SCIENCE NORTH SCIENCE NORD
SUDBURY, ONTARIO, CANADA

Systems as Algorithms	Grade 8 and Structures and Mechanisms

Lesson Plan

Coding Tool	Algorithms
Cross-curricular	N/A

Big Ideas

- All systems include an input and an output
- All systems can be modeled as algorithms.
- The inputs and outputs of systems can be broken down into 3 broad categories: energy, matter, and information. These all behave differently in systems in important ways.

Specific Expectations

2.4 Use technological problem-solving skills to investigate a system that performs a function or meets a need
3.1 Identify various types of systems
3.2 Identify the purpose, inputs, and outputs of various systems
3.3 Identify the various processes and components of a system

Description

In this lesson, students link the concepts of systems and algorithms by expressing the actions of a system as an algorithm. Since different inputs and outputs of a system act differently, group inputs and outputs into 3 broad categories: energy, matter, and information, and treat each independently before culminating in examining a complex system that makes use of all 3.

Materials

Pencils and paper.

Computational Thinking Skills

Algorithms.

Introduction

Anything that takes one or more inputs, performs a set series of steps, and produces one or more outputs can be considered a system. Anything that performs a set series of steps can be considered an algorithm. Thus, we can consider any system as an algorithm. (It may, or may not, be practical to write out the algorithm of a given system—some get very, very complicated—but it is still a good way of looking at the problem, especially if your students are already familiar with algorithms.)

The steps of a given system may contain IF/THEN statements, or WHILE or even FOR loops, or it may simply be a straight pass-through, from input to output. Output might be returned every loop (such as in a thermostat, see the below), or only on demand by a user. (The demand being yet another input!)

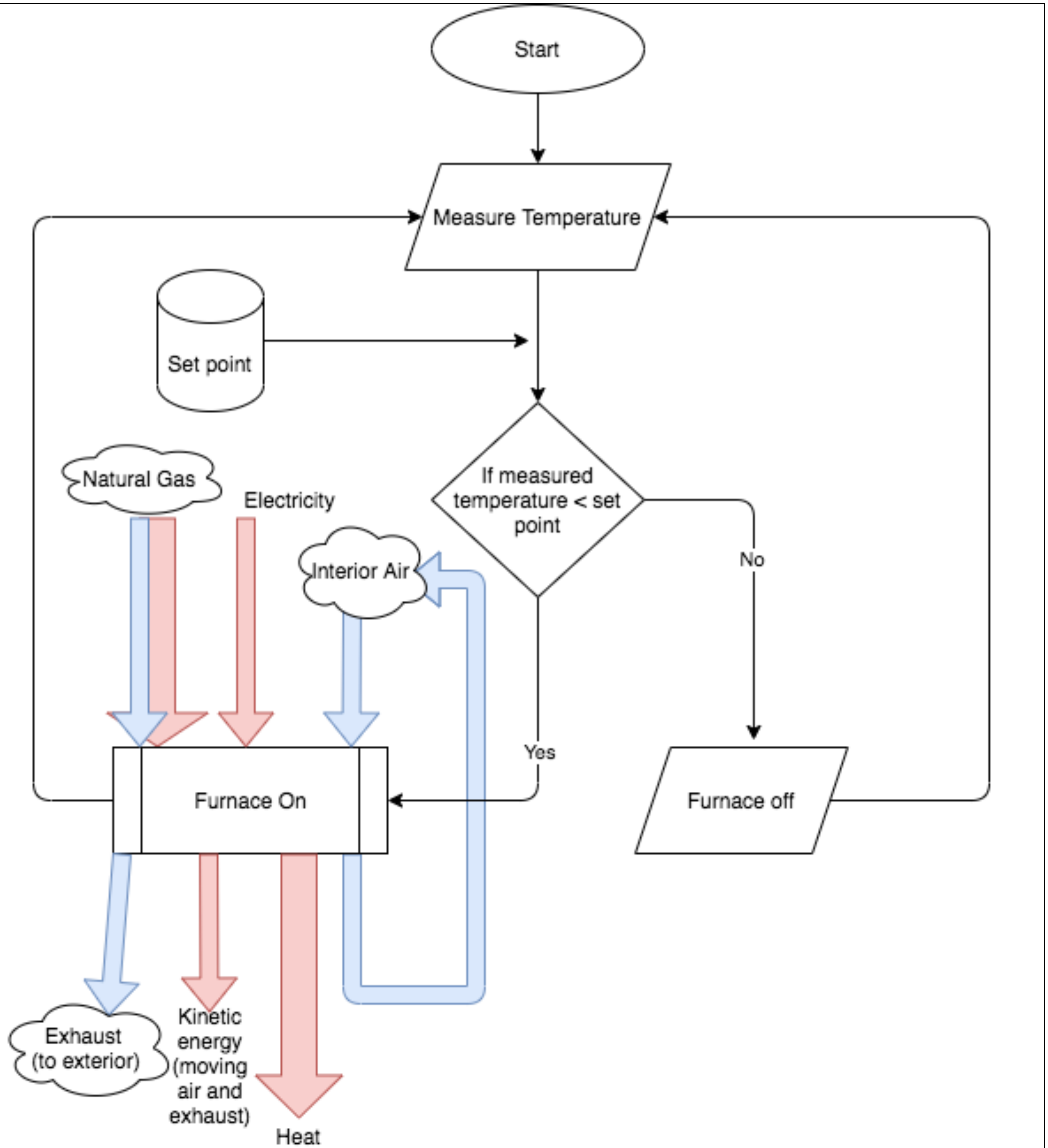
It is traditional in systems theory to use flow charts to represent algorithms. To produce flow charts, if you want students to use a computer, we recommend the free cloud service https://app.diagrams.net/, but they can just as easily be drawn by hand. Alternatively, you can use psudocode to express the algorithms of a system, or just write ouy the algorithm of the system in natural language.

The inputs and outputs of systems can be broken down into 3 broad categories: energy, matter, and information. These all behave differently in systems in important ways.

- ***Matter*** moves from one point to another. There is no “away”; all inputs come from somewhere and all outputs go somewhere. Very often, if you wait long enough, that “somewhere” is the same place. Thus, matter moves in circles.
- ***Energy*** always moves in a straight line, from concentrated sources to less concentrated forms—and eventually to diffuse waste heat. It cannot be created or destroyed, only transformed. The canonical example of this is in a power plant: chemical energy is turned into kinetic energy in a steam turbine, then into electrical energy in a generator. At each step, energy is lost to waste heat. (About 40% at step 1, and 15% at step 2.)
- ***Information***, unlike the other 2, can be created or destroyed by the system. Information is created when something is measured—like the temperature of a room, or the RPM of a motor. If the information is not recorded, then it ceases to exist. Any piece of data or measurement can be considered information in a system.

Let’s look at an example of a simple system that involves all 3 categories of inputs and outputs: a household heating system. For the purpose of this example, the house is heated by a forced-air, natural gas furnace, controlled by a thermostat, as is very common in much of Canada.

In this chart, flows of information are represented by black lines. Thick red arrows represent flows of energy. Blue arrows represent flows of matter. (Natural gas, because it is a source of chemical potential energy, has both red and blue arrows associated with it.) To simplify the diagram, the furnace is represented as a function (or a sub-system) and not further analyzed.



In words--
The system starts. It measures the temperature inside the house (generating an information flow). It compares this to the temperature set point, information the system stores. If the measured temperature is not less than the set point, it measures the temperature again, and

checks it against the set point, again. If the temperature is less than the set point, it turns the furnace on. The function/subsystem 'furnace' takes as material inputs natural gas and interior air, and as energy inputs the chemical potential energy of natural gas and electricity. The function produces material outputs of exhaust (to the exterior of the house) and interior air (into the house), and energy outputs of heat, and the kinetic energy to move the air through the ducts and push the exhaust outside.[1] Information-wise, after activating the furnace the system goes on to check the temperature, again, and repeats the process in an infinite loop.

As psudocode:

```
Start
While True:
Measure(Temperature)
IF ( Temperaure > Set Point ):
RUN FUNCTION Furnace on (Inputs: mat Natural Gas, mat Air, eng Natural Gas, eng
Electricity
Returns: mat Exhaust (to exterior), mat Air (to house), eng heat, eng kinetic)
ELSE:
RUN FUNCTION Furnace off()
```

(Notice how handling multiple inputs and returns of energy and matter is made much more awkward in pseudocode than flow charts.)

Action

Challenge your students to produce a flow-chart or written algorithm about a simple system involving matter, energy and information in their lives.

To simplify the activity, you can introduce matter, energy, and information serially and have the students trace each separately in their system before producing one complete flowchart. To make the activity more systems-curriculum based, focus on having the students trace flows of energy and matter into and out of the environment and trace their effects. To make the activity more coding based, try and focus instead on systems with more complicated algorithms.

Here are a few example systems:
1) An alarm clock. As in our thermometer example, we have the information input (the time) being constantly checked against a set point (the alarm time) in an endless loop with an IF/THEN statement. IF the time matches, the input (electricity) is used to produce the output (sound). This leads to another information input (the off button!) and IF/THEN statement: IF

[1] Since interior air is ultimately drawn from "outside", very dilute exhaust gasses will eventually end up inside the house. Matter moves in circles.

the button is pressed, the alarm turns off. Otherwise it stays on, consuming electricity and producing sound. (see handout for diagram.)

2) A municipal water system, where sensors control the chlorination of the water, and water pressure. (Inputs then are materials untreated water, chlorine (and/or other treatment chemicals, challenge your students to do some research), and energy to run water pumps ; outputs are sewage and waste heat.) Similar IF/THEN loops to the thermometer example are required to check and maintain water pressure and chlorination.

3) An electric powerplant. Obvious inputs are fuel (natural gas, coal, oil, uranium or dammed water) and outputs electricity – but the electrical grid as a larger system has varying need for power. So the 'load', the amount of electricity needed by the grid, is an information input that is used to control the plant with IF/THEN statements.

4) The cruise-control system on an automobile, or autopilot on an airplane. Again, we are comparing a measured information input value (speed, or altitude, or what have you) to a stored set point within an endless loop and following functions in IF/THEN statements. (This is perhaps a good example to work with if you wish to strip away the energy and material components of the system and look only at information flows.)

It can be valuable, having presented these examples to your students (without drawing out the full algorithms), to see if they can list more examples, and then allow the class to choose from the finished list what they'd like to work with.

Consolidation/Extension

If you wish to go further, challenge your students to view themselves as a system, and model as many inputs and outputs of energy, matter, and information as they can think of. Where do they come from? What are they used for? Where do they go? (This exercise is best realized as a flow chart. Using different colours for matter, energy, and information will help keep it clear.) Humans aren't predictable enough to be perfectly modeled by algorithms, but we all have habits and follow them often enough that it works pretty well.

(Note that any other complex system involving all 3 categories, like a public transit system, will also work as well as an extension.)

Assessment

Students can be graded on the detail and effort they put into their algorithms. You can encourage them to choose (or assign) flows of energy or matter that they will need to research, and grade them on their accuracy and citations.

Additional Resources

Algorithms, psudocode and flow charts:
https://www.brainkart.com/article/Algorithm--Pseudocode-and-Flowchart_6945/

https://www.owlnet.rice.edu/~ceng303/manuals/fortran/FOR3_3.html

Systems:
Greere, John Michael, *Green Wizardry, pp.*1-37 (British Columbia: New Society Publishers, 2013)

Laszlo, Ervin, *The Systems View of the World* (New York: George Braziller, 1972)