Tips for Using System Dynamics Tools

Introduction to System Dynamics Tools

System dynamics uses a set of tools that allows its practitioners to visually and succinctly depict interpretations or mental models of systems, communicate those mental models to others and increase understanding of systems. Often the tools will be used together to logically develop and capture a complex mental model; at other times a single tool will be a powerful means to develop some understanding. There is no single formula for the use of any of these tools, but there are a number of hints or tips that can help bring about clear, powerful insights from their use.

A quick overview of the basic system dynamics tools:

Behavior-Over-Time Graphs (BOTGs): A BOTG, consisting of a line graph with time on the X-axis, captures one of the most fundamental aspects of system dynamics—the focus on dynamic, or changing, systems. This simple tool can help students focus on patterns of change over time rather than on isolated events, often leading to rich discussions on how, and ultimately why, something is changing.

Causal Loop Diagrams (CLDs): In addition to depicting the behavior of critical elements of the system, another challenge involves understanding and communicating the interactions that determine those dynamics. At this point, the focus shifts from describing the "what" of the system's behavior to the "why" of its behavior. Central to the idea of system dynamics is the belief that system behaviors are generated from within the system and that they are the result of one or more causal, or feedback, loops. To understand the behavior we must identify and understand those feedback relationships. Causal loop diagrams (CLDs) provide one way to visually capture those relationships.

Stock/Flow (S/F) Maps: Stocks represent the accumulations in a system. Fundamental to the concept of dynamic systems is the idea that the dynamics (changes) of stocks are caused by combinations of in- and out-flows that act in concert to increase or decrease those stocks. Those flows, in turn, are controlled by a variety of feedbacks within the system. The multiple factors that may be influencing the flows and contributing to the feedbacks that control the system's behavior can be better understood by graphically representing the stocks and flows and their relationships.

Computer Simulation Models: The most comprehensive way to test your understanding of how a given system "works" and what policies might change that behavior is to actually build and explore a computer simulation of that system. A computer model can extend understanding by simultaneously computing all of the system's many interdependent relationships over time that have been built into the model—a task too complex for the human mind. "Tips" for such computer modeling efforts, however, are too extensive for a one-two page summary. To learn more about models and modeling, visit the following websites for information and links to other sources of information:

- www.watersfoundation.org (see Training Information/Self-Help)
- www.clexchange.org. (see Additional Resources/System Dynamics in Education) To gain further knowledge of all of the tools, consult "Rubrics for Understanding," available on the Creative Learning Exchange website.

The preceding "Introduction to System Dynamics Tools" was written by staff at the Creative Learning Exchange and edited by staff members in the Catalina Foothills School District (CFSD). The following "Tips" sheets were prepared by staff members in CFSD and were updated in conjunction with the staff at the Creative Learning Exchange.

Tips for Behavior-Over-Time Graphs (BOTGs)

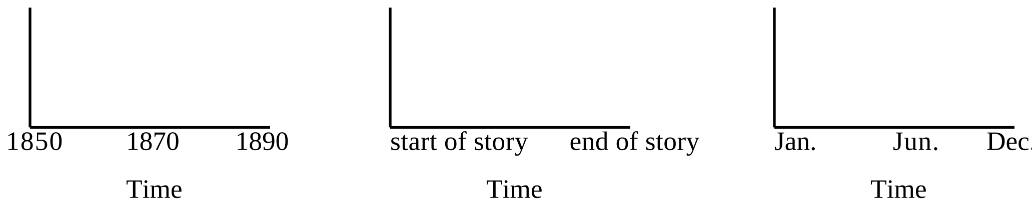
Behavior-Over-Time Graphs (BOTGs): A BOTG is a simple tool that can help people focus on patterns of change over time rather than on isolated events, leading to rich discussions on how and why something is changing.

1. A BOTG is a basic line graph showing the trend, or pattern of change, of a variable over time.

2. The X axis:

- is **always** labeled in units of time or can reflect change in time.
- has defined beginning and ending points; the precision of the definition can meet your specific purpose.

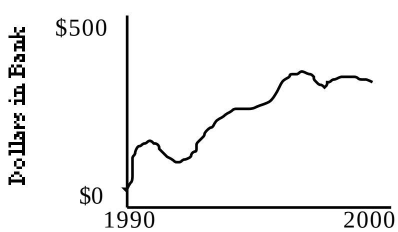
Care should be taken to explain the logic for the time scale. Why does it start and end where it does? Examination of when and where a particular pattern of behavior starts, ends, or changes direction is also important.



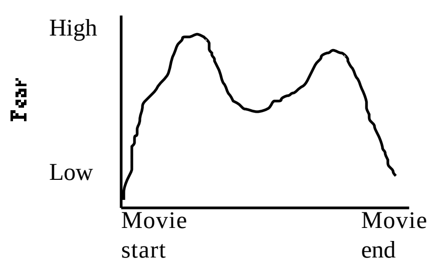
3. The Y axis:

- clearly identifies the variable being graphed and **must** be labeled with that variable's name.
- should not include qualitative words such as more, less, increasing, bigger, etc., in the variable's name; for example, it's difficult to understand "more fear" decreasing over time.
- may represent "concrete" variables (quantities such as population or temperature) or "abstract" variables (like love or stress).
- must have a defined scale. Scales can be numeric (e.g., 2 to 1000 rabbits or "on a scale of 0 to 100…") or descriptive (e.g., low vs. high).

Joe's Savings



My Fear



4. Different interpretations of the behavior of the variable are definitely possible. Both similarities and differences among graphs are grounds for rich discussion about individual interpretations or mental models.

5. More than one variable can be plotted on the same graph to compare them for possible interdependence or causal relationships between variables. Differentiate between the lines with careful labeling or the inclusion of a key. This step can contribute to thought-provoking discussions.

Tips for Causal Loop Diagrams (CLDs)

Causal Loop Diagrams (CLDs) help one understand and communicate the interactions that determine the dynamics of a system. System behaviors are generated from within the system and are the result of one or more causal (or feedback) loops.

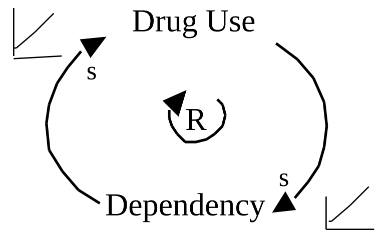
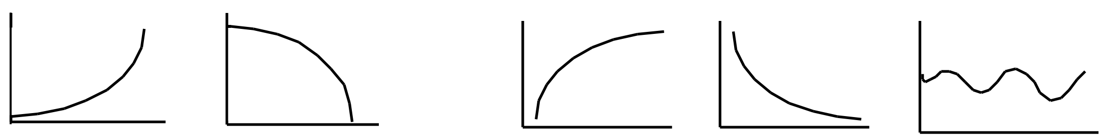


Figure 1

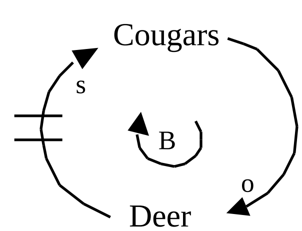
1. CLDs show causal relationships and illustrate circular feedback within a system. *A cause becomes an effect, becomes a cause*. You should be able to read around the loop several times. *"What goes around comes around."*
2. You may choose to identify important CLDs by looking for causal relationships among behavior-over-time graphs (BOTGs) that describe the system or by extracting those found within Stock/Flow maps and computer simulations.

   Since CLDs are about the causes of change, it is helpful to identify how key elements actually did change by drawing accompanying BOTGs (See Fig. 1: As drug use goes up, dependency goes up; as dependency goes up, drug use goes up.)
3. Find a specific focus for the loop(s) you draw, taking into account the purpose and audience for the loop(s). A CLD can help you tell a story or express your interpretation or mental model of how a system works. A single, understandable CLD can describe a simple system or a part of a more complex one.
   Pick one aspect of the system. Focus on a behavior that is changing over time. What are the causes? What are the effects? This/these become the other aspects of the loop(s).
4. CLDs contain 4 elements (See Fig. 1):
   a. variables that are related in cause/effect sequence(s) (See #5 below.)
   b. arrows that indicate which elements are affecting other elements
   c. symbols associated with the arrows that denote the direction of the influence of the relationships (See #6 below.)
   d. a central symbol indicating the overall identity of the loop (either "R" reinforcing or "B" balancing) (See #7 below.)
5. All variables in a CLD must be able to increase or decrease; at least one must be a stock, i.e. an accumulation. (See "Tips for Stock/Flow Maps.")
   a. Choose precise, non-repetitive terms for the variables in CLDs, e.g., "Feelings" is too nebulous a term to include in a loop. Try a more specific feeling such as "happiness," "sadness," or "frustration" instead.
   b. Do not use words such as more/less, or increases/decreases in the variable name. It is very hard to interpret less "more drug use" or more "less drug use."
6. Symbols associated with the arrowhead end of each arrow indicate the effect of the influence.
   a. An "S" means that both variables move in the same direction. If the first variable increases, the second variable will be greater than it would have been otherwise; a decrease in the first causes the second to be less than it would have otherwise been. A "+" may be used in a similar although not identical fashion.*
   b. An "O" shows that the two variables change in the opposite direction. If the first variable increases, the second will be less than it would have been otherwise; a decrease in the first variable causes the second to be greater than it would have been otherwise. A "-" may be used in a similar, although not identical, fashion. *For clarification of the difference between "S" and "+" and "O" and "-," refer to writings by John Sterman and/or George Richardson.
7. A CLD may be "reinforcing" and grow, or shrink, until acted upon by a limiting force, or "balancing" and move toward, return to, or oscillate around a particular condition. Reinforcing loops are marked with an "R" in the center; balancing loops are indicated with a "B" in the center . *Graphs of behaviors from:*

Reinforcing Loops *Balancing Loops*



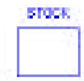
8. If there is a significant amount of time between the action of one variable and the reaction of the next variable in the loop, a time delay can be indicated by drawing two short, parallel line segments across the arrow that connects those two variables.



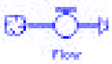
Tips for Stock/Flow Maps

Stock/Flow (S/F) Maps: Stock/Flow (S/F) maps can show interdependencies and feedback within a system by identifying major accumulations and the factors that increase and decrease them over time.

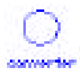
1. Definitions:



stock: an accumulation of "stuff," either concrete (e.g., dollars) or abstract (e.g., anger), that can increase or decrease over time. Stocks are the "nouns" in the system and should be named (and labeled) as such. Stocks can only be modified through flows.



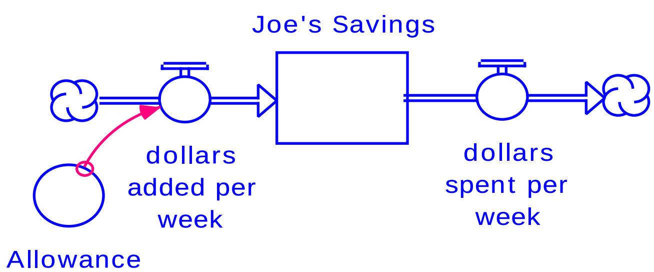
flow: action or process that transports "stuff," directly adding to (inflow) or taking away from (outflow) the accumulation in the stock. A flow is <u>always</u> a rate and is defined in terms of units of the stock per unit of time ("stuff" in the stock per time). Flows are the "verbs" in the system and it's best that they be labeled to reflect that–e.g., "dollars added/ing (per month)" or "anger released/ing (per hour)." The "cloud" at the end of the flow symbol represents the boundary of the system.

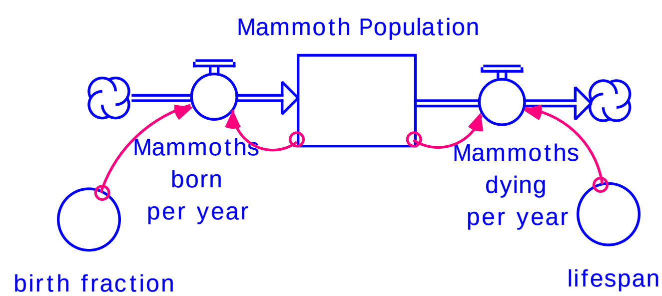


converter: holds information about the system that affects the rate of the flows, or that affects the value of another converter, e.g., allowance affects the rate of dollars added per month.

connector: moves information from one element of the system/map to another. You can think of a connector as a "wire" that carries information (in contrast to a flow that carries "stuff"). It originates at the point where it "picks up" that information and terminates (the arrowhead end) at the place the information is delivered. (Remember, stocks can only be affected through flows, therefore you should not attach a connector directly to a stock.)

2. A "bathtub" analogy may help to explain the concept of stocks and flows.
   - A stock is like the water in a bathtub, the level of which can change over time.
   - An inflow represents water being added through a faucet; an outflow represents water flowing out through a drain.
   - Converters and connectors determine how quickly the water flows in and/or out.
3. Stock/flow mapping (and computer modeling, for that matter) proceeds by identifying the critical stock(s), then determining what flows are important in changing the amount of the stock, and finally by defining what elements in the system influence the rate of the flow(s).
4. To identify which **stock(s)** to include in a map, first identify the critical behaviors of the system and create and discuss BOTGs that reflect those behaviors.
   - When choosing a name for any element in a Stock/Flow Map, keep comparative words such as more or less out of the name, e.g., Level of Stress is preferable to More Stress. (See #5 in Tips for CLDs.)
   - Labeling parts of the map clearly is critically important. The labels make the story clear to others.





5. Converters contain information that, ultimately, affects the flows that affect the stocks. Work outward from the flows in identifying those converters. What converter(s) will affect each flow? What converter(s) will affect those original converters?
6. Once you have drawn your stock(s), flows, converters, and connectors, make sure you look for the **feedback** from the stock(s) that makes a system dynamic. Ask questions such as: Does the accumulation in the stock affect its inflow? outflow? converters? other stocks' inflow/outflow/converters?