Thermodynamics and Statistical Mechanics Reviews
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Report by Bruce Mason

The MPTL multimedia resource discovery and recommendation effort in 2011 focused on resources for teaching Thermodynamics and Statistical Mechanics.

The review process followed the standard procedure described in other Recommendation Reports. See, for example, the report published in Eur. J. Phys. 34, L47 (2013). The steps in this process are (1) the original discovery of resources, (2) preliminary determination of the review-worthy materials, (3) formal peer review by two or more reviewers, and (4) report of the review results.

The discovery of resource resulted in a list of 326 items. A total of 50 items, many containing multiple simulations or learning activities, were reviewed.

Excellent Materials

There were no materials that were rated “Excellent” by both reviewers of an item, although there were a couple of reviewers who individually rated an item as Excellent. This may be partially due to the nature of thermodynamics, which can be abstract and difficult to illustrate. This is also because the reviewers have high standards for the materials, expecting excellent multimedia and information about and support for teaching and learning.

Very Good Materials

The highest ranked materials come from the projects regularly recognized in our reviews. The ones that seem to come closest to “Excellent”:

> http://www.compadre.org/STP/index.cfm: STP ComPADRE Collection, Gould and Tobochnik. This is a successful combination of a statistical mechanics textbook, a series of java simulations, and a library of other statistical mechanics research and resources. Many simulations are developed specifically to support the work in the book. This material would have been rated excellent if there was a complete integration of the simulations with the text. The full text, by chapter, with supplements are at: http://www.compadre.org/STP/filingcabinet/share.cfm?UID=10986&FID=21201&code=8E844C06A4
>
> http://phet.colorado.edu/en/simulations/category/physics/heat-and-thermodynamics: PHET Heat and Thermo. There are some excellent simulations on various topics, including ideal gases and chemical reaction rates. The simulations provide realistic virtual learning environments that are based on research on student learning. The simulations have teaching suggestions created by both teachers and the PHET project. The simulations do not include information about the models and physics used.

http://www.colorado.edu/physics/2000/bec/index.html: Physics 2000 BEC, Martin Goldman. This is an example of material that has been around for a long time, but is still of note. The tutorial is written as a conversation between a professor and student regarding Bose-Einstein condensation, with simple embedded interactive simulations illustrating such topics as laser and evaporative cooling. The material is very well constructed and readable.

There were two multimedia learning collections with a broader coverage of the topic. These indicate the movement towards "e-books" that integrate all different media into a more student-controlled learning environment:

http://www.hippocampus.org/Introductory%20Physics%20I: Hippocampus Thermodynamics, published by the Monterey Institute for Technology and Education. This is a student tutorial designed with animations, text, audio, and questions. As a textbook-like resource, it is not interactive or exploratory in an advanced way, but the requirements for students to answer questions on the materials covered as the presentation progresses will help keep them engaged in the material. The use of multiple presentation modes and multiple representations has been proven to be effective to enhance learning.

http://www.wadsworthmedia.com/physics/cp7af/: Serway Media Library, published by Cengage Learning. This is a series of clear and simple animations and illustrations supporting an introductory physics textbook. Each of the animations focus on a single topic and illustrate it through animations, text-based explanations, and questions for students to answer. The clear design and documentation of the applets and physics are noteworthy.

There were three resource collections that were noted for their combination of simulations and teaching/learning materials. These have reasonable, but not groundbreaking, simulations or animations coupled with excellent tutorial readings often coupled with questions for students and student activities.

http://galileoandeinstein.physics.virginia.edu/more_stuff/flashlets/carnot.htm: Carnot Cycle Simulation and Lecture, Michael Fowler, UVA. This is an online set of notes covering the Carnot Cycle, which in turn is part of a larger set of notes on thermodynamics. The Flash animation showing the operation of the cycle is useful illustration of the topics covered. The animation allows minimal adjustment of the parameters for the cycle, limiting the student engagement and exploration of the topic. The power of this material is the combination of the clear didactic resource illustrated by the operating animation.

http://homepages.ius.edu/KFORINAS/physlets/thermo/thermo.html: Kyle Forinas Physlet-based Thermodynamics Questions. This resource consists of a set of questions motivating student exploration of thermodynamics concepts, illustrated by java simulations. The parameters in the simulations are set for each question, but are modified to help students understand the properties covered. The question sequences for the different topics are well designed and the illustrations add to the conceptual nature of the questions. The reviewers felt that some of the illustrations could have a little more physics included, tips for using this material in class would be helpful, and found a few spelling and grammatical errors.

http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm: Ideal Gas Simulation, Michael Abraham & John Gelder. This simulation was also rated highly in the last thermodynamics review. It provides a gas simulation with the ability to change all the various parameters and plot a wide range of relations between thermodynamic quantities. What makes this material most noteworthy, however, is the set of student activities and explorations included with the simulation. These can be used by instructors in class as written, or as a starting point for creating their own activities. Learners accessing this resource on their own will have a complete learning activity available.

Finally, there are lots of "kinetic theory" (bouncing ball) simulations available. Other than the ones listed above, one item stood out for its display features and flexibility:

http://www.falstad.com/gas: Ideal Gas Simulation, Paul Falstad. This is an excellent example of a kinetic theory simulation. It is noteworthy for the level of control and the different output information provided. The color coding of atoms by energy and a similar color coding used for the heater/cooler in the system, is noteworthy. Although it does not include any pedagogical suggestions, it includes a range of set-up options that encourage the exploration of certain important topics. Like most of Falstad's simulations, the output is somewhat qualitative with the units not given, but unlike most of these simulations there is no information included on the physics model used. The source code is available for download.

Materials of Note

There were a few items that did not get two "Very Good" ratings, but are worth noting as playing an important role in teaching thermodynamics.

The effort to develop remote laboratories has some interesting possibilities for distributed education.

http://remote.physik.tu-berlin.de/farm/index.php?id=126&L=1: Ideal Gas Remote Controlled Lab, TU-Berlin. This is a remote lab where students can run thermodynamic processes in real-time on a real gases. The reviewer was unable to run the lab because of registration and log-in problems. The experiment includes both a data-taking interface and a video stream of the experiment. The data can be saved and analyzed by students. It includes links to simulations and tutorials to help students prepare for the laboratory, but there are not teaching or learning aids included.

There is overlap with other disciplines, particularly chemistry and engineering. There were several collections of this sort reviewed, that were noted but would need to be used carefully in a physics class.

http://www.chm.davidson.edu/vce/index.html: Virtual Chemistry Experiments. This is a series of tutorials, or learning progressions, on topics gasses and chemistry. The experiments are a bit difficult to run at times. Perhaps very good, or good. Chemistry focus so there are some physics mistakes in the material, but overall it can be useful for thermodynamics classes.

http://www.thermofluids.net/: The Expert System for Thermodynamics, S. Bhattacharjee. This was rated Excellent in our last review, but the reviewers this year were less impressed. They felt that the presentation was much more useful for engineering students or teachers, the main audience for the site. The presentation was confusing and disorganized. However, there are lots of problems available for use, some with answers and solutions available for instructors.

http://www.sas.upenn.edu/rappegroup/htdocs/Education/MB/index.html: The Maxwell-Boltzmann Distribution, Andrew Rappe. Developed by a physical chemistry group, this web site is a series of very short tutorials on statistical mechanics. Each explanation includes a series of study questions regarding the topic, some using a molecular dynamics simulation provided by the authors. The tutorial for the MB development is clear and understandable, and the applet is easily run and well integrated into the text. The web site and applet are somewhat old, so there are some broken links and there are more sophisticated and interactive applets available.

Wolfram is promoting Mathematica "Demonstrations" on their web site. Although this is an interesting idea, so far the materials are very simple illustrations, although the code is available (for Mathematica owners).

http://demonstrations.wolfram.com/topic.html?topic=Statistical+Mechanics: Mathematica Demonstrations in Statistical Mechanics. Published by Wolfram. This is a series of Mathematica-based resources that can be viewed on the web. It is an interesting way of collecting and presenting materials, based on a commercial product but freely available for viewing. Source code can be downloaded, viewed, and edited by those owning the full Mathematica software. In general there is little or no pedagogical context for the materials, and there is simple slider control to explore parameter space. There is probably more here for advanced courses with simulations on things such as the Ising model, cellular automata, etc.

There has not been as much research on student difficulties in thermodynamics as many other topics, but two problems have been identified. There were two resources that can be used to help students with the conceptual roadblocks. These are:

The first broad area of student difficulty is developing a basic understanding of statistics, distributions, and probability.

http://www.rossmanchance.com/applets/index.html: Rossman-Chance Statistics Applet Collection, Beth Chance and Rossman. This is a collection of applets designed for statistics education. The collection itself is aimed at a different audience, but some will be useful to help students understand the meaning of probability and how statistical results are dependent on numbers of samples. This shows the possibilities for the use of resources from other disciplines to help support physics students.

The second area of student difficulty is the understanding the difference between "state variables" (path-independent quantities) and "process variables" (path-dependent quantities).

http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=628.0: NTNUJAVA Virtual Physics Laboratory, Fu-Kwan Hwang. The NTNU materials are considered classic simulations covering a wide range of topics. The thermodynamics simulations are somewhat limited, but the Ideal Gas Process simulation is unique in the ways it is designed to address student misconceptions of state variables and process variables. The constant display of changes in energy and entropy will help students distinguish between path-dependent and path-independent properties. This has been found by several researchers to be a major problem with student understanding of thermal physics.

Finally, we are living through the “Youtube” revolution. The resources that our students have immediate access to through web videos range from very interesting to content that is incorrect or promotes misconceptions. It is rare that videos are placed in a learning/teaching context and promote active learning. There are a couple of examples of noteworthy uses of video for physics teaching.

http://paer.rutgers.edu/pt3/cycleindex.php?topicid=8: ISLE Thermodynamics Explorations, Eugenia Etkina. This material provides a set of short learning cycles on basic Ideal Gas Law physics, supported by video-based experiments. Students are asked to predict and explain. This material is not as complete as in other topics, but it gives an example of the context necessary for pedagogically useful YouTube Physics.

http://www.nationalstemcentre.org.uk/elibrary/resource/2087/thermal-conductivity: Thermal Conductivity, published by the National STEM Centre. This is another excellent example of a small video-based resource to help elicit and address student concepts in physics. This one in particular considers the difference between “feeling hot and cold” and thermal conductivity. The video includes a break to have students predict the outcome of the experiment.