Using technology to enhance students’ system thinking skills in science education

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Outline of presentation

- Introduction
- Theoretical Background
  - What is a system and what is system thinking?
  - Why system thinking in science?
- My research in the area (and why use technology!)
  - The Galapagos Finches
  - Oikoskepsi
- Discussion
Introduction

Recent educational reports in the USA (Duschl, Schweingruber, & Shouse, 2007), the UK (Osborne, 2007), and elsewhere in Europe have called for a science education that places an emphasis on scientific literacy that makes the connection between science and everyday life.

The focus of this approach is on the social aspects of science, aiming to prepare young people for life beyond school.

Scientific literacy: both knowledge of the content and knowledge about science (Aikenhead, 2006)
Introduction

- emphasis is no longer only on the content but also on the processes and **thinking/reasoning** skills.

My work:
- using technology to enhance thinking skills....
  - system thinking
  - argumentation

- as a way to promote conceptual understanding
Theoretical Background

What is a system?
Examples of systems?
Theoretical Background

What is a system?
Theoretical Background

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Theoretical Background

What is a system
Theoretical Background

Defining system

“A system is an entity that maintains its existence and functions as a whole through the interaction of its parts. However, this group of interacting, interrelated or interdependent parts that form a complex and unified whole must have a specific purpose, and in order for the system to optimally carry out its purpose all parts must be present. Thus, the system attempts to maintain its stability through feedback. The interrelationships among the variables are connected by a cause and effect feedback loop, and consequently the status of one or more variables, affects the status of the other variables. Yet, the properties attributable to the system as a whole are not those of the individual components that make up the system.”

(Assaraf & Orion, 2005, p.519-520)
Theoretical Background

What is a system?
Theoretical Background

System thinkers are able to:

- analyze phenomena and problems in wider contexts,
- consider multiple cause-and-effect relationships, anticipate the long-term consequences and possible effects of present actions,
- understand the change over time

Theoretical Background

System thinking and science education

- Many phenomena around us (ecosystems, moon phase formation, energy transfer) are examples of complex systems.

- How we perceive the phenomena around us and in what extent we recognize the relations and possible changes, lies in our system thinking skills (i.e. climate change).

- System thinking is a skill that is related both to the nature of science and nature itself but is often neglected in the design of learning environments (AAAS, 1993; Forrester, 1992; Golan & Reiser, 2002; Wilensky & Resnick, 1999).
Theoretical Background

System thinking and science education

- System thinking is an increasingly important skill for navigating information highways, making decisions and solving problems (Hogan, 2000).

- Correlation between system thinking and conceptual understanding in science education (Bell-Basca & Grotzer, 2000).

- Important to introduce system thinking skills in the learning of sciences as a prerequisite for conceptual understanding (Grotzer & Bell Basca, 2003).
Elements of system thinking

Structure–Behaviour–Function framework:

❖ **Structure** - the physical structure of the system,

❖ **Behaviour** - the dynamic mechanisms that allow the structures to carry out the system’s function,

❖ **Function** - the purpose of the system and subsystems.

Hierarchical levels (Assaraf & Orion, 2005):

• **Level 1** - ability to identify the system’s components and processes;
• **Level 2** - ability to identify relationships between separate components and the ability to identify dynamic relationships between the system’s components;
• **Level 3** - ability to understand the cyclic nature of systems, the ability to organize components and place them within a network of relationships, and the ability to make generalizations;
• **Level 4** - an understanding of the hidden components of the system and the system’s evolution in time (prediction and retrospection).
Elements of system thinking

Identification of:

• **Skill 1**: the elements of a system,
• **Skill 2**: the spatial boundaries of a system
• **Skill 3**: the temporal boundaries of a system
• **Skill 4**: several subsystems within a single system
• **Skill 5**: the influence of specific elements of the system on other elements, or the whole system
• **Skill 6**: the changes that need to take place in order to observe certain patterns
• **Skill 7**: feedback effects in a system

(Evagorou et al., 2008)
The projects

- The Galapagos Finches
- OIKOSKEPSI
The Galapagos Finches project

The problem

A number of studies have investigated students’ understanding of complex systems (Wilenksy & Resnick, 1999; Hmelo et al., 2000) in specific domains. Other studies examined students’ reasoning about specific complex systems (Golan & Reiser, 2002).

However, pre-service teachers’ system thinking skills are largely unexplored.
Research Design

Research question

- Can prospective elementary school teachers develop their system thinking through a specially designed instructional approach?
Research Design

1st stage of data collection

Interviews → Instruction → Interviews

2nd stage of data collection

Assessment test → Instruction → Assessment test

Changes
Research Design

1st stage of data collection (pilot)

Sample

• 3 pre-service teachers
• Average age: 21
• Special interest in science and science teaching

2nd stage of data collection

Sample

• 42 pre-service teachers
• Average age: 21
• Special interest in science and science teaching
## Research Design

<table>
<thead>
<tr>
<th>Research question</th>
<th>Data collection tools</th>
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<tbody>
<tr>
<td>Can prospective elementary school teachers develop their system thinking through a specially designed instructional approach?</td>
<td>Pre and post assessment test</td>
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<td></td>
<td>Videotaping of pre-service teachers while working with the instructional material and software</td>
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Research Design

Assessment test

- Questions related to two systems:
  - An ecological system: the ecosystem of sea.
  - A mechanical system: a bicycle.
Research Design

PART A: General questions
Question 2
Which of the following are systems? Why?
Cable: .........................................................
Simple electric circuit: ..............................
Wooden chair: ...........................................
Forest: .....................................................

PART B: Natural System
(d) Describe some interrelationships within this ecosystem.

(f) What will happen if we remove the plankton?

PART C: Mechanical System
(c) How many systems can you see in this picture?
(d) Describe some interrelationships within the bicycle.
The learning environment

The learning environment

- The software begins with an introduction saying how the finches died in 1977.
Instruction

- Choosing the Galapagos Finches software:
  - it presents a complex system, the interrelations among the parts of the system and the changes that are related to the interactions of the parts,
  - provides data that the pre-service teachers can use to investigate their hypotheses
  - applied in previous research (Zembaul-Saul et al., 2002; Sandoval & Reiser, 2003; Kyza & Edelson, 2004), with different purposes, so it is valid as a learning environment
| Day 1 | • Introduction to the Galapagos Finches software and presentation of the problem as presented in the software (How did so many finches die and what helped some finches survive?).  
• Group discussion for the problem and possible answers. |
| Day 2 | • Studying the Galapagos Island data.  
• Discussing in groups the nature and characteristics of a system.  
• Analyzing various systems. |
| Day 3 | • Understanding the fact that the Galapagos Islands is a system  
• Using the data to define the space and time limits for the Galapagos islands.  
• Creating concept maps that represent the relations among the parts of the system. |
| Day 4 | • Emphasis on the problem presented by the software.  
• Using the concept map and the software to find answers to the problems presented by the software. |
| Day 5 | • Preparing a presentation to provide answers to the questions. Data, graphs should be used in the answers. |
Model of a system
Data Analysis

- Data from pre and post assessment tests were coded and analyzed by means of open coding strategies (Glaser & Strauss, 1967) consistent with constant comparative analysis (Goetz & LeCompte, 1984).

- The codes that were developed were analyzed with the research questions as a guide. The categories retrieved from the data sets were compared and contrasted in order to generate common themes and patterns.
Results

Sub-skills that our instruction helped improve:

- Defining a system (21% => 79%)
- Identifying a complex system from a list of objects (7% => 79%)
- Identifying system’s components (95% => 98%)
- Identifying relationships between separate components of the system (57% => 76%)

Skills that our instruction failed to improve:

- System’s dimension within time (prediction and retrospection) (9% => 12%)
Summarizing the outcomes

- Pre-service teachers can develop system thinking skills by using specially designed instructional material and by handling data that allows them to understand the association among the various elements of a system.

- However not all aspects of system thinking can improve, and not all aspects of system thinking belong to the same level of complexity.
Summarizing the outcomes

- The findings of this study suggest trying to recognize, if possible, a model (learning progression) for developing system thinking skills.

- Implications for future research include studying pre-service teachers’ transfer of their system thinking skills in their teaching practices.
The Oikoskepsi Project

The problem

- There are limited resources for teaching system thinking within science, especially for younger students, and involved the designing of a learning environment with the potential to support elementary school students in their effort to develop their system thinking skills.

The purpose

- To investigate the impact of a simulation-based learning environment on elementary school students’ development of system thinking skills.
The Oikoskepsi Project

- 13 students (11 to 12-year-old), 9 boys and 4 girls, suburban school in Cyprus,
- Mixed ability and socio-economic status,
- Voluntarily follow after-school computer lessons, offered by the teachers of their school,
- No previous experience with computers or inquiry-based learning environments,
- Familiarized with a concept mapping software and the use of Internet search engines.

- The learning intervention was implemented over a period of **5 sessions** (90-min periods)
The Oikoskepsi Project

WISE & Models (StageCast Creator)

- Designed within WISE (Web-based Inquiry Science Environment) platform (Linn et al., 2004)
  - Making thinking visible
  - Supporting collaborative learning
  - Allowing scaffolding and prompting
  - Allowing easy access to students’ work.
  - Simulations were used to allow students to virtually explore the system and to investigate the effects of various changes.

Saturday, August 6, 2011
Lesson 1: The problem was presented through newspaper clippings from WISE - Extensive annoyance in a village by the mosquitoes reproduced in a nearby marsh.
Lesson 1: Students were given access to the computer simulation of a marsh ecosystem and they worked in pairs in order to identify the elements of the marsh and record them on a specially designed worksheet.
Lessons 2 & 3: Pairs engaged in discussions about the marsh as a system that consists of subsystems and has identifiable interactions between its elements:

- identify in the simulation the habitat of a certain species, such as the mosquitoes,
- identify predator–prey relationships and to study the relationship between water-level fluctuations and changes in the size of the mosquito population.
Lessons 5 & 6:

- Tried various solutions for the control of mosquitoes (e.g., remove the water from the swamp, spray with different chemicals, introduce new species: eucalyptus, mosquito fish) and were able to see the effects of each one of the solutions on the ecosystem or on individual elements of it over a period of time.

- In the fifth session, they also had the opportunity to study feedback effects through the simulation of a predator–prey system, by recording the oscillations in the size of both the predator and the prey populations.
The Oikoskepsi Project

What changes can you see in the marsh after adding the eucalyptus?

- Changes in the elements of the water: 
- Changes in the elements of the air: 

What do you think that will happen to all the system elements 10 years after we plant the eucalyptus?
Elements of system thinking

Identification of:

• **Skill 1**: the elements of a system,
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• **Skill 7**: feedback effects in a system

(Evagorou et al., 2008)
Why use technology

- The simulation allowed students to have *continuous access to the system* under discussion, to *explore the influence of various parameters* on system structure and behaviour, and to test hypotheses.

- The need to virtually experiment with a system also encouraged the students to come to grips with thinking about specific elements, subsystems, and the system as a whole.

- In that way, the students did not have to struggle with imagining the implications of their suggestions; the simulations made it easier to visualize changes and hence to think more effectively through the effects of the actions they proposed, and also to explore more possibilities.
Why use technology

• The learning environment also enabled the students to work ‘with evidence’ and to have the freedom to select the ‘data’ they wanted to generate by focusing on specific parameters at different times.

• One of the challenges encountered by educators interested in working with complex systems is how to provide access to the real system for the purpose of collecting data without devoting excessive time and implementing complex procedures such as repeated field-study visits (National Research Council, 2000).


References


