Pan Water Cycle: A Multi-Model Conceptual Approach

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ABSTRACT
Using a very simple physical model of part of the water cycle, we construct computational models via Vensim, Excel, and NetLogo to illustrate the science concepts involved. Connections between the physical and computational models are highlighted. We point out the advantages of each modeling tool and illustrate how the mathematics may be camouflaged or used depending on the student audience.

Categories and Subject Descriptors
K.3 Computers in Education

General Terms
Design, Experimentation

Keywords
Computational models, simulations, cycles, inquiry-based learning

1. INTRODUCTION
Cycles in nature include the hydrologic or water cycle and the many biogeochemical cycles, such as carbon, nitrogen, and phosphorus [1]. The water cycle is introduced in elementary and middle school sciences and finds its way in high school [2] and again in college classes too. In this article, we introduce a simple physical model of part of the water cycle and how to extend this model into a computational model using aggregate or systems modeling in Vensim and Excel and agent modeling using NetLogo.

The pan water cycle model was introduced by the Maryland Virtual High School in 1999 [3]. The partial hydrologic cycle or pan water cycle is illustrated in Figure 1 and can be set up in a baking pan with a clear plastic cover or lid. By observing the pan sitting on a hot plate set at low or even in bright sun light, students could discover the cycle. A prompt for the water in the air or how did the water get from the bottom of the pan to the cover may be needed.

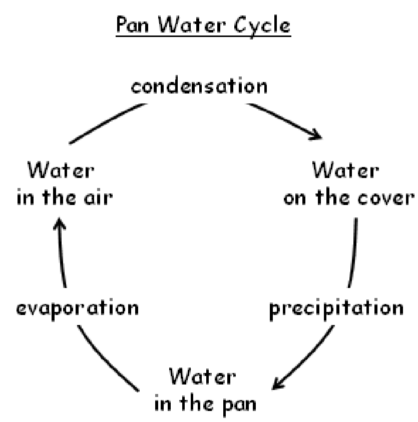

Figure 1. Simple Pan Water Cycle

So why use a computational model? According to Gabel [4] the objectives of instruction in the science classroom should be having students develop a conceptual understanding and use scientific inquiry. Using computational models and simulations is an approach that meets these objectives [5-7].

2. BUILDING THE MODELS
Here we show the construction of the computational models in three different modeling tools and how they support the concept and physical model. The systems-based models require some basic algebra skills and the ability to think of evaporation, condensation, and precipitation as rates at which an amount of water changes per unit time. The agent-based model allows the

user to follow a water molecule through the cycle. In each case, the cycling of the water through the cycle is driven by the amount of heat added by the hotplate or sun.

2.1 Vensim Model

The use of aggregate or systems modeling tools such as Vensim (free for educators) [8], STELLA [9], or Madonna [10] is a great way to construct the cycle since these tools use a concept map-like approach as shown in Figure 2. The blue curved arrows show the dependency of the rates of evaporation, condensation, and precipitation on the amounts of water in each reservoir (box). The first-order dependency is easy to explain by the fact that if a reservoir drops to zero, the rate of the process, such as evaporation, must go to zero as well.

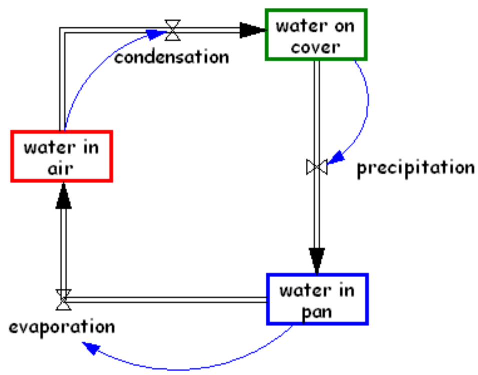

Figure 2. Vensim Model for Starting Cycle

The question to pose to students is "How does the amount of water in each reservoir (pan, air, and cover) change as time passes?" Students could make a prediction. To get the Vensim model to run, we need to introduce a rate constant for the rates of evaporation, condensation, and precipitation. In Figure 3, fractions with a range of zero to one have been added for evaporation, condensation, and precipitation. These make the mathematics easy to grasp since each rate (amount of water per unit of time) can be represented as a product, such as Evaporation = evaporation fraction * water in pan.

Since the pan water cycle is a closed system (no leaks from the container), the conservation of mass of water can be incorporated into the model by introducing total water, the sum of the water in the pan, in the air, and on the cover. The idea that the system can lose water via a leak, now an open system, is also considered in the final model shown in Figure 3.

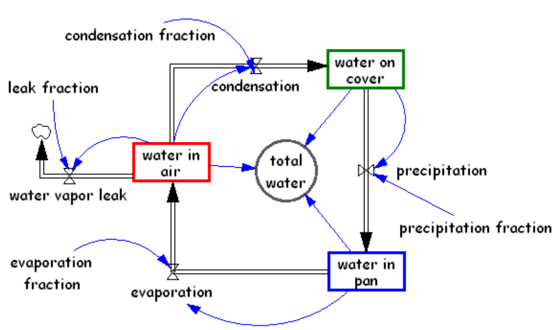

Figure 3. Final Vensim Model

Figure 4 illustrates the graphical results for the model with the evaporation fraction at 0.2, the condensation fraction at 0.3, the precipitation fraction at 0.5, and the leak fraction at zero. The curves on the graph are color coded to the box colors on the model in Figure 3.

The system establishes equilibrium as evidenced by the three flat lying curves at a time of 9-10 minutes (Figure 4). Students can adjust the fractions of evaporation, condensation, and precipitation constant to see how the model responds. With some simple "what if" or predict-test-analyze and then explain questions, instructors can drive students to explore and discover the behavior of this system. Students should also discover the closed system nature of this model, since the total water is constant at the amount placed in the pan to start.

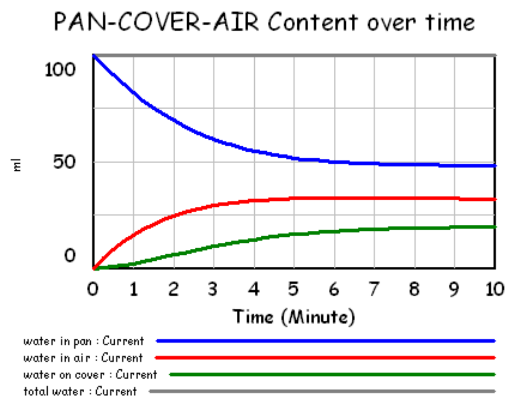

Figure 4. Vensim Model Results

How would the model behave if there was a loss of water? Students should make a prediction. Now students should explore increasing the leak fraction variable to see how the model behaves. The system is now an open system with water loss and it does not come to equilibrium as the closed system did. We placed the leak on the amount of water in the air since water vapor loss could easily occur. Could the leak be elsewhere? Students could explore modifying the model to examine this question in context to the complete hydrologic cycle. One could even pose this question to students to ponder and discuss – Is the global water cycle an open or closed system?

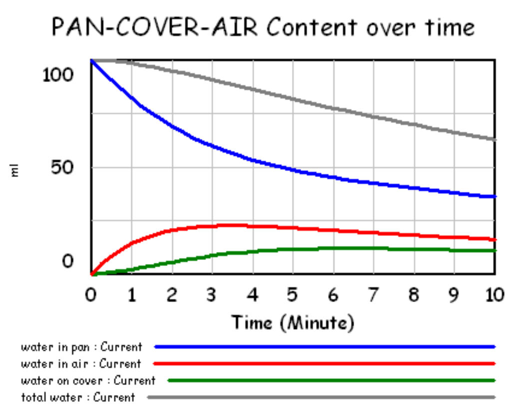

Figure 5. Vensim Model Results with Leak

2.2 Excel Model

For the Excel model, the camouflaged differential equations generated in the Vensim model must be converted to simple difference equations. Each reservoir will have an amount at time t +1 that depends on its original amount at time t plus input minus output or HAVE = HAD + CHANGE. The equations are shown in Figure 6.

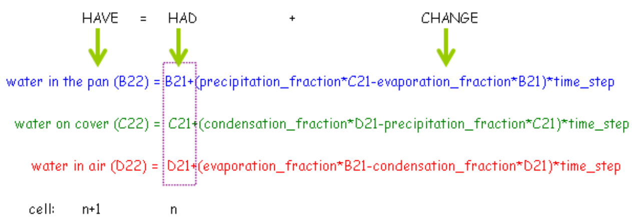

Figure 6. Difference Equations for Excel Model

This model allows students to see the algebraic relationships that drive the mathematical model. We have used named variables in Excel to make the equations as algebraic looking as possible. The mathematics could be camouflaged if needed, but we use this model to introduce it in a scaffolded approach. The approach is simply using algebra and considering what goes into and out of each of the reservoirs over time.

In addition, the interactive features available in Excel are used to set up sliders for the students to use to manipulate certain parameters such as the precipitation, condensation, evaporation, and leak fractions as well as the initial amount of water in the pan. This model provides the teacher with a user-friendly, multivariable simulation for student exploration that uses off-the-shelf software. More information on designing interactive simulations in Excel can be found in [11]. This model will function in OpenOffice Calc as well.

Both the Vensim and Excel models are performing numerical integration using Euler's method [12] to obtain the plotted results. The time-step for the integration is adjustable in both Excel and Vensim. Decreasing the time-step decreases numerical integration error and smoothes the curve. This may or may not be a topic of discussion with students.

2.3 NetLogo Model

Here we use an agent model that depends on the behavior of the individual particles and the interaction between them. Since the model (Figure 7) closely mimics the actual physical model of a pan of water with a clear cover, it helps students visualize the movement of water molecules through the cycle. The addition of an on-off tracer aids students as they attempt to follow a single water molecule as it progresses through the cycle. This model requires programming skills to write, but once written is a very useful tool for students to use. NetLogo is freeware with an extensive library of pre-built models [13]. NetLogo allows the model to be saved as a Java applet that can run as a webpage.

The NetLogo model provides a microscopic approach (view of molecules of water) to the pan water cycle. The model begins with all the water molecules in the pan, each having been assigned a random amount of starting energy. Based on the setting of the heat energy variable when the model starts running, molecules that are close to the bottom of the pan gain energy. When molecules collide, they transfer energy to one another. When molecules close to the surface of the water have enough energy, they can escape into the vapor phase. As they rise through the air, they lose energy. So it takes a few cycles for molecules to have enough energy to make it to the cover or lid. Once on the lid, they can lose energy to the container, they can transfer energy to other molecules on the lid or if enough molecules occupy the same space, they "condense" and precipitate. The cluster of molecules falling down in Figure 7 demonstrates precipitation.

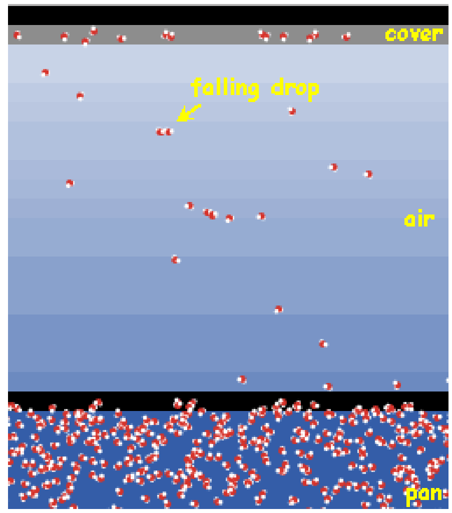

Figure 7. NetLogo Agent Model

The results for a run of the model are shown in Figure 8. These results look somewhat noisy due to agent behavior and a small number of agents. The results will look slightly different for a second run due to the random nature of individual agent behavior. However, we do observe that the system comes to equilibrium (lines level out) just as it did in the Vensim and Excel models.

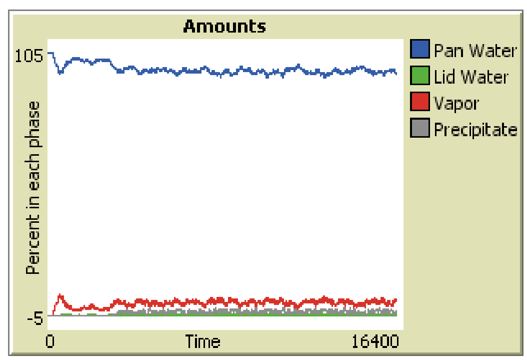

Figure 8. NetLogo Model Results

Since this model is driven by the addition of heat energy, it provides a nice connection to solar energy and the real hydrologic cycle. By illustrating the movement of the molecules through the water cycle, the model demonstrates phase changes and gaseous and liquid states of matter, thus providing more scaffolding of concepts for the students.

3. INSTRUCTIONAL USE

This series of models has been used for high school teacher training as part of the Pittsburgh Supercomputing Center's (PSC) Computation and Science for Teachers (CAST) program [14]. In this program, teachers were introduced to computational modeling tools and the development of predict-test-analyze questions to enhance guided inquiry learning. For this topic, we use a physical model and the power of observation to discover the pan water cycle. Then we build the Vensim model, the Excel model, and finish with the pre-built NetLogo simulation making numerous connections to the various models. The pan water cycle has a vast number of concepts involved and it crosses a variety of disciplines. A series of student and teacher handouts for the pan water cycle are available in [3]. From this experience teachers would be ready to construct the carbon cycle model [15]. The authors are presently working on designing computational reasoning modules using these tools through a grant to the PSC [16].

How could a classroom teacher use the pan water cycle? For a visual approach, students could observe the physical model and then investigate the model further with the NetLogo simulation. This gives a nice macroscopic-microscopic comparison and uses no math to accomplish it. To add the ability to manipulate variables and perform graphical analysis, either the Vensim or Excel models could be used. For building the computational model, Vensim is a good place to start since the model mimics the cycle diagrams found in textbooks. Students who build the pan water cycle should be able to transfer their knowledge to other cycles in science.

4. SOME FINAL THOUGHTS

In the laboratory, we run a wealth of single variable experiments while holding many other variables constant. With computational models we have added the multivariable approach via numerical experimentation. In this article a simple part of the hydrologic or water cycle was demonstrated through the use of a physical model and associated computational models. The concepts of evaporation, condensation, and precipitation were introduced to study the physical model's behavior. Each modeling tool brings a different aspect to the table, while together they bring a synergistic wealth of concept connections to the understanding of this simple cycle. The models explore the macroscopic, microscopic, and symbolic realms.

The use of computational models and simulations creates an engaging pedagogy in the classroom. Students must answer many higher-order thinking questions as they predict-test-analyze and explain through numerical experimentation. Both scientific and algebraic thinking are enhanced as students develop a deeper understanding of the pan water cycle.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

[1] For a good general introduction - Biogeochemical Cycle in http://en.wikipedia.org/wiki/Biogeochemical_cycle

[2] **National Science Education Standards** (1996) http://www.nap.edu/openbook.php?record_id=4962

[3] Higdon, D. and Verona, M.E., Pan Water Cycle Model http://mvhs.shodor.org/mvhsproj/water/water.html

[4] Gabel, D. (2003). Enhancing the Conceptual Understanding of Science, **Educational Horizons 81** (2), 70-76.

[5] Sinex, S.A. and Halpern, J.B. (2011). Fostering a Conceptual Understanding in Undergraduate Materials Education: A Multivariable Animated Spreadsheet Approach, **Mater. Res. Soc. Symp. Proc. Volume 1320**, Warrendale, PA.

[6] Sinex, S.A. (2010). Radiometric Dating for Novice Learners: Visualizing, Modeling, and Simulating via Animated Spreadsheets, **Spreadsheets in Education 4** (2), Article 5.

[7] Trout, C., Ragan, S., and Sinex, S.A. (2011) Building Dynamic Conceptual Physics Understanding, **The Physics Teacher**, in press.

[8] Vensim from Ventana Systems, Inc http://www.vensim.com/

[9] Stella from ISEE Systems http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx

[10] Berkeley Madonna from http://www.berkeleymadonna.com/

[11] Sinex, S.A., Developer's Guide to Excelets, http://academic.pgcc.edu/~ssinex/excelets/

[12] Shiflet, A.B. and Shiflet, G.W. (2006). **Introduction to Computational Science**, Princeton University Press, Princeton, NJ.

[13] NetLogo from Center for Connected Learning at Northwestern University http://ccl.northwestern.edu/netlogo/

[14] CAST: Computation and Science for Teachers http://www.psc.edu/eot/k12/cast.php

[15] Shaffer, D. and Wallace, K., Carbon Cycle Model http://mvhs.shodor.org/mvhsproj/carbon/carbon.html

[16] PSC CAST Grant http://www.psc.edu/publicinfo/news/2011/031511_CASTfunded.php