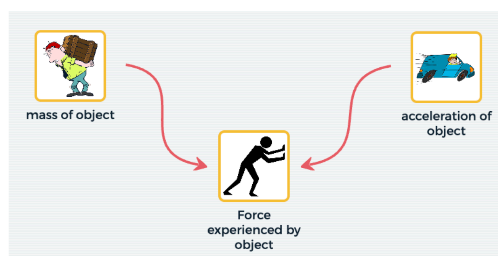
SageModeler is a free, web-based computational modeling program that supports student investigation into the structural and dynamic complexity found in systems of different types. Phenomena can be mapped, modeled, and simulated in ways that promote comprehensive thinking about a system's scope, as well as a deeper and more precise understanding of causal relationships and structures that can lead to system behavior over time. These "systems thinking" ideas, along with the computational thinking skills (such as problem decomposition and algorithmic thinking) that accompany them during the modeling process, lie at the heart of modeling with SageModeler.

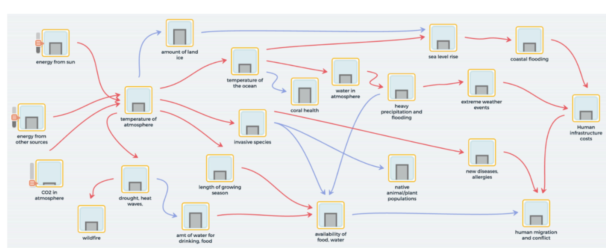
Using SageModeler, students can represent their understanding of a system as a model diagram, static equilibrium model, or dynamic time-based model. Each of these model types requires students to simplify reality and express understanding as a set of essential components connected by causal relationships. Students must break down their understanding of a phenomenon or problem into constituent parts, prioritize those that are most important for a clear explanation, and reconstruct a network of relationships that closely mirrors behavior seen in the real world.

Model diagrams focus exclusively on system components and interconnections. Students as young as elementary age can create a representation of a system and show causal relationships among its components without the need to engage in the computational thinking required to define them. Students select images for each variable and link them with cause-and-effect arrows. The creation of a model diagram can provide insight into the structure and interrelationship of system components and encourage more expansive thinking. Simple diagramming is also an excellent tool for brainstorming ideas to be used in more complex static equilibrium and dynamic time-based models.

Static equilibrium models treat a system as though it is stable at any given point in time. The effects of independent variables are instantly carried through the model, resulting in a new model state. All connected components represent entities that change only when a user adjusts the value of an independent variable (one of the model inputs). Such models can vary from simple to complex, but always address the question "How will a change in one input variable affect all other variables in a system?" A simple model might represent an algebraic expression like F=ma, and help students better understand the relationships among the different variables in this representation of Newton's second law (see example 1). A far more complex model might



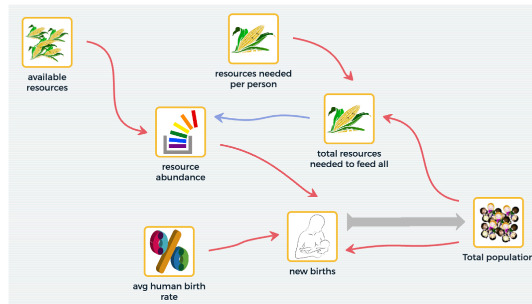
Example 1: Newton's 2nd law



Example 2: Effect of greenhouse gasses

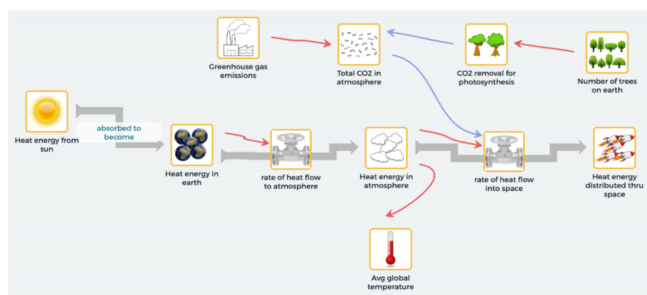
These materials are being developed and researched with funding from the National Science Foundation (Grant Nos. DRL-1842035, DRL-1842037, and DRL-2033922) in partnership between Michigan State University's CREATE for STEM Institute and the Concord Consortium.

address the question of how components in the Earth's climate system will be affected by an increase in atmospheric CO_2 concentrations (see example 2). Static equilibrium models offer a robust platform for investigating any open system, where a manipulated input has immediate impacts on all other system components, and their inherent stability makes them excellent vehicles for exploring the breadth and scope of systems containing large numbers of interacting components.



Example 3: Limits to growth

Dynamic time-based models focus less on structural complexity and more on the wide variety of behaviors that can emerge from within systems containing components that can accumulate in number or amount. Such systems often contain chains of circular connections that loop back upon themselves like a dog chasing its tail. These "feedback" loops allow a system to react to itself, with some parts of the system monitoring those that accumulate, and in turn activating connections that will further influence the accumulations. These self-referencing models are best used for questions that involve changes in critical system components as time passes, or questions that explore behavior over time. Rather than focusing on how a manipulated input will impact other system components, dynamic time-based models offer insight into how feedback systems can generate behavior that is unique to the model's structure and specific to its initial conditions. Questions like "How will a population grow when faced with limiting resources?" (see example 3) and "Why will increasing concentrations of greenhouse gases upset the temperature balance that Earth's atmosphere has provided for so many centuries?" (see example 4) are best investigated using dynamic time-based models.



Example 4: Emissions and global temperature

Whatever type of question you choose to explore, constructing models in SageModeler can help students both to visualize their understanding of how systems are constructed and to test their assumptions about the causal relationships underlying a system's behavior.

Try a step-by-step tutorial that walks you through both static equilibrium and dynamic time-based modeling in this Getting Started document (also available en español).

To learn more about SageModeler, explore many additional sample models, get access to help documents, and more, visit the SageModeler website.