Exploring Solar System Formation with NetLogo – Joel Schwartz

Purpose

This activity is designed to introduce concepts of late-stage solar system evolution through computer simulation. The methodology of scientific research is interwoven and emphasized, using both realistic and hypothetical object gravitational behavior. Additionally, familiarity with the Netlogo platform and its underlying logic is promoted.

Overview

During this activity, students will be introduced to the functional form of Newton's Law of Gravitation, as well as its role in the motion and merging of planetary bodies. Next, students will practice running the NetLogo "Solar System Formation" model and adjusting its user controls. After breaking into groups and selecting specific aspects of the formation process to consider, students will use the module to conduct their own investigations about the problems. Students will also adjust parameters within the program code to uncover how the simulation environment is affected. The activity will conclude with all groups presenting their results and findings to the class for discussion, analogous to formal research.

(The nature of this activity is highly flexible, and therefore this syllabus is presented as a suggested format for the lesson. Changing the emphasis or focus as appropriate to the class is strongly recommended.)

Student Outcomes

Students will be able to:

- State the functional form of Newton's Law of Gravitation, and explain its components.
- Describe the role of gravity in moving and coalescing objects.
- State the significance of various user inputs in a computer simulation.
- Construct suitable simulations for examining their chosen aspect(s) of solar system formation.
- Modify parameters within the source code of a program, and describe the impact they have.
- Draw conclusions about their chosen problems using the data collected during simulations.
- Convey their findings in a presentational form, and defend the conclusions obtained.
- Describe the results of other group investigations presented during class discussion.

Standards Addressed

Lesson applies to NGSS :

- HS ESS1-4 (computational representation to predict solar system motion and orbits)
- HS ETS1-4 (computer simulations to model impact of complex real-world problems)
- HS PS2-2 & -4 (momentum conservation validity; gravitational force prediction)

Time

Approximately three 1-hour class periods, or the equivalent thereof.

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Level
High School Astronomy (though could be adapted to other levels, as well.)

Materials and Tools

NetLogo (Uri Wilensky, Northwestern University) available free:
http://ccl.northwestern.edu/netlogo/

Laptops/Computers (with NetLogo installed; enough to facilitate small groups at least)

"Solar System Formation" NetLogo module (Joel Schwartz, Northwestern University):
https://northwestern.box.com/s/8dyj8r7vubooesctylubsyfelea1u4q1
(Contains detailed operating information and programming notes)

Preferred media for recording/presenting data (workbooks, Google Docs, projector, etc.)

Preparation
Install NetLogo onto any computers which will be running the module, and have the "Solar System Formation" file easily accessible to students. For the highest lesson quality, the educator is advised to explore the module firsthand prior to the activity. It would best be conducted after an introductory lesson on the nebular hypothesis, but this is not required.

Prerequisites
Basic concept of different solar system objects, as well as relative sizes of each. A familiarity with the NetLogo interface is preferred, but not mandatory.

Background
The formation of the Solar System is a process that is fairly simple to observe the consequences of, like our Earth and Sun, but can be complicated to fully understand. Part of the reason for this is that we cannot conduct similar *physical* experiments under the necessary conditions (the scales involved are literally astronomical!) Computers, though, can help circumvent this issue by allowing us to construct computational models which *simulate* these otherwise impossible experiments. This activity will enable you to explore solar system formation and programming logic using one such modeling environment, NetLogo.

Before getting started, you may wish to consider a few foundational questions:

- What is the Solar System, and what are its major components?
- What force binds and moves these components, and what does it operate on?
- Do you know any mathematical equation describing this force?
- How is the Solar System unique, and how is it not?

After an introduction to the NetLogo platform and "Solar System Formation" module, the class will break into small groups to conduct independent investigations into the formation process. For your group's specific topic(s), you will want to follow these research principles:

- Hypothesis: What do you predict as the solution to your problem(s)?
- Strategy: How will you use the module to test out your hypothesis and gather information?
- Experiment: What user settings are important? Construct, observe, record, and modify!
- Analysis: What are the observations and data telling you about your problem(s)?
- Conclusions: What are your ultimate findings? Are further simulations needed for an answer?

In addition, each group will also try changing particular portions of the source code to see what impact this has on the model's behavior. At the end of the activity, each group will give a brief presentation defending their methods and conclusions to the class. Understand that this parallels the real world of scientific research, where everyone benefits from the contributions (successful or not) of others in a rigorous yet respectful environment. Happy experimenting!

Teaching Notes

The initial discussion of Newton's Law of Gravitation should take place before acquiring computers. Write the formula, found in the Info tab within the module, on the board and define each component as you go. This would also be a good time to ask related conceptual questions, such as what happens to the force when the distance between objects is halved. Be sure to emphasize that gravity is the dominant force in the behavior of solar system objects (review these as needed.) Introduce the NetLogo module, going through both the "What Is It?" & "How It Works" sections of the Info tab with students. Pay attention to defining the *italicized* words, as students will likely be unfamiliar with them.

After forming pairs/groups of students, obtain the necessary computers and have students open the module on them. A suggestion at the beginning is to ask students to set up and run the simulation using only the default settings. During this time, you can also go over, as a class, the top portion (up to the Sun/Moon mass ratio) of the "How To Use It" section in the Info tab. This will explain the function of the "Initial Parameters" controls in the Interface tab. Ask students to share their observations of what has occurred in the default simulation so far, then allow time (~15-20 minutes) for them to continue exploring the module on their own. A good reminder is that explanations of all interface controls/graphs can be found in the Info tab (very helpful for frequently asked questions!)

Once students are reasonably comfortable with the interface, the activity can proceed to the research stage. Have each group convene and select the specific aspect(s) of the model they will investigate for the remainder of the activity. A collection of 12 potential problems is detailed in the "Things To Notice" & "Things To Try" sections of the Info tab; feel free to include your own ideas for consideration, too. (It is probably preferable for each group to have a unique set of problems, though overlap has the advantage of comparing multiple points of view.) After the selection process is complete, let go! Allow the groups to continue the activity as independently as possible. One of the main features of this lesson is that it mimics the way research is performed in the real world. The module is very open-ended in its construction, which gives students a great deal of freedom in planning and experimenting with their simulations. The ideal approach is to rotate between the groups and *gently* assist them along if they encounter difficulty. They should state an initial prediction, offer a strategy to probe their chosen aspect(s), generate and run the desired simulations, compile their results, and test additional situations if possible. Ask questions which encourage discussion between group members, not merely quick answers.

About halfway through the research phase of the activity, have students pause momentarily and switch to the Code tab of the module. Briefly describe the function of the code, then introduce the concept of a *parameter*. A good idea here is to point out examples of parameters within the code, then have students try to identify others. (For both of these tasks, the first paragraph of the "Extending The Model" section in the Info tab is useful to read as a class.) Ask the groups to consider what effects these parameters might have on the overall model, and have them adjust the values (directly in the code) for some of their subsequent simulations.

Reserve the last portion of the lesson for informal presentations by the groups about their findings. They should briefly describe the problem(s) they focused on and how they investigated them. After stating their findings, encourage questions from the class that (respectfully) challenge the limits of validity the group's conclusions have. The key here is to practice recognizing what is reasonable versus what is not, and it should be reiterated to the students that these qualities are inherent in any scientific study or model. The effect that changing the parameters in the code had should also be covered during the presentations.

The time breakdown for the entire lesson would ideally be:

- 30-45 minutes: Gravitation intro and module exploration
- 90-120 minutes: Research stage and adjusting code parameters
- 30-45 minutes: Presentations with class discussion

Assessment

- Survey for comprehension & ask level-appropriate questions about gravitational concepts.
- Systematically meet with each group about their investigation ideas and actions.
- Ask questions requiring extension of knowledge during summary presentations/discussion.

Additional Information

Again, the above lesson layout is a suggestion for how to utilize the "Solar System Formation" module, but it is by no means the only way! The simulations can be run in a very open-ended manner (not necessarily even from an astronomy perspective), and thus educators are encouraged to devise appropriate plans for their classrooms, using this document as a guide.