“Small changes can cause big problems over time“: Insights from a Systems Thinking Intervention on Ecosystems with 4th-Graders

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Abstract

System Dynamics education in K-12 has become an important mission within the System Dynamics community. This paper presents a scriptorium for conducting a four-hour systems thinking intervention on ecosystems for 4th graders. We used a three step approach: A general introduction to stocks and flows using the bathtub game serves as the basis for discussing the ongoing dynamics of global warming. A second application to an ecosystem is the classic predator-prey relationship. For discussing the kids’ learnings we do not only present the kids’ immediate feedback but also their feedback gathered three months after. Finally, we reflect on insights from this intervention.

Key words

Ecosystem modeling, global warming, K-12 Education, pedagogic techniques, systems thinking

Introduction

According to FORRESTER (2007) many K-12 institutions in the USA make substantial progress in using System Dynamics "as a common thread running through all subjects" or in using other systems thinking tools. There is great experience in teaching System Dynamics to kids, going back about forty years (Sterman, 2011). The importance of K-12 for the System Dynamics community became obvious when the System Dynamics Society rewarded high-school teacher DIANA FISHER with the Lifetime Achievement Award in 2011 (Fisher, 2011a). In her paper, FISHER presents systems thinking and System Dynamics modeling concepts that have been taught to students between five and eighteen years of age. Besides this article, there are publications, for example, presenting meta studies about past publications (Hopper & Stave, 2008), reviewing pedagogic techniques (Kennedy, 2009), introducing a way to introduce System Dynamics in school curricula (Fisher, 1997; Lyneis, 2003), collecting different systems thinking games (Booth Sweeney, 2001, 2009; Booth Sweeney & Meadows, 2010; Fisher, 2011b) that can be used for a curriculum or for a single course, or studies of the benefit of System Dynamics application in classrooms (Booth Sweeney & Sterman, 2007; Fisher, 2009).

This paper has a different focus. It concentrates on the preparation and the execution of a four-hour systems thinking intervention with 10-year-old kids from the point of view of non-school teachers. Even though being familiar with the System Dynamics method and with teaching System Dynamics to adults, we did not have any experience in teaching it to kids. We share insights from the planning and the conduct of the session to make it easier for those interested in teaching systems thinking to kids to design their own intervention.

The Metropolitan School Frankfurt invited us to carry out a session with the overall topic being ecosystems. In the following we describe the details of the day: We start the intervention by introducing the basic concept of System Dynamics – stocks and flows – using the bathtub game. We then apply the insights of the bathtub game to the global warming issue. Afterwards, we move on to a different ecosystem, the predator-prey dynamics. We then discuss the kids' immediate and later feedback on the course. The paper ends with limitations and ideas for future scopes.

Ecosystems Modeling at the Metropolitan School in Frankfurt

In February 2011 we had been invited by the Metropolitan School Frankfurt to hold a four-hour-session on systems thinking in ecosystems in a 4th-grade class of sixteen ten-year olds. The Metropolitan School Frankfurt is an IB (International Baccalaureate)-school and preschool, providing an education for around 300 students from over 30 countries. The school believes in a child-centered, inquiry based pedagogy and is open to use systems thinking concepts for teaching.

The curriculum for the 4th-grade has a unit of enquiry – a focus theme for several weeks – on ecosystems. We reviewed existing System Dynamics K-12 teaching material (Booth Sweeney, 2001, 2009; Booth Sweeney & Meadows, 2010; Davidsen, 1994; Fisher, 1994, 1997, 2003, 2008, 2009) and exchanged experiences with LINDA BOOTH SWEENEY, LEES STUNTZ, DIANE FISHER from the Creative Learning Exchange, and TOM FIDDAMAN from Ventana Systems, an expert for ecosystems modeling (Fiddaman, 1997).

There are many interesting and suitable topics to introduce systems thinking in general and the dynamics of ecosystems in particular to kids. They differ in their applicability for different age groups. We decided to focus on two main story-lines. This gave us the opportunity to go into more depth where appropriate during the time available: we expected that the predator-prey dynamics would suit very well the understanding of 4^{th}-grade students. Furthermore, we chose global warming as a more complex ecosystems topic. For introducing the kids to stocks and flows we selected the bathtub game.

FISHER (2011) identifies sixteen topics under the scope of systems thinking suitable for children aged 5-10 years. We covered seven of them in our session: simple interconnectedness, reinforcing feedback, balancing feedback, accumulations and flows, drawing simple stock-and-flow diagrams, simple population dynamics, and time horizons.

After having decided on the general approach we designed a detailed session schedule. It includes session length, session objective, leading questions, sequential questions, media used, and class set-up for each exercise and sub-session (see Table 1). In order to keep the kids' attention we varied the class set-up. We shifted between kids doing group work at tables or on the floor, kids walking around, teacher-centered leaning, using different media like slides, video, paper and pencil, flip charts, or tape markings on the floor to visualize a giant bathtub. Even though we designed a detailed plan of the session, we did not precisely stick to it as we went into more detail here or there when we observed ongoing interest with the children. However, the level of detail gave us the confidence that we can rely on our framework and work with the kids in a flexible way.

#	Time (start) -	Length -	Time (end) -	Objective	Leading question	Sequential questions/to do	Media used	Required media	Class set-up
1.	9:00	0:10	9:10	Introduction: Kids learn about the instructors and the objective of the class	What are we doing today?	You will learn about - systems - stocks and flows - dynamics	none	none	kids sit at their desks
2.	9:10	0:20	9:30	Understanding the dynamics of a system I	What is a system?	- stylized bathtub with inflow and outflow marked on the groud - instructors decide how many kids "flow" in and out of the bathtub - play for 8 or 9 periods - 1 kid marks the # of kids entering, leaving, and being in the bathtub on the blackboard/flipchart in spreadsheet columns - color code: leaving: red entering: green in the bathtub: blue	- large square/bathtub with inflow and outflow marked on the ground - red, green, and blue chalk/whiteboard pens - blackboard/ whiteboard/flipchart	- masking tape - watch - slips of paper with instructions of # of kids entering/leaving the bathtub for instructors	- initial conditions: 3 kids in the bathtub other kids stand in the inflow tube outside the bathtub and enter the bathtub when told to enter - kids walk in and out as noted on the slips of paper and as told by the instructor - both instructors pay attention that the kids enter or leave the bathtub correctly
3.	9:30	0:15	9:45	Understanding the dynamics of a system II	What is a system?	- the kid who filled out the spreadsheet on the flipchart/whiteboard/blackboard with # of kids in the bathtub, flowing in and out transfers the numbers into a graph, using three different colors (red=outflow, green=inflow and blue=stock) - in groups of two, all kids transfer the numbers on the flipchart/blackboard into a graph, using three different colors	- blank sheets of paper - red, green, and blue pencils for all kids	white paper for all kids	kids sit on the floor in half-circle around the blackboard/ whiteboard/flipchart
4.	9:45	0:05	9:50	Understanding the dynamics of a system III	What do system dynamics look like?	- "what do you see in the graphs?" - describe the graph of the stock. - what happens with the inflow and the outflow at the times when the stock stays constant? In which period is that so? - are there periods in which the inflow is hiher than the outflow? when? what happens to the stock in these times? - are there periods in which the outflow is higher than the inflow? when? what happens to the stock in these times?	- copies of graphs with the kids' own drawings - blackboard/ whiteboard/flipchart - chalk/pens	- copies of kids' graphs	kids sit on the floor in half-circle around the blackboard/ whiteboard/flipchart
5.	9:50	0:10	10:00	Understanding elements of a system	What does a system consist of?	- "where else have you seen accumulations like bathtubs and inflows and outflows?" - kids brainstorm in pairs and tell us wherefrom they know stocks (and flows) and behavior over time - instructors note the items on the blackboard - instructors show some pictures of other stocks(traffic jam, dams, etc.)	- blackboard/ whiteboard/flipchart - chalk/pens - ppt with pictures of systems (incl. CO2 pic - this is the bridge to the CO2 bathtub game)	- blackboard/ whiteboard/flipchart - chalk/pens	- kids get together in pairs and stand up - they brainstorm on the question asked - they sit down on the floor as soon as they have found an example
		0:15				*Pause*			
6.	10:15	0:10	10:25	Brainstorming and getting an understanding about stock, inflow, outflow of radiation	What is the sun doing good to the planet earth?	- have a brief discussion on the interaction between sun, earth, radiation, atmosphere, radiation warming the earth (what do you experience when you stay outside in the sun? - I get warm). - draw a picture of sun, earth, radiation, atmosphere, CO2 molecules - CO2 prohibits reflected radiation from leaving the atmosphere - currently, mankind emits much CO2, so the stock of CO2 in the atmosphere increases - what is happening to the radiation? - "it stays in the atmosphere" - and what is the consequence? - "it warms the earth"	- blackboard/ whiteboard/flipchart - chalk/pens	- blackboard/ whiteboard/flipchart - chalk/pens	kids sit at their desks
7.	10:00	0:15	10:15	Experiencing physically climate change dynamics and assessing three different climate policies I	How do mankind change the climate and what can we do to stop it?	- let's have a look at what happens to the CO2 bathtub if we - continue to do what we do? (business as usual) - 1 kid sketches the # of kids in the stock, the kids flowing in and out in a spreadsheet on the flipchart - stock initial = 6 - 3 kids in per period - 1 kid out per period, then increasing to 2 kids - follow-up questions: what have you experienced? - it is pretty crowded in the bathtub of CO2 molecules, isn't it? - what was the initial number of CO2 kids in the atmosphere bathtub? - what is the current number of CO2 kids in the atmosphere bathtub - why has the number of CO2 kids in the atmosphere bathtub increased? - "because the inflow is much higher than the outflow" - what happens to the CO2 bathtub if we want to stabilize CO2 emissions? - inflow down to 2 kids per period	The Bathtub Game	- blackboard/ whiteboard/flipchart - chalk/pens - Over-sized graph pad (or slide on a projector) - Colored markers	- interactive group game - 1 volunteer for keeping track of stock, inflow, outflow

#	Time (start) -	Length -	Time (end) -	Objective	Leading question	Sequential questions/to do	Media used	Required media	Class set-up
8.	10:15	0:15	10:30	Reviewing the three different policies	How does a climate expert explain the impact of the three policies?	- to catch up, show ppt with CO2 in atmosphere bathtub with sources and sinks - let kids brainstorm on sinks and resources for repition - kids are in three groups and watch the video - Group 1: listen carefully to scenario 1 - Group 2: listen carefully to scenario 2 - Group 3: listen carefully to scenario 3 - kids discuss in groups the following questions: 1. what is the main message of the scenario? 2. what does it mean? Groups vote a spokesman/spokeswoman to answer the two questions	http://video.google.com/videoplay?docid=8235725143334110601&pr=goog-sl#	- projector - laptop - internet access	- listen & repeat - kids sit at their tables/on the floor
		0:05				*Pause*			
9.	10:35	0:10	10:45	Putting the climate change scenarios into action: what can we do to reduce CO2 emissions?	What can we do to reduce CO2?	- follow-up question: what can we do to further reduce CO2 emissons? - Instructors collect ideas on the whiteboard/flipchart/blackboard this can also be followed-up by the teacher in class later		- blackboard/ whiteboard/flipchart - chalk/pens	- kids sit together in groups of three to brainstorm on possibilities to reduce CO2 emissions
10.	10:45	0:10	10:55	Understanding the relevance of time horizons	Nothing is stable	- we are currently using finite resources that have been produced millions of years ago (show picture of carbon forrest) - "what is this?" (show ppt graph of peak oil) - understanding that looking at different time horizons provide different views on problems	Peak oil graphs (Sterman, 2000)	- projector - oil slides from Sterman on ppt - laptop	kids sit at their tables
		0:15				*Pause*			
11.	11:10	0:05	11:15	Introducing another ecosystem	Can we apply the stock-and-flow concept to other ecosystems?	- talk about predator/prey (show ppt with picture of lux and snowshoe hare)	- slides with lux and snowshoe hare and deer	- projector - slides with lux and snowshoe hare and deer - laptop	kids sit at their desks
12.	11:15	0:10	11:25	Transferring the insights of stock and flows and the bathtub concept on represent the stock-and-flow-concept in drawing	How can we draw stock-and-flows if we do not have a giant bathtub marked on the floor?	- draw stock-and-flow structure on flipchart	- blackboard/ whiteboard/flipchart - chalk/pens	- blackboard/ whiteboard/flipchart - chalk/pens	kids sit at their desks
13.	11:25	0:20	11:45	Understanding another ecosystem	What are preys and preditors in ecosystems and how do they interact with each other?	- let kids chose eco system in pairs - let kids draw their own ecosystem of predator/prey using the stock and flow concept	- ppt - paper for kids - pens for kids	- ppt with ecosystems - laptop - projector - paper for kids - pens for kids	kids sit at their desksgroupwork in pairs
14.	11:45	0:15	12:00	Understanding dynamics in a second-order-system	How do the size of predator and prey herds determine each other?	- develop the dynamics of the interaction between predator and prey on a flipchart together with the kids - use the snowshoe hare/lux example to show that this is really happening in reality	- blackboard/ whiteboard/flipchart - chalk/pens - ppt with snowshoe hare and lux	- blackboard/ whiteboard/flipchart - chalk/pens - ppt - laptop - projector	kids sit on the floor
15.	12:00	0:10	12:10	Getting feedback on the session	What was good and bad? What can we learn for future systems thinking interventions?	- What did you like about this class? - What shall we do differently next time?	- oral feedback	- flip chart and pen to write down the feedback	kids sit on the floor

Table 1: Detailed course agenda

In the following we present the three main sessions in more detail.

Introduction to the Stocks and Flow Concept: Bathtubs are Everywhere

The first exercise to be carried out covered three topics under the scope of systems thinking suitable for children: simple interconnectedness, accumulations and flows, and time horizons. Stocks and flows are the basic concepts of the System Dynamics methodology (Forrester, 1958, 1961; Sterman, 2000). Stock-and-flow-models depict real world structures. STERMAN AND BOOTH SWEENEY (2002), for example, have shown in experiments that people have difficulties understanding the interrelationships and dynamics between stocks and flows even in simple structures. Yet, it is crucial to understand a system's underlying structure responsible for the observed dynamics as system structure drives system behavior. Therefore, we laid the basis for understanding global warming issues and predator-prey dynamics by introducing stocks and flows.

We started the morning in the classroom with a ninety minutes introduction of the basic concept of stocks and flows (Sterman, 2000). The exercise is adapted from QUADEN, TICOTSKY AND LYNEIS's (2008) 'In and Out-game'. We had taped a simple bathtub structure with masking tape on the floor in a room adjacent to the classroom to visualize an abstract picture of a bathtub, as can be seen in Figure 1. In addition, we added an 'invisible' connection between the inflow and the outflow so that kids who 'flew' out of the bathtub could circle back to the inflow: we only worked with fifteen kids and we would have reached limitations of playing the game soon if each kid flew in and out of the bathtub only once.

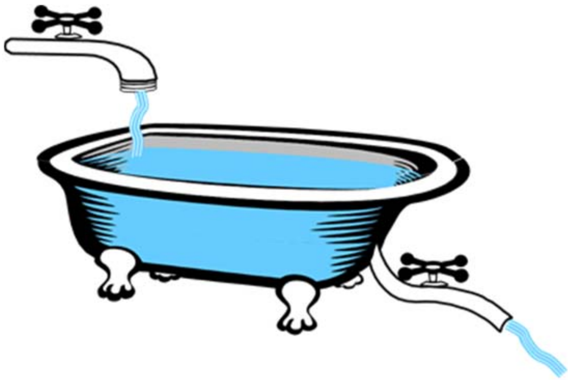

Figure 1: Simple bathtub structure to represent stocks and flows (Sterman, 2000)

We briefed the kids on the structure and the rules of the game. To start the game we asked for six volunteers to populate the taped bathtub on the floor. The rest of the class moved into the inflow 'above' the bathtub. We had also prepared a flip chart with a blank table with columns to fill in the number of kids in the bathtub and the number of kids flowing in and out of the bathtub. One kid was appointed to track the changes in the table on the flip chart every time period. For each time period we announced the number of kids entering (flowing in) and leaving (flowing out of) the bathtub (see Table 2). The kids self-organized who entered and left the bathtub. We varied the number of kids entering or leaving the bathtub. Thus, the stock showed a peak and trough over time. We observed that it was fairly easy for the kids to understand what happened during each time step.

In the subsequent debrief the kids sat on the floor. The kid who filled out the flip chart explained how and why the number of kids in the bathtub changed. Then we presented a blank over-time graph on a second flip chart next to the filled-out table with the number of kids in the bathtub. We distributed blank paper and pencils to the kids and asked them to copy the graph on their papers. Looking at the numbers for the stock on the flip chart, they drew the over-time behavior of the stock. Afterwards we analyzed the graph together, asking the kids for the reason of the emerging peak and trough shape. They were able to correctly explain that the peak (trough) occurred when the inflow was larger (smaller) than the outflow. As the kids were able to describe what happened in the bathtub we infer from this that they understood the relationship between stocks and flows.

Period	in	out	stock
0	-	-	3
1	5	2	6
2	2	7	1
3	8	1	8
4	8	4	12
5	3	6	9
6	2	1	10
7	1	9	2
8	12	0	14
9	3	7	10

Table 2: Numbers used in the Bathtub game

After a break we asked the kids to transfer their learning to familiar situations where they had observed similar ‘stocks’ and ‘inflows’ and ‘outflows’. The kids brainstormed in pairs and described examples of stocks and flows and possible behaviors over time. We noted their answers on the flipchart to capture the results in a way that was visible for the entire group. The long and creative list of situations included ‘stocks’ like cars in a dealership lot, people in a shop, cars moving on roads, laundry in a washing machine, etc. To debrief the first exercise we showed them pictures of other systems, including herds, dams, and traffic jams (see examples in Figure 2).

Figure 2: Examples for pictures of stocks and flows presented

The First Ecosystem Exercise: Global Warming

The global warming exercise focusses on the same system thinking topics as the first one. Yet, it is not abstract like the one described above, but it captures a specific topic. The global warming exercise is adapted from QUADEN, TICOTSKY AND LYNEIS’s (2008) ‘In and Out-game’ that the kids were familiar with from the first session. We are aware that explaining global warming through a simple stock-and-flow structure is highly simplified as it does not cover linear effects, evaporation as a cooling process, water vapor, and clouds which are relevant parts of the system, too. Yet, understanding bathtub dynamics, or stock and flows, can still help understanding the climate's response to human greenhouse gas emissions. We did a brief introduction explaining the basic concept of sun radiation, greenhouse gas accumulation, and heat reflection on a flip chart. We ensured that the kids understood that an increase in the greenhouse gas level diminishes the radiation of heat back into space, thus heating up the earth's atmosphere, leading to more droughts, severe floodings, etc. Also, we discussed human activities that release greenhouse gases into the atmosphere, like burning fuel, coil, and natural gases. We talked about natural greenhouse gas sinks like oceans and plants (see Figure 3). The children were well aware that humans have emitted greenhouse gases into the atmosphere because of their activities in addition to the natural greenhouse gas level because of the teacher's preparation of that particular topic.

Following the briefing, we went back to the adjacent room with the taped bathtub on the floor. We reenacted the bathtub game with the kids now representing atmospheric greenhouse gas molecules and the bathtub being the earth's atmosphere. Six children represented the initial stock of greenhouse gases. For the following turns, the inflow was always larger than the outflow (see Table 3).

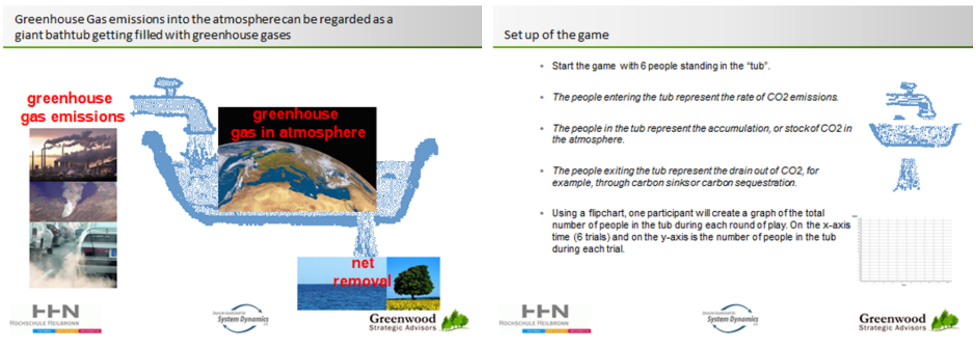

Figure 3: Slide presented on global warming (left-hand side) and instructions for the instructors (right-hand side)

Over time, with an increasing number of kids in the bathtub – or greenhouse gases molecules in the atmosphere –, it became uncomfortable for the kids in the available space. The kids learned the way the system works through experiencing. It helped them to understand quickly what was happening and what was going to happen in the bathtub – e.g. the bathtub will become even more crowded.

We then stopped the game to discuss with the kids what to do to prevent the bathtub – or the atmosphere – from becoming unpleasantly crowded with kids – or greenhouse gas in the atmosphere.

As the greenhouse gas absorption volume of sinks cannot be changed in the real world, the kids agreed on the solution to stabilize the level in the bathtub by reducing the inflow to a level equal to the outflow. We continued playing the game with the respective settings. The kids then noticed that their idea was correct as the overall number of kids in the bathtub effectively did not change anymore – or, transferred to the greenhouse gas example, the number of greenhouse gas molecules in the atmosphere did not increase any further. Like in the first exercise, we tracked the numbers for inflow, level, and outflow in all games to reinforce the concept of representing them as graphs. Again, we discussed the over-time behavior of the greenhouse gas molecules in the atmosphere as a debrief.

Period	in	out	stock
0	-	-	6
1	3	1	8
2	3	1	10
3	3	2	11
4	3	2	12
5	3	2	13
6	2	2	13
7	2	2	13
8	2	2	13
9	2	2	13

Table 3: Values used in the CO_2-Game

We continued the debrief with discussing the challenge of greenhouse gas accumulation in the atmosphere using a different media. We watched the 'Climate Change Bathtub Simulation' video that is available from climateinteractive.org and which is based on Fiddaman's (1997) study. It "is a brief, animated, interactive simulation game that teaches several principles regarding the dynamics of the global carbon cycle and climate change. Designed for children and adults, its purpose is to improve understanding of how changes in carbon dioxide emissions will affect levels of carbon dioxide in the atmosphere" (2012). In the video, Andrew Jones from ClimateInteractive discusses three possible approaches to the greenhouse gas emission problem in order to keep greenhouse gas emissions at a level for the temperature increase not to exceed 2°C – as world leaders have agreed: 'do nothing and let the inflow of emissions further increase', 'stabilize the greenhouse gas emission at today's level', or 'reduce the level of emissions'. Most people intuitively, and wrongly, prefer the second solution which does not solve the problem: the inflow level is still higher than the outflow. Instead, the annual rate of emissions needs to decline rapidly.

The video corresponds well with the bathtub-based games played beforehand. Andrew Jones picks up the picture of water filled in a bathtub and compares it to greenhouse gas molecules in the atmosphere. This reinforced the experience the kids had made through playing the games.

Before watching the video, we split the class into three groups and asked each of them to focus on the underlying message of one of the three approaches. Despite the video's complexity, it turned out to be well suited for the kids. Although its length of eight minutes is close to the limits of the kids' attention span they watched the video with great interest. Afterwards, the kids decided on a presenter for each group. They prepared a brief statement about their designated scenario and its implications with regard to global warming. All groups summarized their scenarios well, showing that they understood the implication of the different inflows and outflows for the greenhouse gas level in the atmosphere.

To conclude the global warming exercise, we briefly discussed implications of time horizons (Sterman, 2000, and see Figure 4). Burning fossil fuels today depletes a stock of fossil deposits. This stock was accumulated over millions of years whilst its depletion happens in the span of a few decades – an example of unsustainable dynamics – which will reduce the rate of discharge of greenhouse gases going forward.

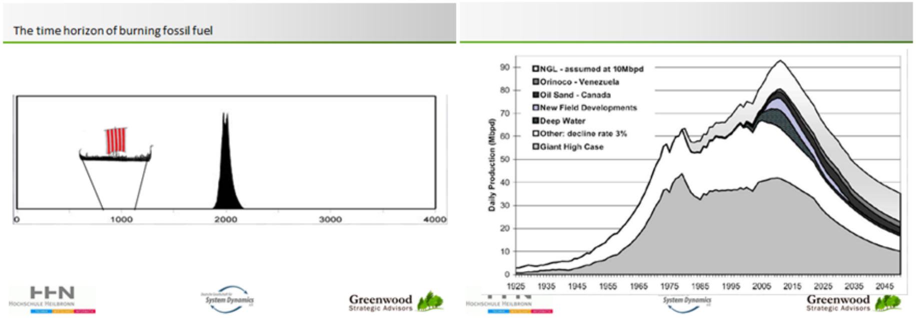

Figure 4: Pictures presented to discuss time horizons

The Second Ecosystem Exercise: Predator-Prey

The challenge in the third exercise was to apply the stock-and-flow concept to the predator-prey system. We covered seven of the sixteen topics under the scope of systems thinking with this exercise: simple interconnectedness, reinforcing feedback, balancing feedback, accumulations and flows, drawing simple stock-and-flow diagrams, simple population dynamics, and time horizons

In addition, we were following three objectives running this exercise. First, the kids should learn about predator-prey-population-dynamics as another example for natural system dynamics. Second, we introduced the depiction of stocks and flows. Third, the kids were asked to transfer their learning insights of stocks and flows and the bathtub concept to another natural system.

The predator-prey dynamics are well discussed in the literature (Goodwin, 1967; Lotka, 1910; Swart, 1990; Volterra, 1926). The underlying structure reflects the mutually dependent populations of predators and prey, like the Canadian lynx and the snowshoe hare, in an isolated area. This relationship can be depicted in a simple two-stock model, as shown in Figure 7. It is a simplified model, for which we assumed that there is a stock of prey, hare, and a stock of predators, lynx. The stocks are connected via one balancing feedback loop. For reasons of simplicity we excluded the lynx’s nutrition alternatives next to the hare. Both populations are increased by births, determined by the fractional birth rates and the size of the stock. In addition, the lynx’s birth rate is determined by the number of hare available. The lynx death rate is determined by its fractional death rate and the number of lynx alive. Hare deaths are determined by the lynx hunting success rate, the number of lynx available for hunting and the number of hare.

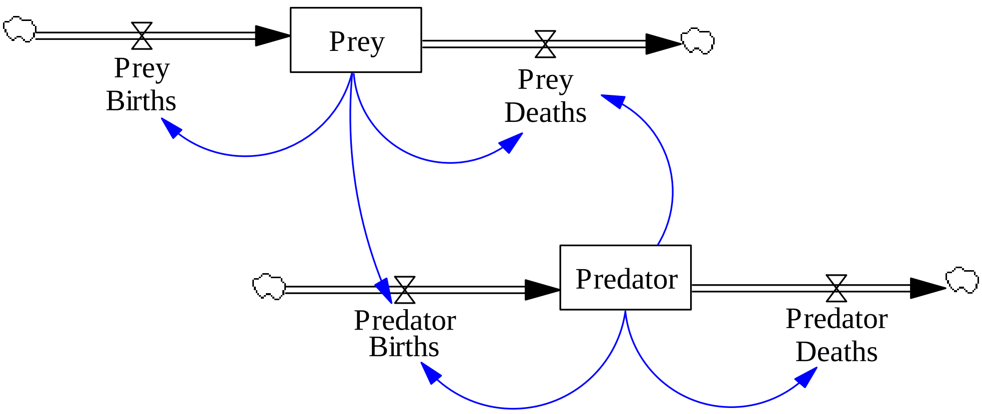

Figure 5: Very simple, not internally consistent predator-prey structure

We decided to show the kids this simplified version in order not to overwhelm them with information.[i] However, a more sophisticated version of this model produces the dynamics shown in Figure 6. The figure depicts the behavior of the two populations, with the red, dotted line for the hare and the blue line for the lynx. As can be seen in the figure, the dynamics between the mutually dependent populations exhibit oscillating behavior with regularly repeating peaks which increases in amplitude and wave length. There is also a time lag between the peak of the lynx and hare populations.

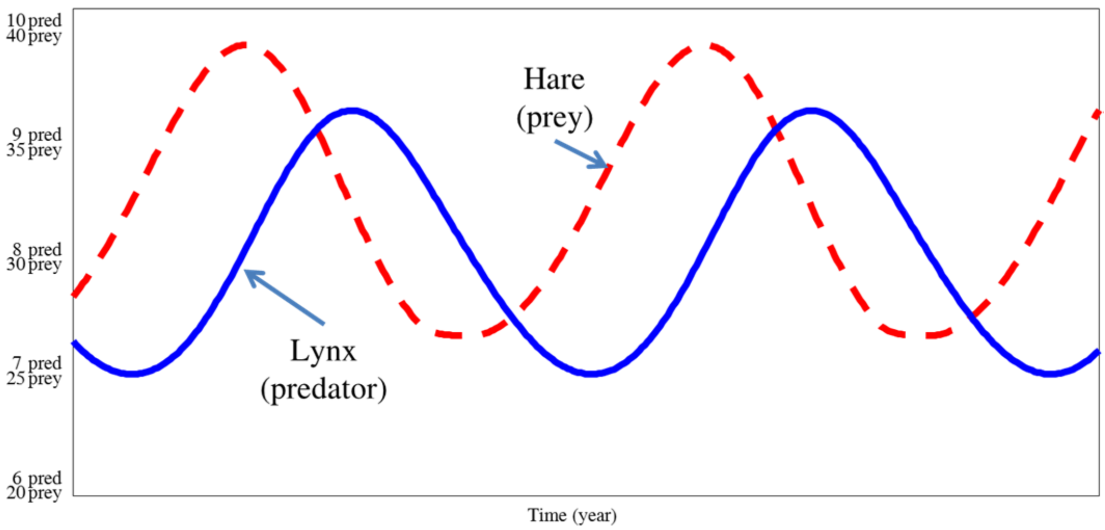

Figure 6: Predator-prey dynamics

Kids understand very well that hunting prey leads to a decrease in the overall population of hare. Thus, if there are too many predators, the lynx cannot find enough food. Therefore, fewer lynx survive which allows the hare population to start growing again. As more hare are again available, the predator population starts to recover and grow in size, too. The cycle keeps on repeating, creating the predator-prey dynamics.

We introduced the exercise with showing the slides depicted in Figure 7. We talked about two examples, the lynx/snowshoe hare and tiger/deer systems. We then, piece by piece, developed the basic stock-and-flow-structure on a flip chart. Afterwards we asked the kids to think in pairs about predators and their prey in special ecosystems and how they interact with each other. We gave them hints on different ecosystems, including desert, rain forest, a large forest close to Frankfurt, Antarctica, tundra, and savanna, and let them chose their favorite ecosystem to identify typical predators and prey.

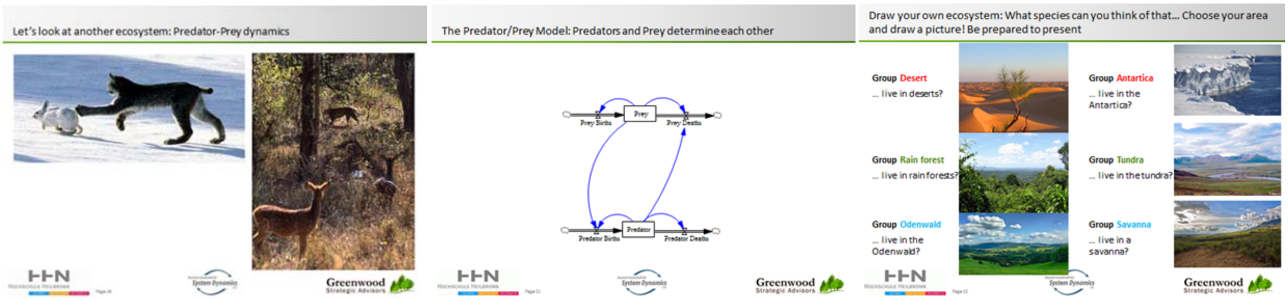

Figure 7: Slides presented to the kids on the predator-prey exercise

The kids identified predator-prey relationships, for instance Grizzly-Salmon or Penguin-Fish in Antarctica. One girl showed great understanding of the predator-prey dynamics: she drew the two stocks and their links and illustrating snake-frog dynamics. She then extended the model by another stock-and-flow-structure to include flies, stating that “flies are eaten by frogs, aren’t they?”

To close the session we taped the predator-prey-models to the wall, arranged by ecosystem. After a break the pairs then presented, one by one, their predator-prey-models and the group discussed the insights.

To visualize insights, we drew a step-wise graphical representation of the over-time-behavior of a typical predator-prey-system on the flip chart. To not overwhelm the audience we did not do a computer simulation or presented the results as shown in this paper in Figure 6. Instead, we verbally walked the children through the system’s dynamics, showing how both populations grow initially. When the prey population topped out and began to decline, a child remarked: “The predators will be gone soon, too. They will have nothing to eat.” While this level of anticipatory understanding of the system’s dynamics is outstanding, all children were eagerly participating. We noted that learning speed differed individually and task-wise but all children could finish the tasks on their own. The support and guidance of the class teacher was tantamount in achieving this as he could read the class’s behavior and knew exactly when to support us or them.

Children's Insights on Ecosystems Applying Systems Thinking

We closed the morning with a wrap-up session. The kids sat on the floor and their teacher asked them one by one for feedback and we noted the kids' statements on a flipchart. Not surprisingly, as we had just analyzed the predator-prey dynamics in detail, most of the kids answered that they learned about these particular dynamics. Notably, one child remarked that it had realized that objects in the real world can be represented using graphs.

Three months later we asked the teacher to let the children write a brief note on what they took from the systems thinking exercise. Answers were manifold and well-thought-out. The statements were more diverse than in the immediate feedback-session – probably because there was no synchronization by listening to the opinions of previous speakers. The statements can be categorized into five areas. First, many kids referred to the concept of inflows and outflows. One girl stated that "We learned how the inflow and the outflow work". Another said that she "found the inflow and outflow interesting because I never knew about it". Second, kids recalled the bathtub concept. One girl said that she "learnt that little molecules that are in the bathtub can overflow." And one of her co-students "found the bath tub 'play' interesting though the greenhouse effect was more interesting". Greenhouse gas emissions were a third theme mentioned by several participants. One girl "thought it was interesting how carbon dioxide can affect the world" and another one stated that "carbon dioxide is a big problem for our world".

One boy even explicitly applied the bathtub concept to explain the greenhouse gas exercise when stating that "I thought that the bath tub game was very interesting in explaining the greenhouse effects".

Regarding predator-prey dynamics one boy learnt "that predators will never run out of prey because where there is nearly no more prey it will start again." He could reproduce the gist of the circular dynamics created by the interlinked loops.

In the last group of answers kids moved the point of view from specific problems like bathtubs and greenhouse gases to a more general level. One kid stated, for example, that "small changes can cause big problems over time" and one boy "learnt that little problems can get big and we can die from it".

Conclusions

Limitations of the Systems Thinking Intervention

There are a few limitations to our intervention. First, we have only covered seven of the sixteen topics that FISHER (2011) identifies for being suitable for children aged 5-10 years. We have not touched

1. Surfacing your mental model
2. Change over time
3. Circular causality
4. Unintended consequences

5. Small generic structures (linear, exponential)
6. Using and building very simple simulations
7. Archetype: escalation
8. Archetype: fixes that fail
9. Looking at a problem from multiple perspectives

Yet, it was not the intention of the four-hour-Systems Thinking intervention introduce all topics. It was the aim of making the kids aware of another way of looking at ecosystems with Systems Thinking. The entire sixteen concepts could be part of entire curriculum that is designed for the entire school year – like it is being done for the Carlisle Public Schools in Carlisle, Massachusetts, for example (Fischer, 2011).

Future Scope of the Systems Thinking Intervention

As the teacher appreciated our systems thinking intervention possible future actions arise. The intervention schedule is developed and tested for a class of 10-year olds. We could thus use it for conducting similar sessions with parallel classes at the same school. As mentioned above, the school management is open to use systems thinking concepts for teaching. Thus, we would not need to invest time in convincing the school management or the teachers to apply the System Dynamics approach for teaching.

For a school, in which a teacher stays for several years with the same class, we could develop a Systems Thinking approach which covers several units over the years. This approach would be elegant in two ways: first, in another three years of time, we would have designed four Systems Thinking interventions, one for each school grade. Moreover, the sessions would build up on one another. This would have two positive effects: first, the kids could refer to ideas of the Systems Thinking concept that they had learned before. Second, we, the instructors, could build on previously taught session and pick up content discussed with the kids before. Further, we could also offer these courses in parallel classes. If successful, the Systems Thinking approach could gain more attention with the teachers – which will be the basis for introducing an entire curriculum in the long run for the first four grades – and maybe even longer.

Reflections on the Systems Thinking Intervention to 4th-Graders

As noted in the opening paragraph, there exist many games that can be played with K-12 students to introduce them to systems thinking. Yet, it is difficult for non-school-teachers to estimate kids' needs and capabilities and then to identify matching games. There is a lack of experience with this age group. We summarize a few drivers for making such a session a success from our point of view.

In our case, the special topic on ecosystems was well prepared by the teacher. The kids had talked about ecosystems in general and about global warming and its effects in particular – even though not as detailed as we had done. Thus, the kids had been prepared to learning more about the topic. We also found that a close cooperation with the teacher is necessary previous to running the systems thinking intervention. Teachers know best their kids and their respective learning behavior. So, while planning the intervention we exchanged ideas on what topics would suit the curriculum, the kids' intellectual capabilities and their interest. During the session, the teacher knows which questions to ask to keep the kids focused. And she or he can assist if the learning speeds vary too much so that all kids are kept in the loop.

Many wonderful systems thinking games can be played with kids. When we read about the different interventions we realized that our initial approach's breadth was too large. Therefore, choosing a specific topic, like ecosystems, is necessary to focus on and to cover in greater detail.

We invested quite some time into preparing the session and designing a detailed timeline, a presentation, and flip charts. Even though we did not stick to the timeline when carrying out the session, it gave us confidence and flexibility at the same time. Still, sub-sessions should not be designed to be too long. Long enough pauses in between the sessions are important for the kids to recover. This turned out to be very important to keep the kids' attention and interest.

What turned out to be most insightful for us was realizing that the kids need a playful approach with many activities. We knew that four hours of systems thinking intervention is a fairly long time for young children as they have a shorter attention span than adults. Using different learning styles, including slide presentations, flip charts, self-study, and group work with kids sitting on chairs, sitting on the floor, or walking around, like in the bathtub and the global warming game kept the attention level high.

Doing a feedback session in the end of the course is highly important to make the kids' leaning stick. Interestingly, the additional feed-back session about three months later turned out to be even more insightful. It showed what had really stuck to the kids' minds. The result was rewarding.

Finally, being non-school-teachers, we needed to base our session on existing material and experience. Existing publications are very well suited to design an entire curriculum on teaching System Dynamics in the K-12 environment. The objective here, however, was only to do a morning with systems thinking. What helped us to steer our thoughts on how to proceed was the openness of the practitioners in the field who were very helpful and supporting.

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[i] For a more sophisticated System Dynamics version of the predator-prey model see Swart (1990), for example.