototype in order to explore game play, roles, graphical language, and children's response to systems thinking core concepts in a fast iteration design process. It allows children to structure cause and effect loops, direction of influence, interconnectedness and a holistic view.

Goals

The aim of the game is to construct as many cause and effect loops as possible in 30 minutes. To do so the children use two types of hexagonal tiles. The first type is a set of illustrated elements that stands for stocks, like the sun, rain, flowers, and rabbits. The second type of tile is the connectors that represent flows. Children use both to construct meaningful connections.

The tiles





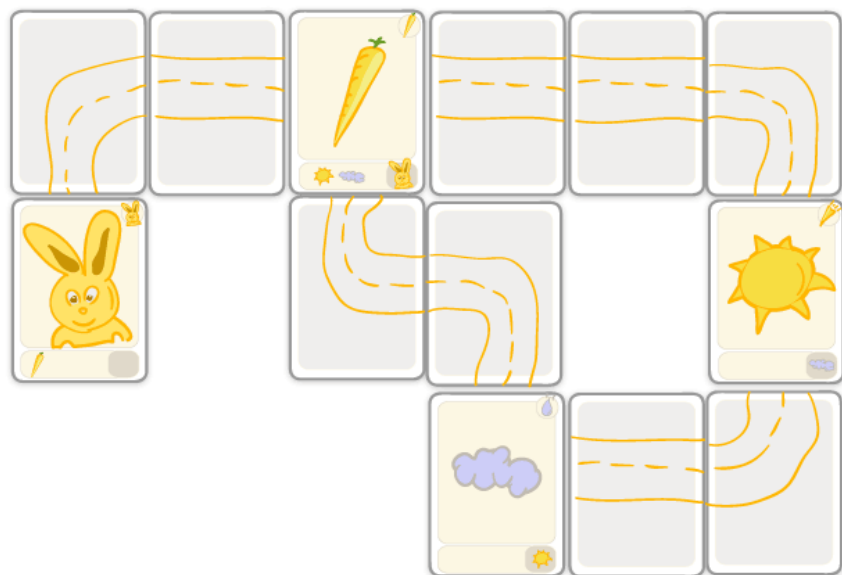
The game was composed out of tiles that represented different elements (like cars or fish), connector tiles, and empty tiles. The connectors, representing the flows, connected the different elements, the stocks. If children wanted to add elements that were not on the existing tiles, they could use the empty tiles to draw new elements.

Design process

Insights gained from the Light Wall project set a few guidelines for the Eco-Sim project. It seemed that a contextual theme from the world of children would help them to quickly understand the game. I tried to simplify the system construction process and design different tools for different tasks. Flow tiles were designed differently than stock tiles. Finally, this game had a structured goal. Children could play as a group and attempt to build cooperatively the biggest map possible and get the highest score as a team, or compete with each other. Much like other board games, Eco-Sim can be placed in more than one game category. On one hand it has some aspects of strategy and simulation, but on the other hand it requires knowledge which young children will develop in the course of the game.



Settlers of Catan



The first prototype was designed as a card game, for two players. Each player would get seven cards and, on his or her turn, would start to make connections. I had many debates about the level of complexity I should introduce into the game. Should I add quantities to this stage or be satisfied in the act of connection excising elements or drawing new ones? The current stage would require general knowledge and deduction capabilities. Adding a way to measure how stocks are change could add more interest or create unnecessary confusion.

Eco-Sim user testing



User testing in a local primary school

I conducted a user testing session in a primary school, in Banchette, Piedmont, Italy, with 17 children aged 6. Patrizia Lo Cigno, an educational coordinator from Alce Rosso Servizi Educativi, accompanied me, guided the children and translated my questions and their answers. We started by introducing the different parts, explaining the rule of the game and dividing the children into two groups.

Each group had to build the biggest cause and effect map possible. For each element the children get a point. The team with the highest score wins.

As result of the children's high level of interest, the game lasted about an hour instead of the 25 minutes I had originally assigned to it. The children played cooperatively, reasoning about the different connections they made and debating them. Although I did not know how to react to an illogical cause and effect loop, this was not a problem. Some of the children's rationales were unique but none was fictional. One connection that attracted my attention was a complex connection system they made between the sun, a man and a woman, and trees. As they said, the sun influences the people by tanning them, and the trees influence the people by shading them. Their use of the connectors, as the picture shows, is a bit rough, because this set was made of paper, rather than wood or cardboard. Still, this did not stop them constructing new structures. To both groups we had to explain the way to position the directional connectors. After a short explanation, the rationale of the cause and effect matched the direction of the connector.



After the game had finished and the winning group had danced their victory dance, I asked them questions to explore their understanding of the game, systems thinking and the game's design.

As the children played the game as a group, a few were more active than others, participated more in the discussions, and sketched more elements on the empty tiles. Both the education specialist and the children considered this aspect of the game important and entertaining.

For children, the tiles might work better in a different form, like a square, as it will provide less interconnection between the elements. It became difficult to place elements on the table, and their hexagonal shape prevented the tiles from sharing borders.

The children understood close relations very well. They constructed and understood direct causality structures such as that a tree gives shelter to a monkey, or that the sea is the home of the

fish. They constructed sequential chains of cause and effect such as the sun melts the snow, which turns to water that goes to the river that helps the carrot to grow, which is eaten by the rabbit.



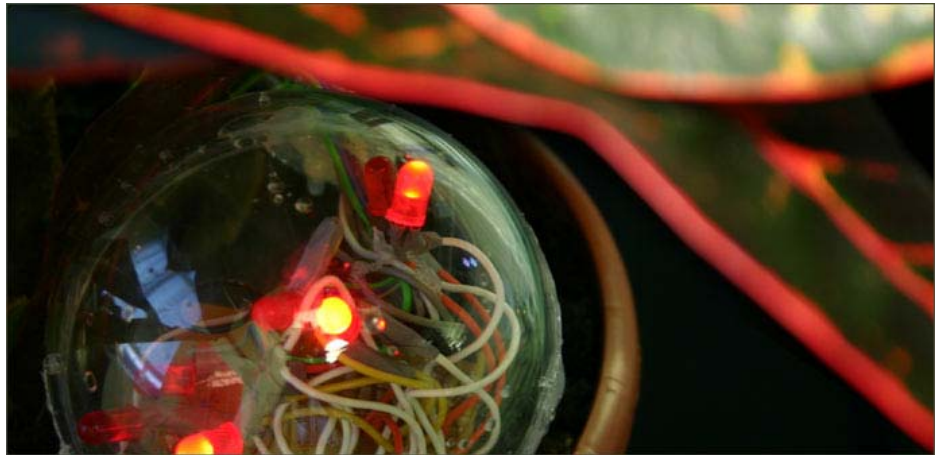
I asked the children to describe the connection between the car that they placed on the right side of the map to the rabbit, positioned on the left. Between the two there were more than seven elements and I expected to hear about the process in which the car is made wet by the cloud, that hides the sun, that melts the snow, and so on. The children, on the other hand, had a different answer and simply said that the car will run over the rabbit. This could be interpreted in two ways. The first is that they see the general system they constructed as a series of small systems, whose inter-connection is not that clear to them. The other explanation could be that for the children the complex connection was obvious, as it was in front of them, so they came up with an answer similar to the way the game is played – coming up with new cause and effect chains. In both cases, their ability to elaborate the map opens interesting possibilities in designing an interactive simulation map.

The use of graphical iconography to create meaningful narratives for the children, on their way to learn systems thinking principles can be considered a success. The children quickly related to them and could construct systematic structure. They talked

within the group about cause and effect, types of influence, and drew new elements. They had some difficulties understanding feedback loops, and negative flow without prior explanation. They understood both terms after they got an explanation from us.

Eco-Sim provided valuable insights. The use of tools in which the children can create narratives which help them learn systems thinking was a success. It allowed them to discuss their ideas within the group and allowed the teacher to give an explanation, based on the narrative they built. The children liked the graphical iconography and provided insights on the design of the interactive Eco-Sim as well as that of the Power Eco-Pod.

Mini Eco-Pods



Water sensing Eco-Pod

Overview

Mini Eco-Pods is a system that allows children to keep track of their class garden and natural elements over time. The Mini Eco-Pods system builds on outdoor education methods, in which children are encouraged to explore nature. Mini Eco-Pods enhances this method of teaching by allowing children to monitor their garden and allowing them to keep track of the changes of different natural elements. Using this information the children can compare and reflect on past events and their influence on the garden.

The system is composed of four monitoring devices (the Mini Eco-Pods) and an information display and retrieval system. The first three monitor (respectively) water, light, and temperature periodically. The fourth Mini Eco-Pods takes a picture of plants in its proximity. The information is stored in the Mini Eco-Pods until children retrieve it.

As children tend their class garden, they can place their Mini Eco-Pods near their plants. As they do so, the Mini Eco-Pods start the tracking task. Each time children can take the Mini Eco-Pods and place them on the display and retrieval system. By doing that, the information stored in each Mini Eco-Pods is transferred to the display system. The display system allows the children to see the daily changes and understand the impacts of past events.

Mini Eco-Pods design process

The Mini Eco-Pods design looks at nature as an example for learning systems thinking principles. Some schools use outdoor activities to teach holistic and systems thinking principles to children of 10-12. In one of the programs, students divide into small groups and work in the school's garden. They experience social and botanical relationships as they work with their classmates and teachers. With this, students learn about interconnectedness and are able to map the different factors of that ecosystem. When students work in this program they can observe changes and discuss with peers the effects of different natural elements on the garden.

Working with their peers develops their social skills and provides them with a clear snapshot of the current situation. However, in systems thinking it is the visualization and simulation of the system over time that allows understanding of the system. Systems thinkers need to map, reflect on, and simulate the various factors in order to gain better insight on the system. Capra writes in *The Challenge for Education* that "relationships need to be mapped. You can draw a map of relationships, interconnecting different elements or different members of a community. When you do that, you will discover certain configurations of relationships that appear again and again" (1999).

In this sense the constructive act, of being part of the ecosystem, is an important one because it allows children to map current situations. However, this method does not allow them to locate their understanding and simulate the change over time. Mini Eco-Pods allows this understanding as it places the current events in relation to the past.

Approaching the Mini Eco-Pods interface design, I wanted to understand how children assign events to time and what their mental model of time is. I conducted conversations with parents and educational experts. To get the children's ideas I chosen an indirect way – a drawing booklet. I wanted children to think about

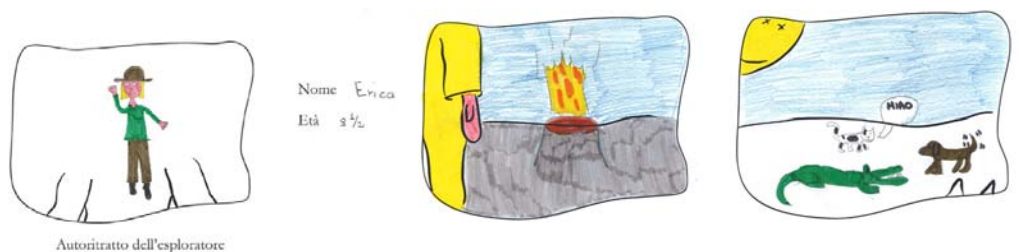
this issue without the time constraints of an interview, and have the freedom to react as they liked.

User research

I made this illustrated drawing booklet "The Journey" to understand a child's time perceptions in an indirect way. The book tells the story of an astronaut who lands on a planet with no clocks. As he explores the planet, he asks himself how the locals keep track of time. Parents received the booklet and introduced it to their children. It was designed as an activity that the children could do by themselves after an introduction from the parents. Each page had short sentence describing the situation, and a rectangular space. The rectangle contained a black and white illustration outline that children could build on.

I worked with two children aged five and a half, and three children aged nine and a half, for comparison. I received the booklets back after three weeks on average.

Diario dell'esploratore



From the booklets it is possible to see several similarities. All children drew the sun as an indication for time. They said that the sun helped local people know the time by changing its position and color. The sun and stars appeared in all the booklets. Some gave alternatives to the sun. Erica, nine and a half, also drew a volcano that erupts once an hour, and dogs and cats trained to make a noise every hour.

Diario dell'esploratore

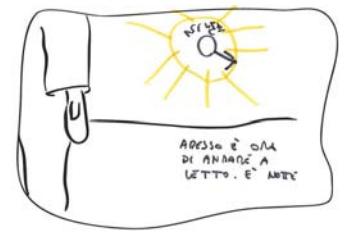


Autoritratto dell'esploratore

Nome

Età

MATTEO
5



Diario dell'esploratore

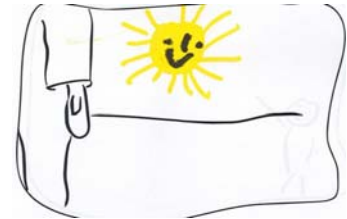


Autoritratto dell'esploratore

Nome

Età

ANDREA
5 1/2



Children used concrete objects from nature to represent time. Andrea drew a sun that acted like a clock, and used arrows and numbers to represent the fact that the sun acted like a clock. He hinted that he knows that numbers (an abstract concept) can be used to tell time. As the children matured, they gave more examples for time-telling tools (volcano, dogs), and assigned the time concept with more complexity. Instead of talking about time as an indicator of other events, they talked about time as an entity on its own.

In general, they referred to concrete attributes such as color, sound, location and action as a sign of a change, and brought examples from nature to signify that change.

This has a direct implication on my display interface design as it dictates that in order to design a system that displays the a calendar, which is new to most children, I should use familiar objects, concrete forms and differentiation to signify change. Abstract representation, such as a weekly or monthly time view might not be the right solution for them. A set of color-labeled boxes could be better.

Daniela, the mother of Andrea, introduced me to the "color for each day" idea being used at her son's school. As the name hints, each day is labeled with a different color: Sunday is green, Monday red and so on. When a teacher refers to an event that will

happen in the two weeks time, he or she will state that it will happen after two green days have passed. This idea aims to help children understand the concept of time by providing a visual image. The abacus similarly uses a way of using a concrete object to create a conceptual model of an abstract idea.

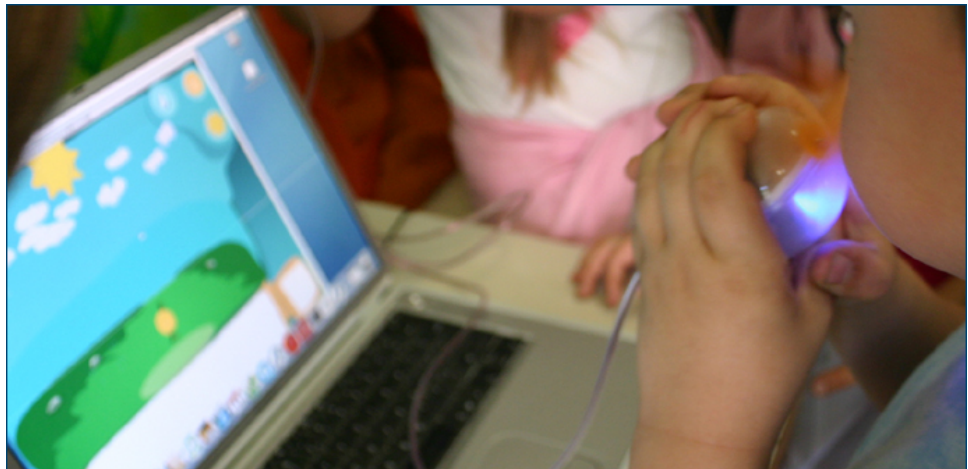
Conclusions

The work on the Mini Eco-Pods lasted four weeks. I presented the idea and an early prototype to educational experts and interaction designers. Although this was not a formal user test, the presentation yielded interesting results. From the discussions I conducted with Vittoria Burton, an education specialist from Alce Rosso, an education cooperative that provides education services in Ivrea and the Canavese region, I was encouraged to keep and pursue this idea. She thought that placing young children's garden activities in a context of time is important from a pedagogical point of view. Combining that with the opportunity to learn about nature in a systematic way provided another benefit. The ability to view the plant growth and reflect on the connections between the different natural elements seemed to her a powerful outcome.

Having this project reviewed by interaction designers provided other insights. There was a concern that the physical distance between the Mini Eco-Pods and of the display could blur the meaning of that action. The design of the Mini Eco-Pods should help children to understand that, as they take their Mini Eco-Pods from the garden to the screen, they are taking "the wind", and placing "the wind" into the display.

Due to the length of this exploration, I did not have a chance to gather children's opinions about the interface display or the interaction as a whole. However, the information gathered during this process was important in the creation of the next exploration, the Power Eco-Pod.

Power Eco-Pods



Power Eco-Pods prototype



Wolverine #1



Thor's battle against the giants (1872), by [Mårten Eskil Winge](#).

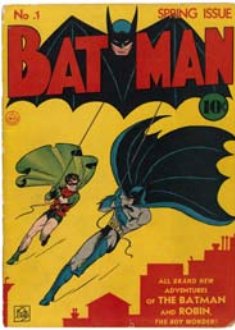
Overview

Power Eco-Pods is a TUI-controlled system which mimics the growth of a flower. The system is comprised of control devices connected to a display screen. The control devices represent the elements of nature, such as the wind and the sun's. The display screen presents an ecosystem which contains wind, rain, the sun's light and a flower.

Children can manipulate each of the devices by a movement characteristic of the natural element it represents: waving the wind pod violently, for instance, activates an internal windmill. As children use the manipulable, they can see the results of the action on their controller device as well as on the display.

A group of children is encouraged, as a game, to physically enact the role of the elements whose pod they hold. Their combined effect is shown on a computer screen as the gradual growth (or death) of a flower, accompanied by other monitoring graphics, in a simulated ecosystem.

The design of Power Eco-Pod was influenced by its predecessor, the Eco-Pod, not only on its reliance on nature as an environment children in which could build appropriate conceptual models of systems thinking. The Eco-Pod promoted major changes



Batman Comic
Issue, 1940

in Power Eco-Pod's game play. While the Eco-Pod and the child were two different entities, in Power Eco-Pod they became one. The possession of "super powers", which allow them to control the light, wind, and water, is not a simple matter. Gods and superheroes had supernatural abilities at birth and used tools to increase their ability. Thor, the god of thunder and lightning, used Mjollnir, a magical war hammer, while going giant hunting. The implant of adamantium into Wolverine's body transformed him into a modern antihero who can extend six retractable claws from the back of each hand. With wands or rings, even children could obtain magical powers. Unlike mutants, superheroes or gods, Batman was one of the few that did not possess any super abilities. Only through training and a large arsenal of specialized devices, could Bruce Wayne obtain super powers.

The use of devices that store super powers is common not only in comic books. It can be seen in role-playing games such as Dungeons and Dragons, both on and off screen. Typically, a player acquires by luck or force a magical device. The device enhances the player with special powers which run out after a few uses or turns.

Transforming the Eco-Pod from a sensorial device to an activation device that with the right kind of manipulation could give children super powers, seemed, like in the comics, inevitable.

Design research

In order to design the Power Eco-Pod's interface I wanted to understand children's ideas and graphical language in relation to the elements of nature. To do so I designed an illustrated booklet: *The Explorer*. In this story, the explorer returns from his travels with a big suitcase. Unfortunately, there is a big hole in it so it is empty. He opens it for the children and asks for their help. Can they fill his suitcase with the coldest and the hottest things, wet and dry things, darkest and lightest things?



In questa tasca c'erano tutte le cose calde

In questa tasca c'erano tutte le cose buie

In questa tasca c'erano tutte le cose solari

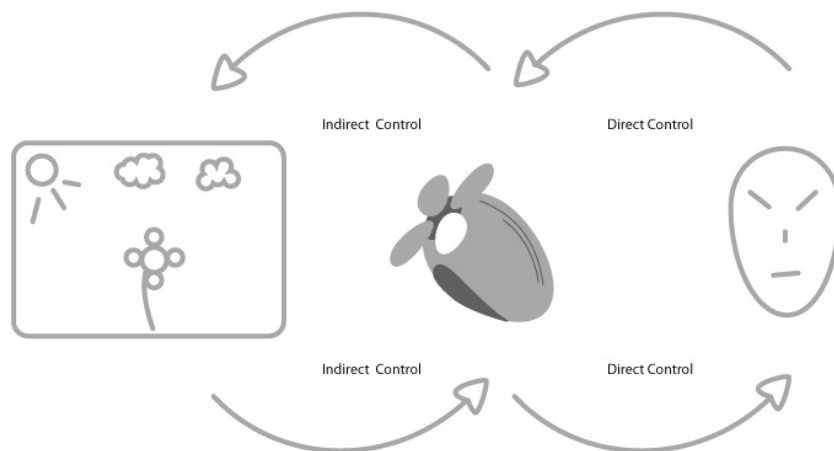
Children drawing the hottest things (left), the darkest things (middle) and the lightened things (right) in the worlds

After I received seven booklets back, I compared the drawing and noticed some interesting results:

Some concepts were more approachable to children than others were. All the children had an idea of what is wet, but not all could draw dry elements.

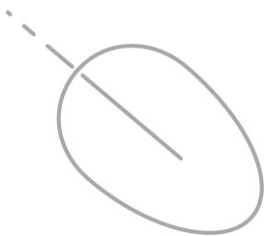
The children used a variety of objects to represent the answer for the question. Some of things they illustrated contained the quality they were asked about, such as the sun as an example for a lightened thing. On the other hand, Dracula is an example for a dark thing as he appears at night. The objects were valued not only for their qualities but also for the circumstance, they were in. The graphical language that they used had an iconic quality, symbolizing the object rather than trying to depict it. The results of this session led me to design a simplified, iconographic interface.

Design process

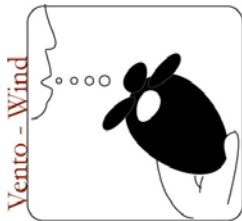


The challenges I was facing in the design process were both on the physical domain as well as the digital one. On one hand, I had to design an intuitive screen based interface that will allow exciting game play. On the other hand, I had to design physical experience that will reflect the natural elements, both in the way they would be controlled and the way they represent the elements on the screen. Lastly, both digital and physical experiences had to create a seamless playful environment that allows children also to learn.

I started with the design of the manipulable controllers. I selected to use the shape of an egg for all my tangible exploration. This shape embodied the relation to nature, had a basic shape and had a direction. By unifying the language, I was hoping to concentrate on the design of the interaction rather than the shape. An egg seemed to fit both the nature of my exploration and the form.



Power Eco-Pod first stage



The first set of controllers I designed represented wind, the water, the sun's heat and sun's light.

The wind controller was designed so as a child blows on the propeller a beam of light shines according to the intensity. Blowing at this controller would cause the "wind man" in the game to move the clouds.



The child could manipulate the temperature controller by rubbing it. Gradually, as he generates heat through his actions, the Eco-Pod lights up, and transfers that information to the sun in the game.



The water device used small translucent beads. As the child tilted it, like shaking bottle full of water, glowing light would shine on the beads and back on the Eco-Pod. The device detects the tilt speed and frequency, and changes the light intensity accordingly. With this motion, the child could pour rain from the clouds in the game.



The light/energy device required the child to spin the device, as if the child is charging it with energy, and light it up, as well as the sun. If the action were extremely successful, the red light would light up.

Preliminary user testing



I conducted two user tests with the devices in order to explore what the children would think about it, what metaphor they draw from it, which one appeals to them more, and what types of action they prefer. The first test I held at a primary school in Banchette with six children aged six. The second I did with two children aged five and seven. From the user test I gained the following insights:

- There is a need for an explicit and immediate reaction to a user's action, both on the device and on the screen.
- The reaction must start as a response to the user's action, but can proceed as long as it follows the rationale of the element it represents.
- There is a need for complexity in the interaction with the Eco-Pods. A device that has only one action loses its attraction after a while. Although some of this complexity will come from the act of controlling the screen interface, the physical device can be improved.
- Children and adults mapped the devices differently. While adults sought direct and clear representations, children were looking for challenge in the action, and change and ambiguity in the reaction to the device. For example, most adults thought that the water device inappropriately represented water. The children on the other hand held and

played with it, staring at the shiny shimmering lights for a long time.

Power Eco-Pod second stage

In this stage, I redesigned the devices and explored the game interface and flow. I wanted that the Power Eco-Pods would interact with the children on three forms. The first was the direct feedback from the device as a reaction to their action. The second is allowing control over the screen interface and the third was getting feedback from the screen to the device.



I designed the new Power Eco-Pod to have more control over the elements they control. The sun Power Eco-Pod now controlled the sun position (left, right, forward and backward) and light intensity. The child does this by holding and covering the pod, thus “energizing it”. The pod reacts to this action by generating light and generating heat, transmitted by small pins. By moving the pod to the sides, the sun moves as well. The child controls the wind man by using the wind Power Eco-Pod. This pod controls the wind man’s position as well as the wind intensity. To this device I added rotation indicators, so as the child rotates the device, an appropriate LED blinks.

The display interface



The power Eco Pod interface allowed children to influence the growth of the flower and the other elements. The water, light and flower status are displayed periodically on the event window. The

goal of the playing team is to keep the flower alive as much as possible. The challenge becomes more complicated as they have to work together and not disturb each other in this task. Another issue, which challenges the team, is that if they produce too much sunlight or too much rain they have to ask for their teammate for help, to dry the land or water the flower.

Secondary user testing



I conducted a second user test in a primary school, in Banchette, in two sessions of eight children aged 6 at each time. Patrizia Lo Cigno again accompanied me.

The aim of that session was to explore the value and properties of the physical and screen interfaces, as perceived by the children, in relation to systems thinking. The children were extremely intrigued by the new pods, as some of them knew the old version. We explained the goal and allowed them to play, in teams, and attempt to grow the flower. Although the prototype had several operational problems, the children kept asking to play, attempting to make the flower grow. When a team succeeded, the entire room burst out in screams of joy.

After the children had played, I asked them questions regarding the game, usability, mapping of the interface and understanding of the icons in the status window. I also asked them questions regarding the relationships between the natural elements, the influence they had on each other and on the flower.

Their answers indicated that:

- I should increase the interface reaction to the children's actions
- Mapping an action, when supported by both the physical object and digital interface, helps the child associate and map the connection between the different mediums
- The challenge of the physical operation enhances the digital activity
- The children understood how to use the Power Eco-Pods, but better response in the pods could allow more intuitive interaction
- Despite the resemblance between the status icons and the main interface, after the first explanation the children used them to learn what the flower needs and act upon that.
- The children understood very well how the wind, sun, flower and rain are interconnected. They also understood that the ecosystem is always changing as a result of their actions
- The Power Eco-Pods gave them and the class an opportunity to converse about systems thinking concepts and provided a real example to learn from, through play.

Conclusions

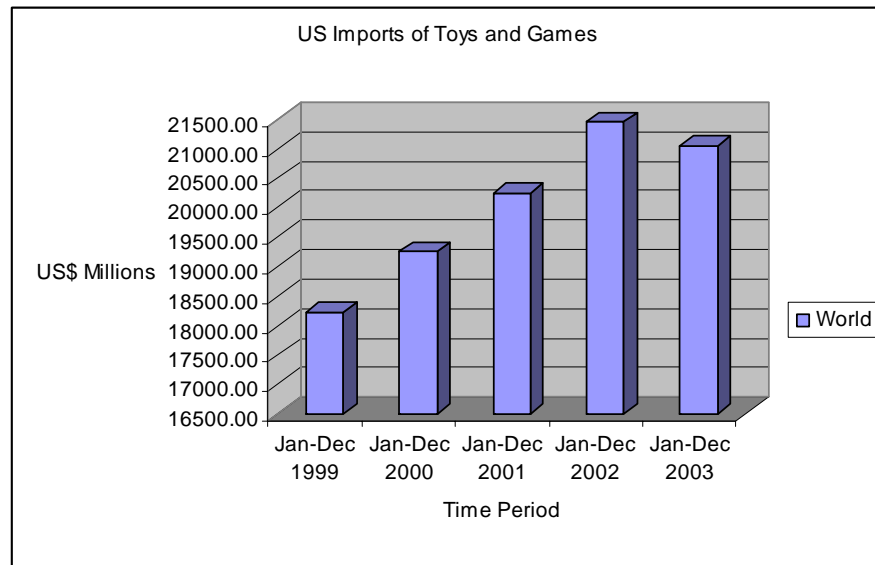
The work on the Power Eco-Pod lasted six weeks in which I was able to create "just-enough" prototypes for children and adults, and observe how they interact with the different systems aspects. From the user research I conclude that Power Eco-Pod enhances both the learning experience and learning systems thinking at an early age. The game allowed children to play in a contextual environment, in condensed time, and explore hands-on the mechanism of systems thinking. Doing so with tangible devices allowed them be a part of that system and internalize systems thinking concepts in a concrete way.

5. Economic study

Potential market analysis

A US toys and games market study divides the toys and games market into three areas: Games consoles, games software and traditional toys and games.

CHART A – US Imports of Toys and Games



Source: US Department of Commerce

The leading import source for the US toys and games market in 2003 was the traditional sector, led by HS 9503 (non-wheel and non-doll toys; like models, puzzles, toy musical instruments and motorized models), which accounted for nearly 37% of US imports. In value terms this sector was worth US\$7.8 billion in 2003, a slight increase of 1.5% from the previous year. The games consoles and software sector generated the second largest import value in 2003, reaching a value of US\$5 billion, equivalent to 23.7% of the import value.

Among the various reasons to buy toys, educational value is at the top of the list for parents. In a recent survey, which ranked these reasons, the educational value of the toy ranked second, before

price, durability, design, request from the child and brand name, and only safety ranked before it.

With toy sales reaching \$2.8 billion in 2002 in US alone, this market holds vast opportunities along ferocious competition. Companies such as Mattel, Hasbro and others alike are driven by a strong marketing approach that considers production cost, package design, product size and longevity as important elements in the toy design process. Working at high quantities and low profit margins drives these companies to seek a competitive advantage which will allow them to gain the upper hand in the battle of the toys. Providing an educational value can be a competitive advantage towards both the private and the public sector. With growing expenditure in educational development, this market offers not only high volume, but positive brand awareness and exposure to teachers, parents, and children in a national scale. In most western states, the expenditure exceeds 12% of total government expenditure and 6% of the GDP, as stated at the Human Development Report, 2004.

The organization

Educational values, interaction design and user research can be at the core of the company. Not only will help it differentiate it from the main activity of other toy companies, it will allow it to give them services and develop ideas and toys. To do this kind of work, the company structure will be based on small research and design teams, which will offer specialized services to toy companies.

The first service is the ideation and prototyping workshop. With this service, the toy company can get a two-week innovation workshop, aimed to produce novel ideas, alongside with prototypes, movies, promotional presentation and documentation. The Eco-Pod is an example of an outcome for such a service, producing not only the idea but also building series of prototypes and testing them with users. User testing can be part of the first service, but can also be offered separately for companies which need to explore ideas that they developed. The aim of this service

is to bring knowledge of local market trends, ideas and responses to products. This service will be conducted at the local markets the company wants to explore.

Marketing

We believe that there are more than few reasons for other companies to use our services. A High level of result in a short time is one reason. This will appeal even to companies that have an internal research center, as it brings an external view of their research objectives. Price is important factor, and having the ability to explore and research without the need to establish an expensive internal research center is of great value. Customization and agility allows companies to satisfy their specialized needs on demand, with no strings attached.

Establishing brand recognition and market penetration

To base the companies in a good starting position there is a need to associate our brand with the key assets we are offering and a showcase which shows our capabilities. Promoting the perception that we are the experts in designing educational toys is one goal. This can be achieved by conduct research with education organizations and submitting it to relevant conferences. It will offer important public relations tools, to both commercial and the public sector. Submitting our work to design competitions can offer another promotional value and commercial recognition. With achievements in both areas, establishing positive relations with toy brand leaders will become much easier.

Promotional innovation session

Establishing good communication with our target audiences is the first step for commercial partnerships. Offering small innovation sessions at the customer's location can help do this. The price for such a session should be relatively low, but at least cover expenses.

Price

Three charging mechanisms can be offers to our customers. **Per service** allows companies to purchase services for their current needs. To make this operation method profitable our company needs a certain volume of purchased services. **Flat rate** allows companies to pay a yearly/monthly fee and receive a certain amount of services at lower prices.

SWOT

Strength

As the economic situation forces many companies to close or minimize their research centers, many of them are exposed to the risks involved with this move. As most manufacturers can offer products at similar prices, the design and marketing of products plays an important role, and has great influence on the financial reports. Providing these companies with cutting edge solutions is of great value to them, as can seen by their investments in technological based research centers.

The ability to test ideas in an early stage, both in the company and with the target users, is important to most companies. It allows better acceptance of the proposed design and generates the team vision needed to produce the product. It also allows exploring flaws and values in the design, and helping improve or dismiss it before it causes extensive expenditure.

Weaknesses

Preliminary market penetration consumes time and resources in both the commercial and public sectors. With no brand awareness it can be difficult to convey to our customers reassurance in our capabilities to deliver high value.

Opportunities and Threats

Providing innovative solutions at an affordable price offers a great opportunity in the toy industry, but also in other fields. As other industries are forced to focus on their core business, this type of

service can appeal to them, providing that we can design a service with a competitive edge over other research centers. Competitors in this arena are focusing on technological values, user research or design. Most others do not provide an interaction design approach or the ability to design and test ideas with users in rapid design iterations.

However, other research centers already established their work portfolio and records of successes stories. Most of them also enjoy being in academic institute. To use this fact for our advanced our research should be branded as one that is based on practicality rather than theoretical study.

6. Conclusion: Final evaluation and analysis

Did the tangible interfaces I designed play an important role in the learning of systems thinking?

I believe that they did.

In *Flow*, Mihaly Csikszentmihalyi writes about the state of optimal experience, "flow" in which people are totally engaged with a task. "...instead of being buffeted by anonymous forces, we do feel in control of our own fate. ...we feel a sense of exhilaration, a deep sense of enjoyment" (1990, p.3). In "flow", which is common in games and sport, people are devoting their complete involvement to a task out of their free will.

During my exploration, I observed how children enter this optimal experience state and explore systems thinking principles with deep excitement and enthusiasm. For them, gaining new knowledge was as easy and challenging as play.

Children easily enter this state while playing games. The Eco-Pods had an important role in the transformation from daily experience to the special play mode. The uniqueness of the Power Eco-Pods, in form and action, allowed children to assume the role of the natural elements, play the game and gain knowledge.

In this sense, the tangible devices I designed gave children a concrete way to bridge the abstract idea of systems thinking by placing it in a familiar environment that they could physically play with and learn. Indeed, in the user testing I conducted, children understood cause and effect, interconnectedness and change over time.

7. Sources

- Barbara T. Bowman, M. Suzanne Donovan, and M. Susan Burns. Eager To Learn: Educating Our Preschoolers, Committee on Early Childhood Pedagogy, : National Academy Press. 2001
- Bertalanffy, Ludwig Von. General System Theory, George Braziller, New York, 1968.
- Bransford, Ann L. Brown, and Rodney R. Cooking. How People Learn; Brain, Mind, Experience, and School, Committee On Developments In The Science Of Learning, Commission On Behavioral and Social Sciences and Education, 2001.
- Capra, Fritjof . From The Parts To The Whole: Systems Thinking In Ecology and Education. Berkeley: Center for Ecoliteracy, 1994.
- . Theory Of Living Systems. <[Http://Www.Ecoliteracy.Org/Pages/Principlesofecology.Html](http://www.ecoliteracy.org/pages/principlesofecology.html)>.
- . Ecoliteracy: The Challenge for Education In The Next Century, 1999.
- Csikszentmihalyi, Mihaly. Flow: The psychology of optimal experience. New York, NY: Harper Perennial. , (1991).
- Forrester, Jay W. Learning Through System Dynamics as Preparation for The 21st Century, Keynote Address for Systems Thinking and Dynamic Modeling Conference for K-12 Education, 1994.
- . System Dynamics and Learner-Centered-Learning In Kindergarten Through 12th Grade Education, December 21, 1992
- Friedman, William. Constructing The Past and The Future: How Children Understand Time. < [Http://Www.Oberlin.Edu/News-Info/Observations/Observations_Bfriedman3.Html](http://www.oberlin.edu/news-info/observations/observations_bfriedman3.html)>.
- Hartshorn, Robert and Boren, Sue. Experiential Learning Of Mathematics: Using Manipulative, ERIC Digest, 1990.
- Heddens, James. Bridging The Gap Between The Concrete and The Abstract. Arithmetic Teacher, 33(6), 14-17, 1986.
- Hoge, John D. Teaching History In The Elementary School. ERIC Digest, 1988.
- Human Development Report, 2004, Commitment To Education: Public Spending, <[Http://Hdr.Undp.Org/Statistics/Data/Excel/Hdr04_Table_10.Xls](http://hdr.undp.org/statistics/data/excel/hdr04_table_10.xls)>.
- Ishii Hiroshi, Freim Phil, Su Victor, Mikhak Bakhtiar. Curlybot: Designing A New Class Of Computational Toys, 2000.
- Ishii. Hiroshi, Raffle. Hayes Solos, Parkes. Amanda J. Topobo: A Constructive Assembly System With Kinetic Memory, 2004.
- Kim, Sohee. Mathematical Word Problem Solving: Comparing Strategies for Improving Performance Of Individuals With Learning Difficulties. University Of Illinois At Urbana-Champaign, 2003.
- Lionni, Leo. Fish Is A Fish, 1970.

- McClelland, Neil. Seeing The Big Picture, Literacy Today (Issue No. 28), September 2001.
- Mcnerney, Tim S. Tangible Programming Bricks: An Approach To Making Programming Accessible To Everyone, Masters Thesis, MIT Media Lab. Cambridge, MA. 2000.
- Montessori, Maria. The Montessori Method. New York Frederick Stokes Co, 1912.
- Ormrod, J. E. Educational Psychology: Developing Learners, Fourth Edition, 2003.
- Product Market Study: US Market for Toys and Games, December 2004,
<[Http://Edms.Matrade.Gov.My/Domdoc/Reports.Nsf/0/ACAE900E77E723E748256FAC002A5A36/\\$File/United%20State%20Market%20for%20Toys%20and%20Games.Doc?Openelement](http://Edms.Matrade.Gov.My/Domdoc/Reports.Nsf/0/ACAE900E77E723E748256FAC002A5A36/$File/United%20State%20Market%20for%20Toys%20and%20Games.Doc?Openelement)>.
- Randell Cliff, Phelps Ted, Rogers Yvonne. Ambient Wood: Demonstration Of A Digitally Enhanced Field Trip for Schoolchildren <[Http://Www.Slis.Indiana.Edu/Faculty/Yrogers/Papers/Randell_Abstract_03.Pdf](http://Www.Slis.Indiana.Edu/Faculty/Yrogers/Papers/Randell_Abstract_03.Pdf)>.
- Richmond, Barry. Systems Thinking: Critical Thinking Skills for The 1990s and Beyond.
<[Http://Www.Clexchange.Org/Ftp/Documents/Whyk12sd/Y_1993-05stcriticalthinking.Pdf](http://Www.Clexchange.Org/Ftp/Documents/Whyk12sd/Y_1993-05stcriticalthinking.Pdf)>.
- Roberts, Nancy. Teaching Dynamic Feedback Systems Thinking: An Elementary View Management Science, 1978.
- Rousseau, Jean-Jacques. Emile Or On Education, 1762. <[Http://Www.Ilt.Columbia.Edu/Pedagogies/Rousseau/Em_Eng_Bk3.Html](http://Www.Ilt.Columbia.Edu/Pedagogies/Rousseau/Em_Eng_Bk3.Html)>.
- Salen and Zimmerman. Rules Of Play. The MIT Press, 2003.
- Senge, Peter. The Fifth Discipline, Doubleday Currency, New York, 1990.
- Sowell, Evelyn. Effects Of Manipulative Materials In Mathematics Instruction. Journal for Research In Mathematics Education, 20, 498-505. (1989).
- Suydam, M, & Higgins, J. Activity-Based Learning In Elementary School Mathematics: Recommendations From Research. ERIC Clearinghouse for Science, Mathematics, and Environmental Education, 1977.
- Ullmer and Ishii, Emerging Frameworks for Tangible User Interfaces, 2000,
<[Http://Www.Research.Ibm.Com/Journal/Sj/393/Part3/Ullmer.Html](http://Www.Research.Ibm.Com/Journal/Sj/393/Part3/Ullmer.Html)>.
- Vygotsky, Lev. Play and Its Role In The Mental Development Of The Child" 1933.
<[Http://Www.Marxists.Org/Archive/Vygotsky/Works/1933/Play.Htm](http://Www.Marxists.Org/Archive/Vygotsky/Works/1933/Play.Htm)>.
- .Mind and Society, 1930.
<[Http://Www.Marxists.Org/Archive/Vygotsky/Works/Mind/Index.Htm](http://Www.Marxists.Org/Archive/Vygotsky/Works/Mind/Index.Htm)>.
- William, Friedman. Constructing The Past and The Future: How Children Understand Time, OCTOBER 14, 2002.
- Zuckerman Oren and Resnick Mitchel. System Blocks: Learning About Systems Concepts Through Hands-On Modeling and Simulation, 2004
- . A Physical Interface for System Dynamics Simulation, 2003