# The DigitalSeed: an interactive toy for investigating plants

**Mauro Cherubini[1], Hugh Gash[2] and Thomas McCloughlin[2]**
*[1]École Polytechnique Fédérale de Lausanne, Switzerland, and [2] St Patrick's College, Ireland.*

Plant growth, development and reproduction are fundamental concepts in biology; yet there is a recorded lack of motivation for young people to grapple with these concepts. Here we present the 'DigitalSeed' toy for making investigations around these concepts more accessible to children through hands-on digital interaction. This is part of an on-going project investigating improved ways of learning involving digital media. To date, this project has addressed the learning of 4-5 year olds, but it is anticipated that the project could be extended to older children in mainstream and special needs education. In the case of older children, specific curricula requirements would be addressed, although this is a secondary goal.
*Key words*: Constructivism: Plants; Play; Sensors; Simulation

## Introduction

The aim of this work was to provide young children (4-5 years) with play-driven (Raymo, 1973; Henniger, 1987; Wassermann, 1988) experiments with plants and seeds relating specifically to plant reproduction, growth and development. Experimenting with plants, and in particular with the life cycle of plants, is problematic in formal schooling. Children hold constrained views of what plants are and how they function (Bell, 1981; Darley, 1990; Kinchin, 1999); and children typically prefer working or learning about animals rather than plants (Wandersee, 1986; Schneekloth, 1989; Simmons, 1994; Tunnicliffe and Reiss, 2000; Tunnicliffe, 2001).

Furthermore, Hickling and Gelman (1995) report two important biases that impact the way pre-school children conceptualise plants: *the bias of attribution*, namely the failure to classify plants as living or to attribute properties of living things, and *the bias of meaning*, namely the confusion of terms such as 'alive' with concepts such as 'animate'. A young child's only experience of plants within formal schooling might be following a set of instructions to enable cress seed to germinate on damp cotton wool placed on a polystyrene tray (or other container); or in older children designing an investigation to 'discover' the necessary requirements for germination. Nature tables may include plants but these tend to be cut or dried and thus have a very reduced form of interactivity.

Another problem with working in plants in general is their relatively long lifecycles (more than a double class period on a Friday afternoon!) and growing plants means having to leave them aside for another day with all the intermediate problems: students' loss of purpose of the experiment; maintenance of the plants; and preventing others from disrupting the experiment (some of which are relieved by technical assistance where present).

The non-specialist teacher involved may feel that some kind of advanced knowledge that (s)he does not have is required to grow plants so this experience in the classroom/laboratory may be avoided. The practical knowledge of the teacher, particularly at primary level, will depend on what experience (s)he had in their initial pre-service education or the 'real' world.

Finally, the growth and reproduction of plants is a non-interactive phenomenon in the temporal domain; in other words, it can only go forward, one cannot go back and check an earlier stage. If the next class is one week later, it may be the case that the plants have grown and developed beyond the desired point in the life cycle.

Notwithstanding such difficulties, working with real plants remains the goal of the biologist; however, the use of digital technology may complement the study of plant biology where such difficulties arise. It is envisaged that digital technology assists the learner gain a deeper understanding of the biological world rather than supersedes it.

This is a qualitative pilot study combining results of clinical interviews with an iterative design process, to produce an interactive toy with physical and virtual components. We regard the children's varying understandings of plants origins' and growth as being potentially reflective of good reasoning within their relatively constrained realms of experience, and inevitably useful in their learning processes (Smith, Di Sessa and Roschelle, 1993). Their imaginative responses inspired our representations and the interactive design.

## Method

We followed a participatory design paradigm, in which we involved pre-school children to understand their initial misconception of plants' growth and then we designed a toy to sustain their explorations and informal learning activities. We then organised a second workshop to observe how children interacted with the toy, and to understand the limits of our initial design. It is our intention to design a second prototype to iterate further observations and design.

We conducted the initial workshop in a primary school near Dublin with 15 preschool children, of four and five years old, of different genders and socio-economic status. Some of them have previous experience with gardening, though that does not ensure consistent or complete understanding of botanical processes. The materials we used included crayons, sheets of paper for drawings, a small box with soil, seeds of various kinds (green beans, maize, oats, apple and tomatoes), fresh fruit (whole and cut apples – red and green – oranges and tomatoes), plants, flowers, and pictures of vegetables, fruits, flowers, and trees (see Figure 1).

Each interview included a child, an interviewer, a note-taker who intervened occasionally, and a tripod-mounted video camera that recorded each session. As in the classical Piagetian clinical interview[1], our prepared questions framed the enquiry but did not dictate a sequence for the conversation with the children. We asked questions that seemed natural in response to each child's thinking. We designed our questions not to imply a yes/no answer or a particular avenue of response, but to reveal each child's unique reasoning. We tailored the questions during the course of the conversations, as we noticed the ways that particular terminology did or did not seem to address or reflect the children's thinking. We tried to be unobtrusive and not to suggest answers. The children expressed themselves by speaking, gesticulating, drawing pictures, and manipulating objects. We welcomed and encouraged each kind of answer. Our goal was to focus on the reasoning process behind the words and actions. Each of the child's communications contributes to our emergent interpretation of an overall consistency in the child's thinking.

We report in the next section the most common conceptions we discovered in the initial workshop. The order of categories does not reflect any sequence of conversation. We have changed the children's names to protect their privacy. Most of the results find a synergic relation with Gelman and Hickling (1995) although we found reasoning on the causal mechanisms pertaining to growth to be less strong.

## Results of the initial workshop

### 1. Origin of the seeds

A seed's origin is not clear to children of this age. We registered different conceptions of the origin of seeds: humans make them, they came from a seed box, or seeds come from far away. Some children have more naturalistic conceptions: seeds can be found in the soil, or in the plants but not in a specific location. None of the children interviewed seemed to relate the seed with the fruit of the plant, even if the half-apple, with its seeds, was visible in front of them.

For example, consider the answers to the question 'Where do seeds come from?'

Five year old Carl's first answer assumed a non-naturalistic source. *'From … the apple shop.'* 'What would happen if I was unable to find the seeds in the apple shop. Where do I have to go?' '*I think I don't know, maybe from the apples.*'

*Mary (4):* '*You can find them under the ground.*' '… How does this seed get inside this apple?' '*Mans just put it in there*'.

*Sarah (5):* '*From the packages in the shops.*' ' Can you find them anywhere else?' '*Sometimes you can find them in the tree.*'

### 2. Origin of the plant

Children tend to consider the seed and the plant as distinct objects. So the origin of the plant can be as uncertain as that of the seed.

*Carl (5):* 'If I would like to grow another plant like this, what will I have to do?' '*You will have to put in a box.*' 'What do I have to put in the box?' '*You have to put a tree.*' 'Where do I find the tree?' '*You will find it to the apple tree.*' How does it start?' '*When you have a car, you have to look around for the apple tree. When you find the tree, if it is a small tree, you can put it into a box.*' (Carl offers no explanation of how this or any tree would have originated. Later, he develops an elaborate story about the moon and the sun talking to the plant, which becomes sad but does not sprout any seeds.)

### 3. Growth of the plant/seed

For most of the children, growth means just becoming bigger and bigger. They seem to lack a conception of progress through phases and a perception of qualitative differences in the morphology of the plant.

*Carl (5):* 'Let's imagine that the seed will grow. How will they grow?' '*They will grow bigger and bigger*' 'So they will keep growing bigger?' '*Yes.*'

### 4. Relation between seed and plant

The relation between seeds and plants is not so clear for the children. Some of them think of seeds as food for the plant, implying that seeds help the plant to grow. However, these children do not associate seeds with the plant's origin.

*Patrick (4):* 'What would you do with the seed to make the plant grow?' '*Give it water.*' 'Can the seed grow anywhere?' '*Under the plant.*'

*Cara (4):* 'How does this became a flower? What do you do with the seed?' '*You put them in the flowers*' (She points to the flower). 'And what happens to the seed?' '*It grows up.*' 'What does the plant need when it gets hungry?' (pointing to the seed) '*This.*' 'The seeds?' '*Yes.*' '… Do seeds have a mummy or daddy?' '*Yes.*' (pointing to another seed) 'This is its mummy?' '*Yes.*'

### 5. Flowers and fruits

None of the children seem to sense the sequence seed – plant – flower – fruit – seed. This is also related to the idea of pro-

Figure 1. The initial workshop setting. The materials included crayons, sheets of paper for drawings, a small box with soil, seeds of various kinds, fresh fruit, plants, flowers, and pictures of vegetables and fruit.

[1]See Introduction of Piaget, 1929, see Berg & Smith, 1985 and the three studies of Leach, Driver, Scott & Wood-Robinson, 1995 and 1996.

gression between phases, stages or states.

*Shannon (4):* 'What is a seed?' '*A seed is … you have to put it into the ground and then is a flower.*'

*Rose (4):* 'What this seed will grow into?' '*A flower.*'

### 6. Roots

Most of the children interviewed do not mention the presence of roots and their function for the life of the plant.

*Sarah (5):* 'Why do plants sit in the ground?' '*Because they have to, till they grow.*' 'Then what happens?' '*Some apple will grow on the tree.*'

### 7. Placement of the seed in order to grow

Most of the children who recognise the seed as responsible for the origin and/or nourishing the growth of the plant still are not clear about where to put the seed so that it will mature or increase in size. They think they should put the seed into the flower or that the seed grows under the plant, which does begin to suggest an idea of relation with the soil. In addition, they do seem to understand some need to access the plant as it grows.

*Mary (4):* 'Where do you have to put the seed to get it to grow?' '*Maybe around the plant in a circle.*' 'How do you get the seeds to grow?' '*They need water.*'

### 8. Species and relation with seeds

Most of them do not have a clear idea of the relation between a certain kind of plant and its seed. So for them it is possible to grow (whatever 'to grow' means for them) an orange tree using an apple seed, an apple tree using a tomato seed, etc.[2]

*Carl (5):* 'If I was to plant this tomato seed, would I be able to get an apple?' '*Yes you could.*'

*Mary (4):* 'Would I be able to use the apple seed to make a tomato tree?' '*Maybe because the seed colour is the same of the apple.*'

### 9. Environmental conditions responsible for the growth

Children consider water to be an important factor in the growth of the plant. Most of them consider also the light (sunshine) as an important factor.[3] Not one addressed invisible conditions for growth such as temperature and the presence of circulating air.

*Patrick (4):* 'What do plants like?' '*Water.*' 'Do plants like anything else?' '*No.*' 'Do you think plants like morning or night time?' '*Morning.*' 'Why?' '*Because they like sun.*'

### 10. Season, cycle and death

They do not anticipate a significant difference in the plant during the course of a year, but most of them do recognise the winter as the period in which the plant is sleeping. The children do not correlate progress in plant growth with the seasonal cycle. Plants, for them, seem to be 'always' there with the same shape and size.

*Shannon (4):* What does the plant look like during the wintertime? *They are dying.*

### 11. Being 'alive'

We wanted to investigate the concept of being 'alive' according to whether the plant possessed the following attributes: growth, reproduction, feeding, and breathing.[4] Most of the children relate the concept of 'being alive' with the idea of motion.[5] Therefore, a plant is not alive because it does not have legs or hands. Other children think that a plant is alive if its leaves point toward the sky and conversely, dead if the body of the plant points to the soil.

*Mary (4):* 'Do you think that this plant is alive?' '*Yes, because is going up.*'

*Sarah (5):* 'Does a plant feel a touch?' '*Yes.*' 'How come?' '*Because it just moved.*' 'So if the plant moves it means that it felt that?' '*Yes.*'

*Renny (5):* 'If I were to touch it, would the plant know?' '*No, because it doesn't have eyes.*'

### 12. Time of growth

*Carl (5):* 'How long does it take the seed to grow up?' '*It takes 5 minutes.*'

### 13. Food for the plant, metabolism

Most of the children are certain that plants drink water, but uncertain about what food plants consume. Often food is identified with rocks among the soil or sometimes with water itself. None of the children considered soil as a source of nutrients.[6]

*Carl (5):* 'What tells you that the plant is breathing?' '*It is thinking that it is hungry*.' 'How do you know that?' '*When it is hungry it has to eat these things.*' 'What.' '*These things in there'* (the little rocks in the soil).

*Renny (5):* 'What do they eat?' '*They eat and drink water.*' '… What does this plant need to grow?' '*Seeds.*'

### 14. Number of plants and number of seeds

*Mary (4):* 'How many plants can you get with 10 seeds?' '*You might have one. You have to get two seeds for each plant.*'

*Sarah (5):* 'How can you make another plant?' '*Just putting two seeds.*'

## The core concept of a cycle

Table 1 summarises commonly held adult and child views. The table also provides a format for thinking through important relationships among the ideas. For each category, we asked the question of what concept/s would be needed in order to understand the idea. Discerning these relationships would help to articulate the conceptual structure of the domain, which would help in building the environment.

This is simply an initial foray into a complex analysis that we hope to pursue further, yet it suggests that the concept of cycle could be an important foundation for many of the other ideas. We do not consider this concept necessarily as a precursor, as it seems that any of the related categories might lead to it just as it might lead to them. Nevertheless, the frequency with which the concept of cycle appears in this exercise reveals its importance.

## The design of the toy

The DigitalSeed (DS in short) is a toy that we designed following the results of the interviews reported above. As we will detail below, it is designed to simulate the transposition of the plant's life cycle that we found fundamental to many

[2] For the case of inheritance see Springer & Keil, 1989.

[3] The light factor can also be related to other issues of conceptualization as explained by Driver, Guesne & Tiberghien, 1985.

[4] The same approach was used in Stavy & Wax, 1989.

[5] For this particular aspect see the study of Richards & Siegler, 1984.

[6] See the summary of some researches in this topic in Bell, 1985.

Table 1. Key ideas and relations

| CATEGORY | ADULTS' UNDERSTANDING | CHILDREN'S CONCEPTION | RELATION |
|---|---|---|---|
| Origin of the seeds | The seed is inside the fruit of the plant. | Seeds are made by humans or can be found in nature in a non-specified place. | CYCLE |
| Origin of the plant | A plant is born from a seed in the adequate environmental conditions. | A plant is always there. | RELATION WITH SEEDS |
| Growth of the plant | When the seed grows, it changes its properties and becomes the plant. | The plant does not grow, or it keeps becoming bigger and bigger. | CYCLE |
| Relation between seed and plant | The seed is the plant not yet born. It will become the plant in the right environmental conditions. | Seeds are food for the plant. | CYCLE |
| Flowers and fruits | Flowers and fruits are part of the chain between plant and seed. | Flowers, fruits and seeds are not related. | CYCLE |
| Roots | Roots are on the base of the plant, where the plant takes in nutrients. | [Roots are not conceptualized.] | FOOD OF THE PLANT METABOLISM |
| Placement of the seed in order to grow | The seed must be under the soil with the right humidity. | Under the plant or into the flowers, or into the plant. | ORIGIN OF THE PLANT |
| Species and relations with seeds from a tomato seed. | An apple seed can generate only an apple tree. | You can grow an apple tree | CYCLE |
| Environmental conditions responsible for the growth | There must be light, water, soil and the right temperature. | Water, sunshine. | CYCLE |
| Cycle | A plant will follow its own cycle from the seed to the mature plant to the newborn seed. | [Cycle is not conceptualized.] | [This seems to be the foundation concept.] |
| Being "alive" | A plant is alive because it is born, it grows and it can reproduce before dying. | Yes, because "it goes up", or no, because it "cannot move". | GROWTH OF THE PLANT |
| Time of growth | A plant grows in weeks/months. | It can grow in 5 minutes. | CYCLE |
| Food of the plant/ metabolism | Water, minerals. | Just water. | ENVIRONMENTAL CONDITION |
| Number of plants and number of seeds | 1:1 | Many to one, one to many. | CYCLE |

other key ideas of the plant biology.

An electronic device was built that represented symbolic images of (i) real objects (plants, seeds, etc) and (ii) actions (growth, pollination, etc) with animated characters.

The DigitalSeed arose from the idea that technology could help children to play with the key ideas of plant growth and development. Particularly, we tried to overcome the time delay necessary to relate environmental changes to effects in the plant's growth. Thus, we started from the problem of the temporal direction of the growth of a real plant and how to overcome it.

Obviously moving into a virtual world altogether (i.e. using a computer simulation or virtual reality) would be the easiest solution but in this case we would have had to dispense with the tangible features of a real plant and the subsequent richness of the learning environment that this produces. Therefore, we finalised our initial design between these two extremes. Without pretending to have all the features of a real plant, we selected those tangible aspects that we were able to preserve in the virtual world. We decided to maintain the physical experience of controlling the following environmental variables:

- *water content of the plant (as opposed to humidity)*
- *temperature*
- *light*

A fundamental part of the learning environment is the interplay between these variables. In the phases of growth, it is not just one factor that is dominant and responsible for growth but rather it is the interaction that is responsible. Humidity, temperature and light exposure are fundamentals factors for life: they have to be present at the same time and in the right proportions.

### 1. The 'tangible' interface

In the real domain, we wanted a robust interface with adequate dimensions, waterproof and shock resistant. We decided to use an iPaq 'Pocket PC' as the elaboration unit and as the display for the virtual world. Compaq's iPaq is a personal digital assistant (PDA) that is relatively easy to use and yet powerful enough to carry out in-depth processing of sensor data. We used environmental sensors as a bridge between the real world and the virtual world, to acquire quantitative differences around the iPaq. This acquisition process was realised through an interface board with a programmable integrated circuit (PIC). Five pairs of light and temperature sensors were installed, one for each face of the ABS box (see below) with the exclusion of the base. We decided to use a flow sensor instead of a humidity sensor because we need to appreciate differential readings rather than an absolute value and above all because the commercial humidity sensor cannot be used in direct contact with water which is exactly which is what we intended the children to experience (see Figure 2).

We packaged this equipment within an ABS cube-shaped box (see Figure 3). We used two funnels, one on the top and one on the bottom of the box, to direct the water flow and to activate the flow sensor; these were fixed in position using 'silicone' bond. A window (the same dimensions as the PDA's screen) was provided to display the story of the seed. Because the temperature sensors and light sensors are all around the cube, it was also possible to detect changes in the direction of the light and the provenance of a principal heat source.

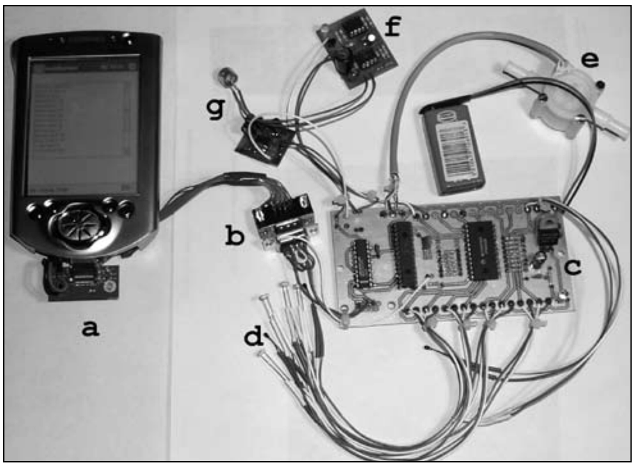
### 2. The virtual interface

The virtual interface was constructed (see Figure 4) using the Microsoft Software Developer's Kit for handhelds, mainly in 'Embedded Visual Basic'. In this program, the story of a seed prior to germination to the production of a new seed was displayed in separate frames. We divided this growth in relevant stages and we match each stage with an animation and with a different software state. The resolution used was of 240 x 268 pixels. Each image was prepared as a bitmap with contours in magenta. In this way it was possible to process each image as a layer and arrange them one on top of the other for the animation process. To advance between stages, the right input from the user was needed in terms of the 'correct environmental conditions' monitored through the sensors.

### 3. The interaction between virtual and real

It was decided to assign 15 minutes to the complete cycle and to work with a definite number of stages of development (n=10) in which the user could interact with growth.

Figure 2. Sensors used with the iPaq. (a) iPaq pocket pc and the cradle, (b) serial connection to the sensor board, (c) interface board, (d) temperature and light sensors – a pair for each face of the box except the bottom, (e) flow sensor to detect 'watering', (f) 'clap' sensor, (g) tri-directional accelerometer. The clap sensor and accelerometer were added for later possible improvements to the interface.



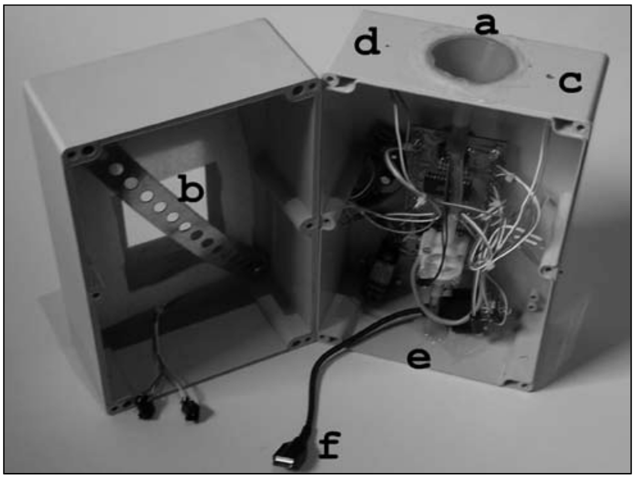




Figure 3. The external interface. (a) funnel for water (b) window for the iPaq display with holders, (c) light sensor, (d) temperature sensor, (e) drain for the water, (f) iPaq connector.

The software was modelled to respond to the environmental condition in three different states: *the right quantity*, *not enough*, *too much*. So, between each stage/state the sensors were checked to decide whether to proceed to the following state or to proceed to a meta-state in which the plant it is not healthy (see Figure 5). During the life of the plant, we also included other animation to enrich the environment and to introduce some other concepts as corollaries.

We wanted to show the direct relation between a certain environmental component and its effect on the growth of the plant. If the quantity was insufficient, the software moved to a meta-state that expressed poor plant health. In the same way, if the quantity was too much, the image expressed the unhealthy state (see Figure 6).


Figure 4. Typical simulation display. (Left) This shows the effect of water falling on the plant and was displayed while the child was pouring water through the funnel. (Right) A bee, upper left, pollinates the tree's flower, upper right.

In the animation dimensions were not considered important for the understanding of growth. This animation emphasises the sequence. In fact, it was possible to zoom in on a specific part of the scene (as in the final frame) when we wanted to focus on the fruit and then on its internal parts, that is, the seed (see Figure 7).

## Results of the follow-up workshop

We worked with the same children: they could interact with the DigitalSeed in a setting and manner similar to that of the first workshop, though this time the objects present on the table included a plant, the DS, some crayons, a mug of water, and a flashlight. While there were shortcomings with the DS in its existing form, we felt that the children's reactions pro-

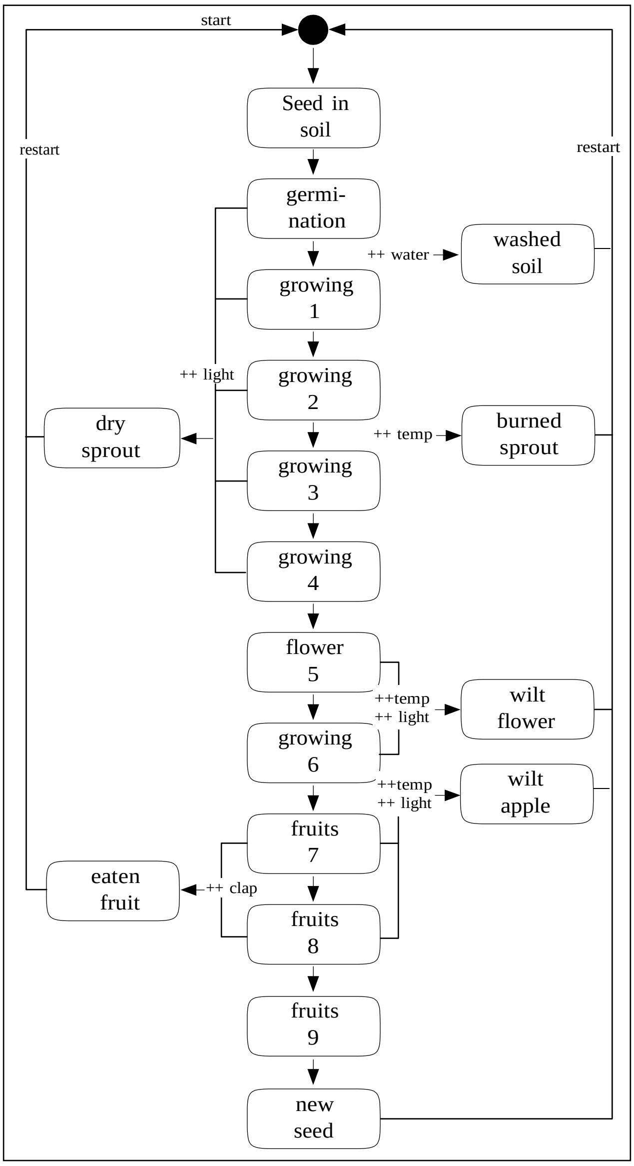



Figure 5. Software flowchart. To successfully proceed through the cycle, the child should provide the right amount of water, and light and temperature exposure of the box. Over- or under-provision results in a simulation of one of the unhealthy states on the sides. Prolonged 'mistreatment' of the box kills the simulated plant and the cycle restarts.

vided important feedback for the next phase of our work.

The proportions of the illustrated seed in the different pictures (e.g. Figure 7) affected children's understandings of the situation. Children had some problems in making sense of the camera effect of zooming in on a particular part of a scene. From the observations, we noted that the illustrated events, presented in just a few frames, produce a crude animation without smooth transitions between stages of plant growth. The children enjoyed the animation, but it did not always clearly represent the changes from one stage to the next. At the end, for example, some of the children thought that the tree had simply 'disappeared' and that a seed had appeared in its place.

The first sequence of the animation attracted particularly the children's interest. This animation showed the seed germinating a sprout, something they likely would not have imagined (at the time of the initial interview, they seemed to maintain a distinct separation between the seed and the plant). Additionally, we thought that the starting point for the DS should be the child's starting point, the plant, as the

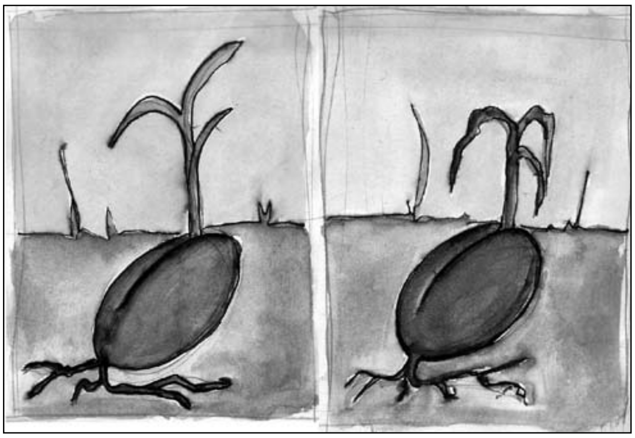


Figure 6. On the left, the sprout in a healthy state. On the right, the sick state.

children often had problems in relating the seed to the plant rather than the plant to the seed.

Also the design of the section through the ground did not seem to help the children conceptualise the presence and function of roots. Some of them referred to these as 'sticks' or 'leaves' that grow under the soil. The design of the pictures was an important issue that emerged vividly in the follow-up workshop. For example, we used a brown colour to express the 'unhealthy' state of the wilted flower, but some children did not recognise this meaning.

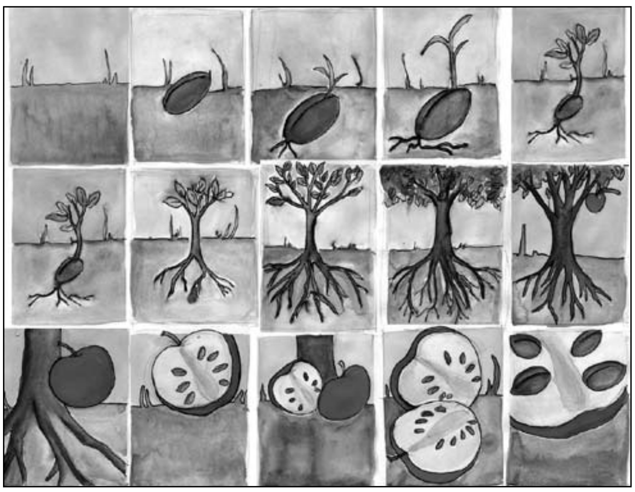
This prototype is large (20x30x20 cm), heavy (1.5kg) and fragile, so the children tended to shy away from it even though they were drawn to the pictures. This inhibited direct manipulation of the box, the water and the lamp. The mechanism designed to save the apple from the bird was hand clapping, though the interface does not suggest this and the children did not guess it. In fact, they did not interpret the bird as a threat.

Finally, the software design prescribes discrete cause and effect relationships between each picture and the next. Because it anticipates a single sequence of events, interactions are limited.

## Discussion

The primary focus of this design was to give the children a sense of the continuity between the stages, emphasising the cycle connecting them: a plant 'born' from a seed and producing seeds that can 'give life' to another plant and so on. So

Figure 7. Frames from the healthy growth sequence (watercolours on cardboard by Valentina Nisi).



flowers, fruits and seeds are conceived as part of this cycle, as part of the reproduction of the plant. The roots of the plants are visible as if the child was looking at a section of the ground in which the plant was living. We 'sowed' the seed under the soil to give the feeling of the right placement of the seed so that they could find the right environmental conditions for growth. In addition, the concept of the species-specificity is addressed in this design by the continuity between seeds and plants of the same kind. The environmental conditions are the interactive variables for the user/player/child.

It is considered that the DigitalSeed could be developed into a more classroom/laboratory friendly version and made available for teachers of biology at all levels. For example, the iPaq or an alternative palmtop computer, could be interfaced with an external computer by Bluetooth or comparable technology. It is important to recall that the DigitalSeed was produced using easily available commercial resources. It is believed that the DigitalSeed (or some version of it) could make a significant impact on the quality of learning in primary and secondary science as a model of the compromise between using live organisms on the one hand, and full computer simulations and graphics on the other. Long winters need not be devoid of experiences with plants.

## Acknowledgments

We would like to thank several colleagues: Carol Strohecker for thinking through the design of the DigitalSeed; Jamie Rasmussen for developing the iPAQ simulation and for helping design the interface of the DS and the workshops; Brendan Donovan, for the PIC programming; and Valentina Nisi, for the art work. Also, we would like to thank Anna Lometti, St. Patrick?s College and California State University, Chico, for helping in the workshop assessment. We thank the children for sharing their ideas with us

## References

Bell B F (1981) What is a plant? – some children's ideas. *New Zealand Science Teacher,* **21** pp10-14

Bell B F (1985) Students' ideas about plant nutrition: what are they? *Journal of Biological Education,* 19(3), pp213-218

Berg D N and Smith K K (1985) *Exploring Clinical Methods for Social Resea*rch. Beverly Hills, CA: Sage Publications.

Darley W M (1990) The essence of "plantness". *American Biology Teacher* 52(6) pp354-357

Driver R, Guesne E and Tiberghien A (1985) *Children's Ideas in Science*, Philadelphia: Open University Press.

Henniger M L (1987) Learning mathematics and science through play.*Childhood Education* 63(3) pp167-171

Hickling A K and Gelman S A (1995) How does your garden grow? Early conceptualization of seeds and their place in the plant growth cycle. *Child Development*, 66, pp856–876

Kinchin I A (1999) Investigating secondary-school girls' preferences for animals or plants: a simple 'head-to-head' comparison using two unfamiliar organisms. *Journal of Biological Education* 33(2) pp95-99

Leach J, Driver R, Scott P and Wood-Robinson C (1995) Children's ideas about ecology 1: theoretical background, design and methodology. *International Journal of Science Education,* 17(6), pp721-732

Leach J, Driver R, Scott P and Wood-Robinson C (1996) Children's ideas about ecology 2: ideas found in children aged 5-16 about the cycling of matter. *International Journal of Science Education*, 18(1), pp19-34

Leach J, Driver R, Scott P and Wood-Robinson C (1996) Children's ideas about ecology 3: ideas found in children aged 5-16 about the interdependency of organisms. *International Journal of Science Education,* 18(2), pp129-141

Piaget Jean (1929) *The child's conception of the world*. London: Routledge and Kegan Paul.

Raymo C (1973) Science as play. *Science Education,* 57(3), pp279-289

Richards D D and Siegler R S (1984) The effects of task requirements on children's abilities to make life judgments. *Child Development*, 55, pp1687-1696

Richards D D and Siegler R S (1986) The Children's understanding of the attributes of life. *Journal of Experimental Child Psychology*, 42, pp1-22

Schneekloth L H (1989) 'Where did you go?' 'the forest'. 'What did you see?' 'nothing'. *Children's Environments Quarterly,* 6, pp14-17

Simmons D A (1994) Urban children's preferences for nature: lessons for environmental education. *Children's Environments Quarterly*, 11, pp194-203

Smith J P, Di Sessa Andrea A and Roschelle J (1993) Misconceptions reconceived: A Constructivist analysis of knowledge in transition. *Journal of the Learning Sciences,* 3(2), pp115-163

Springer K and Keil F C (1989) On the development of biologically specific beliefs: The case of inheritance. *Child Development,* 60, pp637-648

Springer K and Keil F C (1991) Early differentiation of causal mechanisms appropriate to biological and non-biological kinds. *Child Development,* 62, pp767-781

Stavy R and Wax N (1989) Children's Conceptions of Plants as Living Things. *Human Development*, 32, pp88-94

Tunnicliffe S D (2001) Talking about plants - comments of primary school groups looking at plant exhibits in a botanical garden. *Journal of Biological Education,* 36 (1), pp27-34

Tunnicliffe S D and Reiss M J (2000) Building a model of the environment: how do children see plants? *Journal of Biological Education*, 34(4), pp172-177

Wandersee J H (1986) Plants or animals - which do junior high school students prefer to study? *Journal of Research in Science Teaching,* 23(5), pp247-251

Wassermann S (1988) Teaching strategies. Play-debrief-replay: an instructional model for science. *Childhood Education,* 64(4), pp232-234

## Internet References

http://msdn.microsoft.com/en-us/developercenters/default.aspx last accessed 2 February 2007.

http://welcome.hp.com/country/us/eng/prodserv/handheld.html last accessed 2 February 2007

***Mauro Cherubini is a Research Associate at the Centre de recherché et d'appui pour la formation et ses technologies (CRAFT), École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland (formerly of Everyday Learning group, Media Lab Europe). E-mail: martigan@ gmail.com. Hugh Gash is a senior lecturer at the Centre for the advancement of science teaching & learning, St. Patrick's College, (a College of Dublin City University), Drumcondra, Dublin 9, Ireland. Tom McCloughlin (corresponding author) is a lecturer at the Centre for the advancement of science teaching & learning, St. Patrick's College and was formerly Head of Science, Ashbourne Community School, Ashbourne, Co Meath, Ireland. Email: thomas.mccloughlin@spd.dcu.ie***