Deeply Digital: Teaching and Learning[1, 2]

Enseñanza y aprendizaje profundamente digitales

Robert Tinker [1]

[1] Ph.D in Physics, Massachusetts Institute of Technology (MIT). Founder of The Concord Consortium, Concord MA - United States and the Virtual High School, Maynard, MA- United States. rtinker@concord.org

Key words

Educational technology, deeply digital, formative feedback, constructivism.

Palabras claves

Tecnología educativa, profundamente digital, retroalimentación formativa, constructivismo.

Abstract

The incredible educational promise of information and communication technologies is too often wasted on trivial applications such as electronic texts and video lectures. To help distinguish between trivial and optimal applications of technology, educators have started using the term "Deeply Digital". Deeply Digital materials take full advantage of the many ways that information technologies can enhance education. To provide specific examples, two computer assisted drawing (CAD) tools used for analysing buildings that support learning about heat transfer, design under constraint, and the properties of fluids will be demonstrated. Students learn by using the tool, and teachers can track student learning. The tools log everything that a student does, and the logs can be analyzed to provide detailed information about student thinking and skills development. Deeply digital applications like these have the potential to transform engineering education.

Resumen

La gran promesa educativa de las tecnologías de educación y comunicaciones está generalmente desperdiciada en aplicaciones triviales como textos electrónicos y video conferencias. Para distinguir entre unas aplicaciones tecnológicas óptimas y otras triviales, un grupo de educadores ha empezado a usar el término "Profundamente digital". Materiales "Profundamente digitales" aprovechan las distintas maneras en que las tecnologías de la información pueden mejorar la educación. Para proporcionar unos ejemplos específicos, se demuestran dos herramientas de dibujo asistido por computador (CAD) que fortalecen el aprendizaje acerca de la transferencia de calor, el diseño bajo limitaciones y las propiedades de los fluidos. Estudiantes aprenden utilizando la herramienta y sus profesores pueden monitorear el aprendizaje. Las herramientas registran todas las acciones de los estudiantes y los registros (o *logs*) pueden ser analizados para proveer información detallada acerca del desarrollo de las habilidades y el pensamiento de cada estudiante. Aplicaciones como estas tienen el potencial de transformar la educación en ingeniería.

THE IMPORTANCE OF LEARNING THROUGH EXPLORATION

Technology has many applications in teaching and learning, and we look forward to a time when technology has transformed education by providing worldwide access to outstanding, research-based learning opportunities. But as new technologies blossom, sometimes there is a perverse effect leading to a decrease in the quality of the education provided. I see this happening in MOOCs, which expand the reach of education, but too often at the expense of quality. Too frequently, meaningful active engagement of learners is

Robert Tinker. Source: Particular Archive, Universidad de los Andes

sacrificed when information technologies are introduced. Students need ample opportunities to learn by DOING – by exploring systems, undertaking design projects, making measurements, analyzing data, and communicating their results. This is a constructivist model of learning that is not yet used in MOOCs, where the emphasis is on reaching a very large number of students. A transmission or instructivist style (Papert, 1993) is easy to implement with technology by using talking heads and multi-media resources to convey knowledge to relatively passive students. This is a step backwards in educational quality. The difference between instructivist and constructivist learning is the difference between learning how to play football by watching football players or getting out and playing football. Science and engineering learning should and can be constructivist, whether delivered through MOOCs or through more traditional means.

DEEPLY DIGITAL LEARNING

The ubiquitous availability of computers, tablets, and the Internet can make it possible to enhance Science, Technology, Engineering and Mathematics (STEM) education in ways not possible before now. But these technologies must enhance learning, not simply present old approaches in a new format. Educational research from the last two decades provides clear guidance on how best to use technology to improve learning. The use of the right technologies will make new, comprehensive STEM materials more effective than any previous STEM reform effort. Simply stated, we should make full use of what is already known about teaching and learning, and technology makes it possible to do this. The required approach has been labelled "deeply digital."

The term, "deeply digital" made its debut in "Prepare and Inspire," a report prepared by a sub-committee of the (U.S.) President's Council of Advisors on Science and Technology – PCAST (2010), approved by the full council and adopted by President Obama. The report concludes, "We believe that computation and information technology is today poised to play a transformative role in education, and that wise investment in technology-based initiatives can yield enormous benefits." (p73) The report recommends a vastly increased, mission driven, effort to create deeply digital materials that make optimal use of interactive simulations, embedded assessments, and adaptive problem engines.

EXAMPLES OF DEEPLY DIGITAL SOFTWARE

Among existing computer applications, educational computational models are a key ingredient of deeply digital materials; specifically, models that use algorithms based on physical laws. These models are useful in educational contexts if they are used to generate real-time visualizations of physical systems rapidly and to place important parameters and initial conditions under student control. This allows students to learn quickly by watching the model evolve as they explore its performance under different conditions. Exploring a computational model is very much like performing a hands-on experiment or solving a design problem.

One example of an educational computational model is the *Molecular Workbench* developed at the Concord Consortium. We will describe this at length at a workshop tomorrow and our talk the next day, and so mention it here only briefly. *Molecular Workbench* has at its core an engine that computes the motion of atoms based on good approximations of the major electromagnetic and quantum forces acting on atoms and molecules. The engine is embedded in an authoring system that has allowed educators to make hundreds of models of atomic-scale phenomena. Some of the most popular involve models of changes of state, simple chemical reactions, and diffusion. But, as Figure 1 indicates, a huge number of highly specialized educational models have also been generated using this software.

Energy3D provides an example of computational models applied to engineering education. *Energy3D* is a simplified computer assisted drawing (CAD) and manufacturing (CAM) system. Unlike CAD/CAM software developed for professional use, *Energy3D* is easy to use and intuitive, so that students can begin using it with little or no instruction. Because it is simplified, it does not have all the features of professional software, but those it does have been selected for educational reasons. However, unlike most CAD/CAM systems,
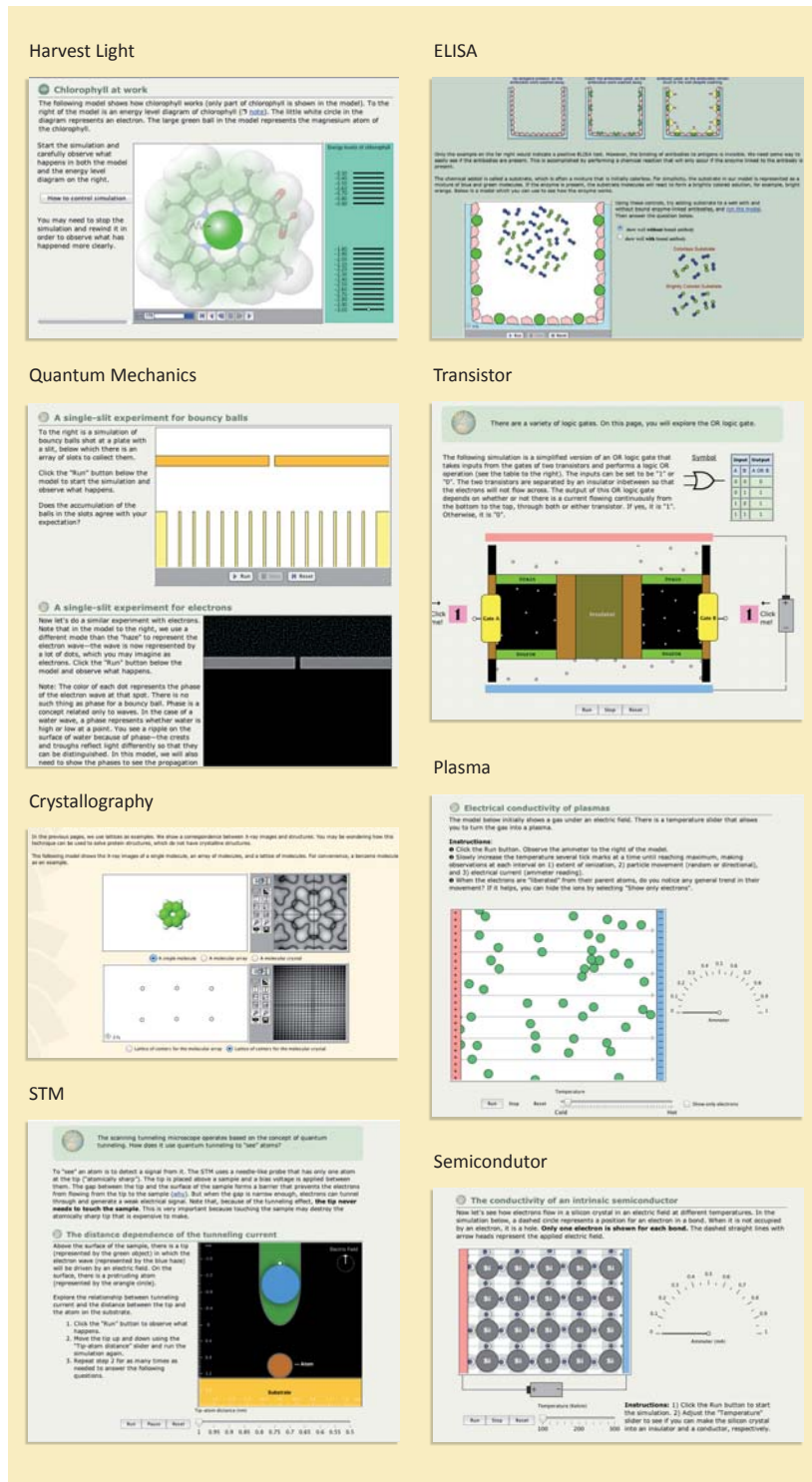
Harvest Light

ELISA

Quantum Mechanics

Transistor

Crystallography

Plasma

STM

Semicondutor

Figure 1. A sampling of Molecular Workbench models. Clockwise from the upper left: chlorophyll, electron diffraction, x-ray crystallography, a biotech assay, a semiconductor, a plasma, a transistor, and a scanning tunneling microscope. All these models run quickly and are interactive, so the student can learn by exploring.
Source. The Concord Consortium (2013).

it can analyze the performance of buildings that have been created using it. With this software, students can design buildings, print out parts, assemble them into 3D models, create villages, and then use the software to generate heat maps of the surroundings by simulating the energy input from sunlight over a day and a year (see Figure 2). This combination of computer design, hands-on construction, and thermal analysis creates a powerful learning environment for beginning engineering students.

Energy2D, also developed at the Concord Consortium, is used to explore design problems that involve heat flow. It uses an accurate computational model of conduction, convection, and radiation, the three ways heat can be exchanged. The computations are sophisticated and accurate, based on the Navier-Stokes equation, which governs flow; the heat equation, which governs how heat is transmitted from one place to another; the ideal gas equation, which introduces buoyancy; and ray tracing, which supports insolation. The engine generates evolving visualizations of the system numerically with arbitrary boundary conditions. Like the *Molecular Workbench*, *Energy2D* includes model-building tools, so it can be used to model many different situations that involve heat flow and buoyancy, as illustrated in Figures 3 and 4.

These software packages support open-ended, constructivist learning because they are all highly interactive and graphic. For instance, in *Energy2D* students can easily change the location, thickness, and thermal properties of the walls, add and remove heat sources, move the sun, and place temperature sensors anywhere. The models generate dynamic visualizations, so by running them the student can see the flow of energy in real time and generate time-series graphs of the temperature detected by any sensor they choose. They also execute quickly, which is key to maintaining student interest and making it possible to undertake many experiments and design modifications in a short time.
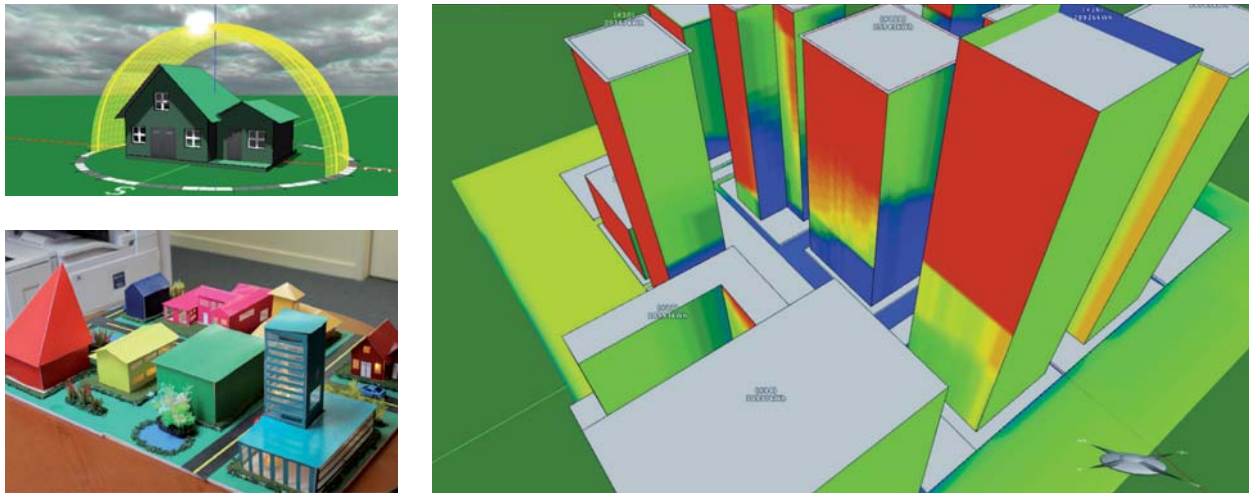
Figure 2. *Energy3D* illustrating (left) a village that students constructed from software printouts, (center) a visualization used in thermal analysis of student designs, and (right) a false-color heat map of buildings and their surroundings that shows how their location influences solar heating. Source. (Xie, C., Zhang, Z., Nourian, S., Pallant, A., & Hazzard, E. 2013; The Concord Consortium, 2011-2014).
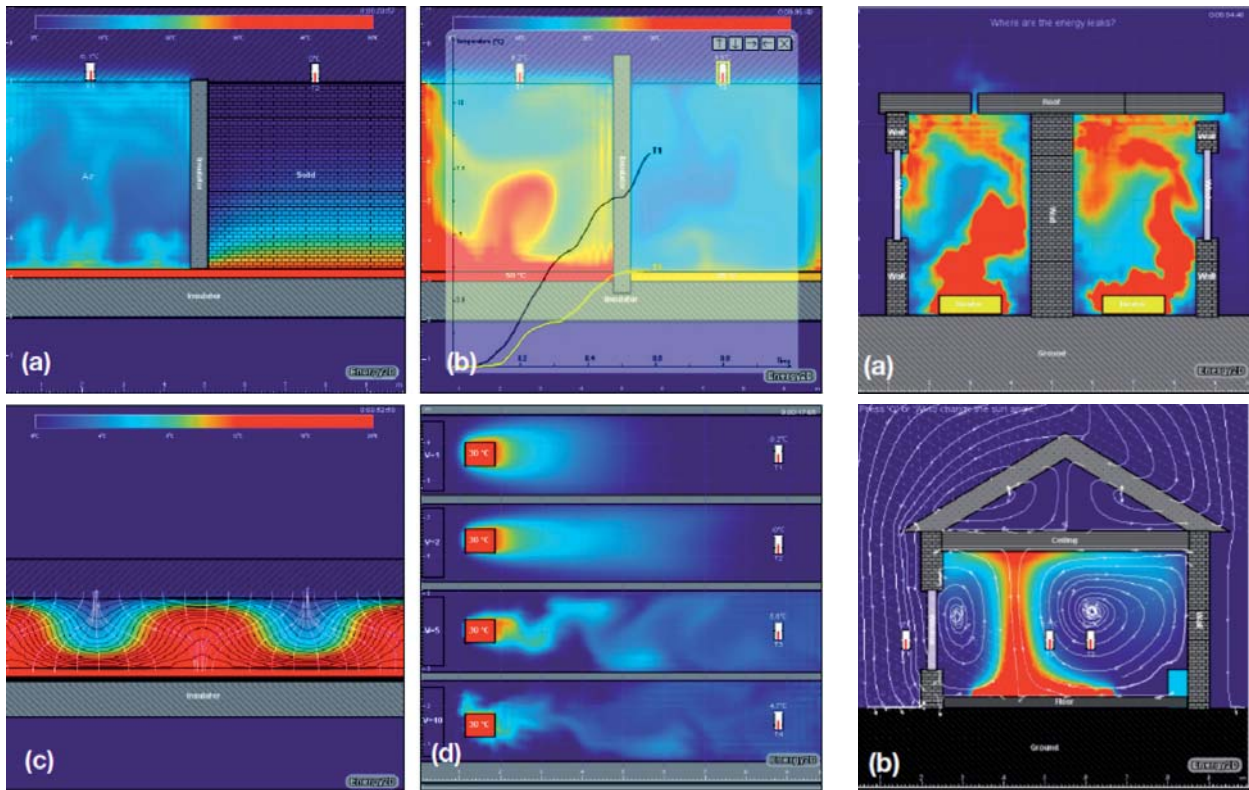

Figure 3. Computational models created using *Energy2D*. Panel (a) shows a comparison of convection and conduction from the same hot surface and the same initial conditions except that conduction is through a gas on the left and a solid on the right. It is obvious that gas conducts heat much faster. Panel (b) shows convection resulting from two different temperature differences overlaid with a map of the temperatures as a function of time. Panel (c) shows Barnard cells that occur when there is an inversion, analogous to atmospheric cloud formation. Panel (d) shows air as it is being blown across a hot object at different speeds. The transition from streamline to turbulent flow can be seen by comparing the examples. Source. The Concord Consortium (2014).

Figure 4. *Energy2D* applied to buildings. Panel (a) compares two rooms heated from below, each with holes to the outside that permit heat to escape. Panel (b) shows radiation heating of the floor by light entering a window, and the resulting uneven heating of the house caused by convection that generates the extreme interior temperatures differences that are often found in cold climates. Source. The Concord Consortium (2014).

These three software packages share another important property—they can rightly be called "meta-models" because they result in hundreds of specific models. While it has required considerable effort to create these sophisticated programs, it would have taken far more resources to create individually each of the hundreds of models derived from the meta-models.

IMPROVING PROJECT-BASED LEARNING WITH STEALTH ASSESSMENT

One of the impediments to using open-ended, constructivist challenges in science and engineering is the difficulty of assessing student performance. As students go about exploring any of these environments in a classroom or a lab, it is often difficult to determine whether they are deeply engaged and learning, or completely at sea and failing to learn anything. To the casual observer, students who are following a plan and making progress can be indistinguishable from students who are paying little attention to the task at hand and wasting time.

When students are using computational models, it is possible to monitor their progress by using the computer to analyze their actions. The software can log everything students are doing and save everything that they have created, such as designs, graphs, and data. With appropriate software, these logs can be summarized and displayed to provide clues to student thinking. Linking educational computational models with educational analytics or "stealth-assessment" is a promising area of current research.

A simple example of stealth assessment based on student logs comes from our research on students who were asked to use *Energy3D* to design a group of building, within certain given constraints. Students were given a set of buildings and challenged to add some more buildings in such a way as to minimize shadowing of other buildings and maximize open space. Figure 5 is a visualization of the number of actions two students performed. It is clear from a glance that the upper student was more engaged. Figure 6 illustrates a more detailed analysis of several students

that categorized their actions into building and revising. It is clear that there are huge differences in the ratios of the number of events in these two categories. These data revealed that some students simply enjoyed creating buildings and paid scant attention to the constraints, while others made more revisions to their designs in order to optimize them within the given constraints.

The combination of stealth assessment and computational models provides fine-grained detail about student progress, but does not subtract from class time by requiring quizzes and tests. Software incorporating this combination is, unfortunately, not yet available for large-scale implementation. Because it solves one of the practical problems of constructivist education by giving detailed assessment data, it is, however, likely to become widespread in the near future. Since it is completely computer-based, it can be employed at a distance and has allowed us to undertake classroom research anywhere there are willing teachers. Naturally, it could be used with online courses and MOOCs.
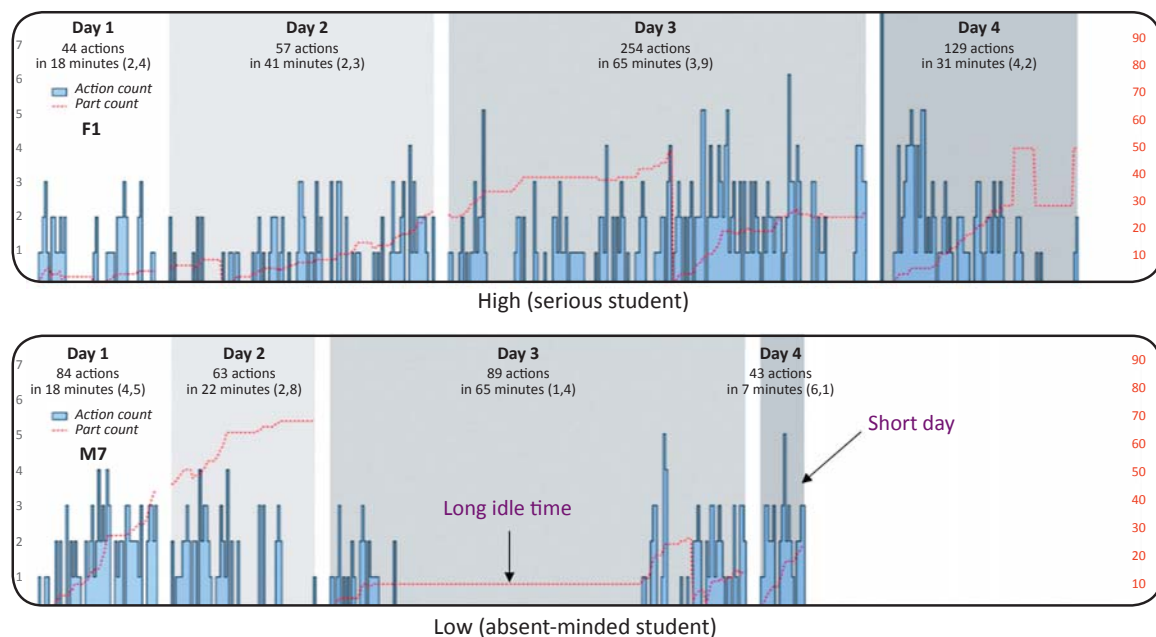

Figure 5. A simple analysis of log data that shows a huge difference in the level of activity for two different students.
Source. (Xie, et al. 2013)

	Total actions	Building	Revision	Ratio of building/revision	Number of designs	Most frequent action
F1	393	130	259	0.50	4	r2
F2	462	163	296	0.55	6	r2
F3	325	97	228	0.43	5	r2
F4	436	202	232	0.87	7	b2
M1	369	176	190	0.93	3	r2
M2	550	238	310	0.77	5	r2
M3	480	232	245	0.95	3	b2
M4	482	367	114	3.22	3	b2
M5	165	95	79	1.39	4	b2
M6	164	60	104	0.58	2	r2

Figure 6. Analysis of student logs. By comparing the ratio of building to revision, we see that, in this small sample, females revised more frequently. Their final designs met the design goals more often, most likely because of their cut-and-try approach.
Source. (Xie, C., et al. 2013)

Summary

Computational models are an essential component of deeply digital educational materials that can have a major positive impact on science and engineering education because they support constructivist learning. Meta-models, such as those illustrated in this paper, are important because they can be used to create hundreds of different, valuable educational, computational models. One of the persistent problems of constructivist learning is the difficulty of evaluating the quality of student work. Stealth assessment using logs generated by these models can give faculty ongoing information about student thinking with unprecedented accuracy. Since both these models and assessments are computer-based, they can be used in all educational settings. This combination of model-based learning and stealth assessment is an area of current research that holds great promise as key parts of deeply digital materials that will transform STEM teaching and learning.

Acknowledgements

References

President's Council of Advisors on Science and Technology (US). (2010). *Prepare and Inspire: K-12 Education in Science, Technology, Engineering, and Math (STEM) for America's Future: Executive Report*. Executive Office of the President, President's Council of Advisors on Science and Technology.

Papert, S. (1993). *The children›s machine: Rethinking school in the age of the computer*. New York: Basic Books.

The Concord Consortium (2011-2014). [Image] Retrieved from http://energy.concord.org/energy3d/

The Concord Consortium (2014). *Teaching and Learning Heat Transfer with Energy2D.* [Image]. Retrieved from http://concord.org/publications/newsletter/2010-spring/energy2d#

Xie, C., Zhang, Z., Nourian, S., Pallant, A., & Hazzard, E. (2013). A Time Series Analysis Method for Assessing Engi-neering Design Processes Using a CAD Tool. Retrieved from: http://concord.org/sites/default/files/pdf/eerg-narst-2013.pdf

The Concord Consortium (2013). *Molecular Workbench* [Image] Retrieved from http://mw.concord.org/modeler/).