

# CAN THE USE OF AN INTERACTIVE COMPUTATIONAL MODEL ASSIST IN TEACHING FORMS OF CAUSALITY IN SYSTEM DYNAMICS?

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## ABSTRACT

This study investigated the effectiveness of a computational model (made with Stagecast Creator<sup>1</sup>) in teaching forms of causality in system dynamics. Systems causality forms were examined within the context of food web perturbations. The research sample included two equivalent sixth grade classes from the same elementary school in Cyprus. The same teacher taught students in both classes a unit on ecosystems that was completed in two lessons (4 class periods). Students in the experimental group were encouraged to use an interactive computational model of feeding relationships within a certain food web as an aid for solving problems about food web perturbations, whereas students in the control group could only get help from text and visual information. Two written tasks were administered before and after the teaching intervention. Tasks were used to measure: (i) students' systems reasoning abilities and (ii) students' ability for transfer of systems reasoning skills in new contexts. The results indicate that the experimental group students were favored by the use of the computational model in making two-way (active and passive) and extended one way causal connections. They were also much better in making interactive connections and transfer causality structures in new contexts. This research provides insights on how science concepts require reasoning abilities that students typically are not familiar with. It also underlines that teaching approaches should aim at promoting reasoning skills as well as content knowledge. Using computational models in promoting students' systems reasoning skills is one example of such an approach.

## KEYWORDS

Systems reasoning, ecosystems, computational models, teaching methodology, collaborative learning

## INTRODUCTION

An important goal of science education today is to enable learners to develop thinking skills. One of the essential components of higher-order thinking is *systems reasoning*: the ability to think about a whole in terms of its parts and, alternatively, about parts in terms of how they relate to one another and to the whole. (American Association for the Advancement of Science, 1993)

Most of the problems – scientific, social, economical etc - that plague us today involve complex, non-linear and highly interactive systems. Thinking about complex systems is becoming an increasingly important skill as it enables the “systemic thinker” to deal effectively with these types of problems and find solutions that are not immediately apparent. (Aronson, 1996) Unfortunately, educational systems failed to prepare students to cope with the complexity of modern life (Forester, 2000); although many systems in our world involve complex chains of cause and effect encompassing two-way causal processes, people tend to construct one-way linear chains when explaining them (Green, 1997). Systemic thinking can be taught, not necessarily in a new context, but as a tool of organizing knowledge in many areas of the existing curriculum. Research has shown that students may improve their systemic

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<sup>1</sup> Stagecast Creator is a commercial software application, <http://www.stagecast.com>

thinking skills when they use systems dynamics as a framework to give meaning to detailed facts in areas such as mathematics, physical science, social studies, biology, history and even literature (Forrester, 1992).

The Science Curriculum can provide students with valuable experiences in analysing complex systems and help them develop the skills and habits of systemic thinkers (Hogan, 2000). Science teaching can lead students to approach natural phenomena by thinking of them as systems of interactive objects. This could be beneficial for both cultivating thinking skills and enhancing conceptual understanding in science. Many researchers agree that students' difficulty in learning advanced science concepts relates to a paucity of causal models in students' understanding (Bell Basca, 2000; Grotzer & Perkins, 2000; Brown, 1995; di Sessa, 1993; Driver, Guesne & Tiberghien, 1985) Learners who apply systems thinking when they assign attributes to several scientific phenomena (e.g. electricity, evolution, gas laws, energy flow in ecosystems), deal with them not as static processes, but as dynamic systems applying non-linear, probabilistic and emergent explanations for them. (Chi, 2000)

The study of ecology could be a paradigm of a curriculum area that teachers could use to develop systems thinking skills. An ecosystem is an example of a system: biotic and abiotic elements are its parts that interact through dynamic processes that allow energy and material flow. Each part effects the behaviour of the whole, depending on the part's interaction with other parts of the ecosystem. Understanding and reasoning effectively about ecosystems involves understanding a number of different types of causal patterns. Causality thinking is a crucial element of systems thinking. Figuring out interrelations in a system requires the construction of causal relations. Learners have to look beyond specific chains and recognize the types of causality that underlie beyond the processes: Simple causal relations (what affects what) and internal circular causality of cause and effect feedback. (Draper, 1993)

According to Grotzer & Perkins (2000) tracing food effects perturbations involves two kinds of causality models: simple linear causality or domino like and interactive causality. Linear causality describes a causal pattern where an initial cause produces a chain of consecutive effects, and every effect becomes a new cause. For example in a food web the disappearance of the primary consumers would affect secondary consumers and that in turn would affect tertiary consumers (mice – snakes – owls).

Linear causality can take two directions. It can either take a one-way direction or a two-way direction when effects are traced both actively and passively. In the previous example if a two-way causal linear pattern were applied effects of the disappearance of the primary consumers would affect the population of producers (passive) and the population of secondary consumers (active) (plants – mice, mice – snakes).

In interactive causality something can be a cause and effect at the same time. For example a decrease in the population of primary consumers within a food web could be the cause for a decrease in the population of secondary consumers and the effect of the decrease in the secondary consumers could be the cause for an increase to primary consumers.

Leach et al. (1996) who investigated children's ideas about ecology support that when pupils use food webs they tend to make predictions in terms of linear cause – effect sequences. Hogan (2000) examined students' systems reasoning about food web perturbations. The results of her study point to limitations in awareness of patterns of systems interactions as constraining students' systems reasoning in ecology. In general students have difficulty in reasoning about the ecosystem as a system. They tend to reason locally and miss the larger picture. (Bell Basca et al., 2000) Research shows that when reasoning about effects in ecosystems, students typically miss the connectedness within the system and the implicit complex causal relationships (Griffiths and Grant, 185; Webb & Bolt, 1990 as cited in Bell Basca et al., 2000). As a result, students cannot understand the interdependence of organisms. They fail to make the connections and find how any change in one population could directly or indirectly affect others. In addition, according to Bell Basca (2000), they do not easily recognize interactive causalities on their

own. Mutual relationships are not easily understood by students and by adults as well: People seldom realize the pervasive existence of feedback loops in driving everything that changes through time. Most people think in linear, non feedback terms (Forrester, 1992).

Systems thinking skills cannot be developed into traditional educational settings in which students passively receive information. Learner-centred environments that require active participation and hands on involvement should be created instead. (Forrester, 1992) Students have to explore systems, find out variables that determine their behaviour and finally, discover the underlying causality of the systems elements. However, real life systems are too complex to be explored. Many variables interact, and cause and effects are distanced both in time and space, most of the times in a scale that makes their exploration impossible in classroom settings. The use of models in science classroom can help teachers solve these problems. Well-designed models simplify real world systems while heightening awareness of the complexity of them; students can participate in a simplified system and learn how the real system operates without spending the days, weeks, or years it would take to undergo this experience in the real world. (Costello, 1993) Exploring models of real systems enables students to engage in systems thinking and enhances their understanding of systems as well as science concepts.

In our study we investigated whether the use of a computational model would assist students in better understanding forms of causality that are implicit in complex system dynamics. We hypothesized that with the use of the model in a collaborative learning environment students could understand the nature of domino and interactive causality and apply it in understanding the relationships of organisms within ecosystems. We also hypothesized that this understanding would be transferable to relationships of parts of other systems as well. Firstly, we probed students' initial causal conceptions about specific ecosystem relationships using a questionnaire. Then we supported students' developing understanding through linear- active or passive- and interactive causal structures with the use of a model. We were interested in whether using a model that was revealing the nature of the causal patterns would be more effective than discussion

## **METHODOLOGY**

### *Overview of research design*

Our sample consisted of two equal in achievement classes of sixth grade students (a total of 52 11-12 year old students) who attend to the same public primary school in Nicosia. One class served as the experimental group and the other as a control group. The experimental group used the computational model during the instruction.

### *Pre- post tests*

Students' causal reasoning skills in both groups were assessed pre/post with a questionnaire that required them to answer to questions referring to perturbations within a certain food web. The food web was illustrated in a picture where all populations were represented with a single animal within their habitat. Additional information in the form of callouts concerning the feeding habits of each organism was provided. (The food web was not given in the form of a diagram)

The questionnaire was divided in two sections: The questions in the first section were giving a cause – a change in an ecosystem population- and were asking for the effects. The second section of the questionnaire functioned vice versa: questions mentioned an effect and asked for causes.

An additional post-test was given to both groups in order to check the transferability of causal reasoning after the teaching intervention. The second post-test was illustrating an economical system within an island where tourists, hotels, hotel employees, farmers etc, interact and interrelate because of the money flow that determines their relationships. The second-post test structure was similar to the pre-test one; cause-effect questions in the first part and vice versa in the second.

### Teaching intervention

Students in the experimental group participated in a teaching intervention where they had chance to interact with a computational model portraying the feeding relations within a food web. We have used the power of programming in *Stagecast Creator* to create models that demonstrate characteristics of complex ecosystems that challenge naïve ontological beliefs (linear causal reasoning vs. interactive, one way linear vs. two way linear). Students used the models in groups to check the predictions they made for the effects of certain perturbations on the food web. Students in the control group had to make the same predictions after discussion in their group and then present them to class. They could check their predictions through discussion and teacher scaffolding. Both groups had the chance to have a revising section in the end, in which students could apply simple and interactive causal reasoning in new questions about the ecosystem.

### Scoring

The questionnaires were scored to assess the students' initial causal structures that expressed through reasoning about ecosystem concepts and to assess whether or not these structures became more sophisticated given the intervention conditions. We diagrammed students' answers (see table 1) in order to identify students' causal structures. Causal structures were identified as *linear* and *interactive*. Linear causal patterns could be either one or multi-step. In order to see the improvement in students' domino-like causality we reported the number of steps. Apart from the number of steps in linear causality, the direction was also reported. (One-way, two-way) Finally, we reported the existence of interactive causality in students' answers. Table 1 shows an example of diagramming and scoring an answer.

Table 1. Diagramming and scoring Questions (Post- test 1, Subject #26- Control Group, Question 2)

Question	What do you think that would happen if the number of mice was increased?			
Answer	The plants would decrease, the snakes would increase and finally, mice would decrease.			
Diagram				
Scoring	Causality			Number of steps
	One Way linear	Two Way Linear	Interactive	
	1 (Yes)	1 (Yes) Active: Snakes eat mice Passive: Plants are eaten by mice	1 (Yes) Mice affect plants and plants, then, affect mice.	2

The answers could not always be analyzed as above. There were instances where students made wrong connections between populations, did not know what to answer, or made broad statements like: “*If the owls die then all organisms would be affected, because this is a food chain.*” All these instances were scored with “0”. Students' answers revealed one more difficulty: they confused cause and effect. For example, in a question “What could be the cause of owl decrement”, they answered, “If the owls decrease then ...”. We scored these answers with “0” as well, but also reported this confusion as a “cause – effect” confusion.

## RESULTS

### Initial Structures

Students' initial causality patterns in both groups were found to be at an one-step linear level. (Average number of steps: 1,15). Very few students made two- way connections. Most of the connections were

predator-prey relationships - “*If snakes are reduced then mice will be increased*” -in an active and not in a passive way. That’s why questions that presented perturbations in organisms that were in the top of the food chain – like owls- could not lead students to the prediction of perturbations in other organisms that *were eaten* by them. Students had to find an organism that *eats* owls in order to make a connection. Very few students made multi-step linear connections and even fewer (4%) made interactive connections. There were also many students (20%) that could not make any connections between organisms, or made wrong or broad connections between them.

Table 2. Students' pre/post causality patterns

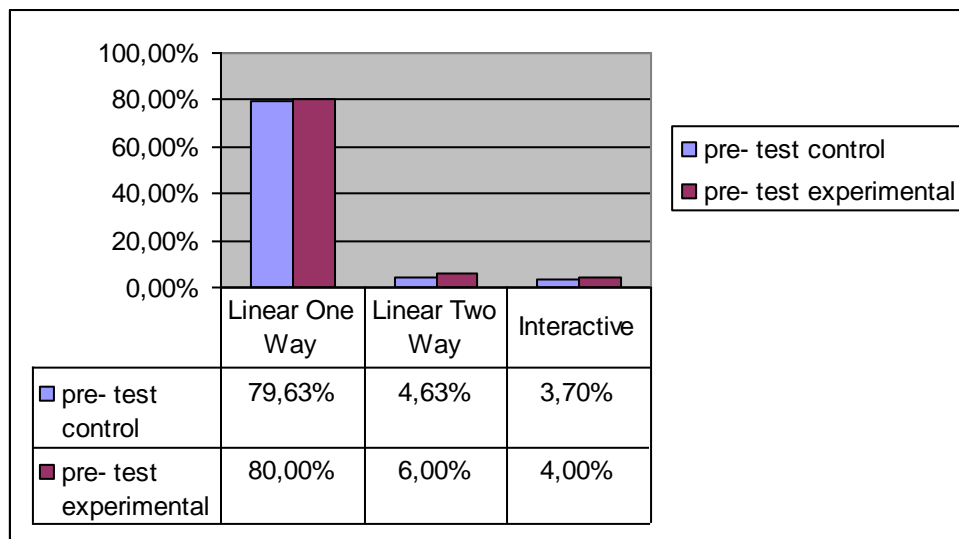
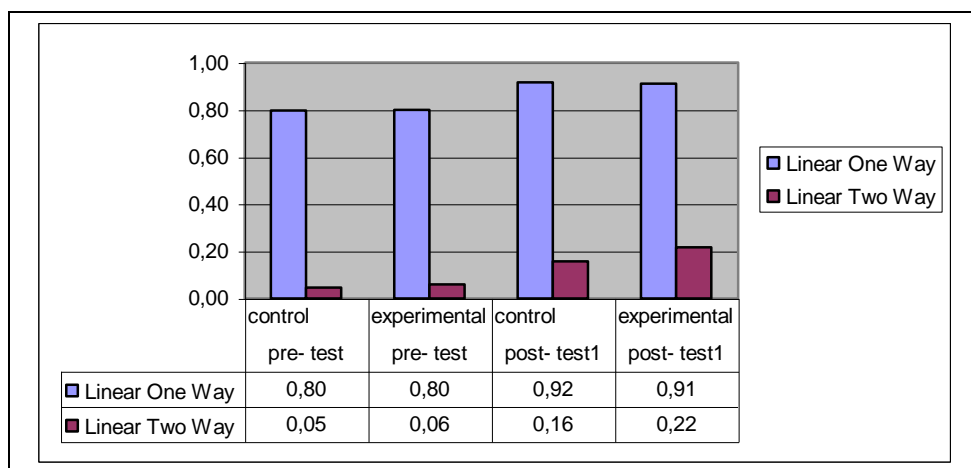


Table 3. Students' pre/post linear causality



*Structures after intervention*

The results indicate that both groups made more connections between organisms after the intervention. However, students in the experimental group were favored in making two-way (active and passive) and domino-like connections (more steps).

*Interactive Causality*

The results here reveal that despite the low performance of both groups in interactive causality (maximum performance 22,7%), students in the experimental group were making much more interactive connections after the intervention (4% before, 22,7 % after) than the control group did (4% before, 7,41% after).

Table 4. Number of steps in students' pre/post linear causality

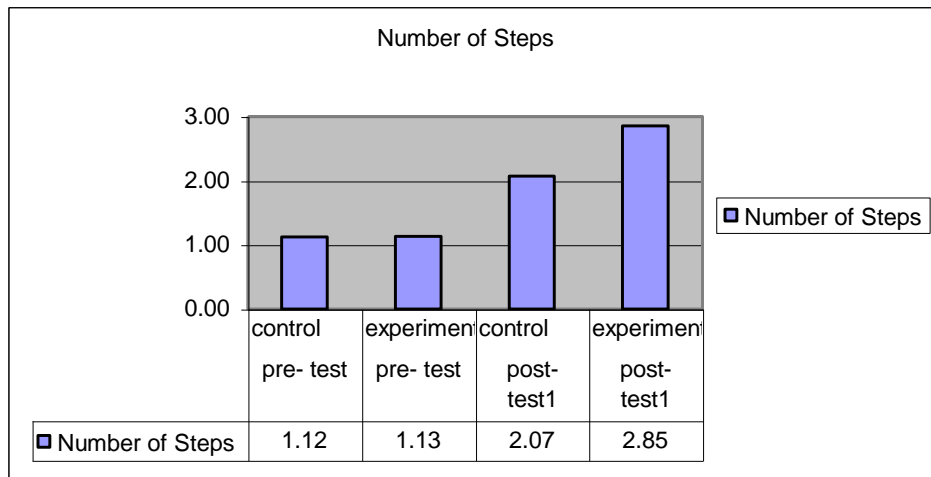
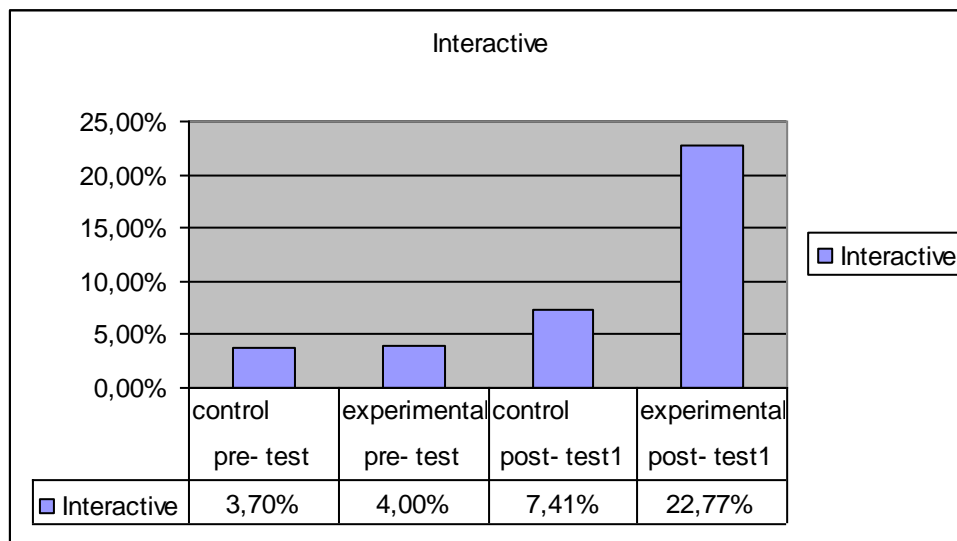


Table 5. Students' pre/post interactive causality



### Transferability

The results confirm that the use of the computational model was much more effective in transferring systems reasoning skills. Students in the experimental group were found to be able to transfer causality structures in a new context whereas students in the control group could not. Table 6 shows the difference in performance that both groups had between the pre-test and the second post-test (the new system). The control group had a negative difference whereas the experimental group had a positive difference in all areas, especially in the domino-like connections.

### Cause-effect confusion

The analysis indicates that both groups had great difficulty to answer questions that were asking for causes, given the effects. Table 7 shows the scores of both groups per question. The first four questions were giving the cause and asking for effects. It is obvious that students made more simple and interactive causal connections when starting from the cause to find effects, than vice versa. The main reason for this lack of performance was the confusion that students had between the concepts of "cause" and "effect". In many instances, they answered questions that were asking for causes by giving effects. Further analysis of the results revealed that the use of the computational model helped students overcome this difficulty, as the percentage of cause-effect confusions were more lower after teaching

intervention in the experimental than in the control group, even though they had similar performance before teaching.

Table 6. Difference in performance that both groups had between the pre-test and the second post-test

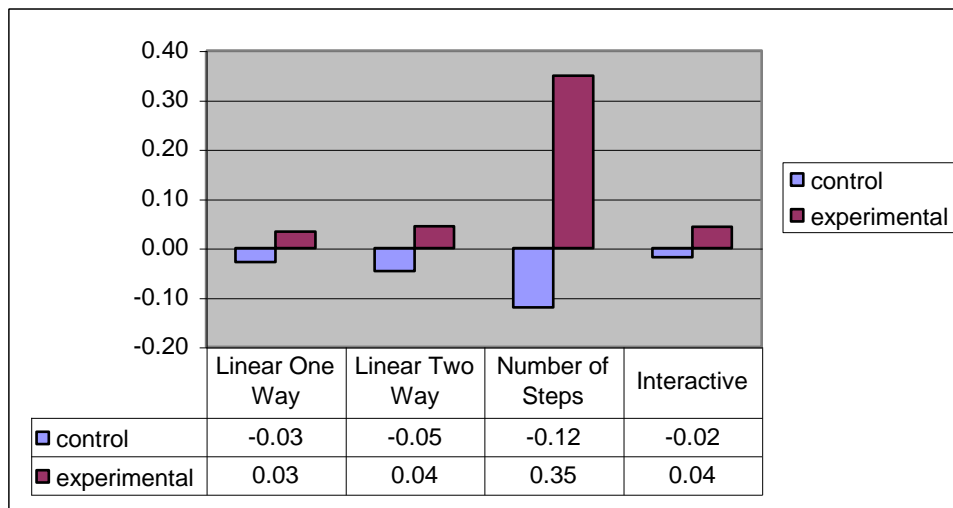
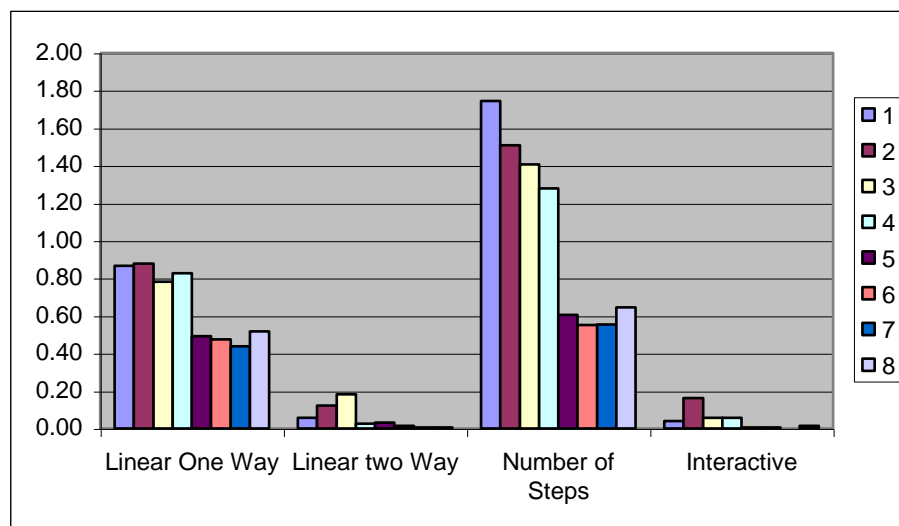


Table 7. Scores of both groups per question



## DISCUSSION

Results in the first post-test do provide support for our hypotheses that:

1. Teaching intervention would assist students in applying more complicated causal structures
2. The use of an interactive computational model would assist the experimental group students in making more two-way linear and interactive connections
3. The use of an interactive computational model would favor students in transferring new and more complicated patterns of causality a new system

Specifically, results indicate that the experimental group was favored by the use of the computational model, since students of this group were able to make more linear and interactive connections among food web populations. Both groups were favored by interventions; the greatest difference though, was detected in their ability to apply interactive causality patterns. Although the ability to make interactive connections was still low after the intervention, the experimental group students made much more

interactive connections than their peers in the control group. Even though, according to our research, it seems possible to teach linear causality patterns in simple environments, this is not the case for complex causality patterns. In order for students to abandon the naïve causality structures that are implicit in their thinking they need to be exposed to environments that support conceptual conflict. Exploring complex causality patterns can help students challenge their own and therefore develop more complicated causality thinking. Traditional teaching approaches as discussion and teacher prompts as used in the control group seemed inadequate in assisting students overcome their difficulties.

#### *Post test 2 – Transferring knowledge*

The results concerning the application of causal structures in an ecosystem environment did not show great differences between groups. Differences between the two groups were noted though in the application of interactive causality patterns. The most important finding of this study was the differences detected between the two groups when they had to apply causality patterns in a new system (post test 2). Our results support our third hypothesis that students' improvement in terms of causality patterns would be transferable in other systems if they were engaged in an interactive learning environment that allowed them the handling of computational models. The experimental group that used the computational model was able to make more linear connections in the new system than the control group. The results indicate that there was a statistically significant difference in experimental group's students' ability to apply linear one way, linear two way and interactive causal patterns , post test 1 and post test 2. We interpreted this finding as being the result of the model enriched environment that was used by the experimental group. It seemed that the use of this environment enabled students to improve their causality patterns and allowed them to transfer their new understandings to a new system.

On the other hand, traditional instruction that did not engaged students in interaction with the model seemed insufficient in helping students confront and improve their naïve causality structures. Students in the control group statistically improved only their two-way linear causality patterns whereas they did not show any improvement in the other areas of causality. Additionally, students in the control group showed difficulty in transferring their knowledge to a new system.

Our results support de Jong's et al. (1999) claim that using models may not improve domain knowledge but rather intuitive knowledge. However, further research is needed in finding ways to detect what do students gain from interaction with models. Our research provides insights on how science concepts require reasoning abilities that students typically are not familiar with. It also underlines that teaching approaches should aim at promoting reasoning skills as well as content knowledge. Using computational models in promoting students' systems reasoning skills is one example of such an approach.

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