

AN EFFICIENT WAY TO INCREASE THE ENGINEERING STUDENT'S FUNDAMENTAL UNDERSTANDING OF THERMODYNAMICS BY UTILIZING INTERACTIVE WEB BASED ANIMATION SOFTWARE

Richard Stanley and Gianfranco DiGiuseppe
Mechanical Engineering Department
Kettering University

Animation software for an introductory *Thermodynamics* course has been developed, which is intended to be part of the WileyPLUS platform (John Wiley and Sons, Inc.). This interactive software is unique because each animation is directly linked to a homework problem and no programming is required of the user. The animations are web-based (hard-coded in Adobe® Flash Action Script), so no external computer programs are needed.

This software is visually similar to web-based *Dynamics* software, which has been developed by the principal author of this publication. The *Dynamics* software has been explained and assessed in several previous ASEE conference proceedings and journal articles.

In this paper, the software functionality will be detailed. The results of student surveys will be analyzed and the pedagogical advantages will be evaluated.

Introduction

In typical *Thermodynamics* courses, most homework problems require the student to solve for a specific entity, which may be a property (temperature, pressure, specific volume, etc.), energy (heat transfer or work), efficiency, etc. The professor typically assigns a set of homework problems and the students solve each problem by hand. The student knows that his or her calculations are correct by checking answers in the back of the book.

Thermodynamics problems are often time-based. For instance, a student may be asked to solve for the work and/or heat transfer of a

process that begins at known state #1 and ends at known state #2. In reality, though, the work and heat transfer vary with time as the system moves from state #1 to state #2. This dynamic nature of many *Thermodynamics* problems is probably lost in the traditional classroom. It is the authors' opinion that computer animations are necessary in order for the students to fully understand the transient nature of the subject of *Thermodynamics*.

Numerous commercial thermodynamics packages are available, many of which may be found at the website "Process Register"[1]. Most of these packages are used as standalone applications and are not developed specifically for educational purposes. For educational purposes, several animation programs have been developed in the recent past[2,3,4,5,6] While these programs provide animations and have useful tools, the animations are not directly linked directly to homework problems of texts.

Several papers have been published by the principal author in the past, which describe web-based animations software for *Dynamics*[7,8,9,10,11,12] The same "look and feel" has been applied to the subject of *Thermodynamics*. A summary of previous comments and findings of the *Dynamics* animations are:

- 1) The primary purpose of the animation software is to help the student appreciate and understand engineering concepts more completely.
- 2) There is no software to install and there is absolutely no programming required of the user.

- 3) The animations can be played on virtually any computer; the Adobe Flash Player is installed on 98.8% of internet-enabled desktops worldwide[13].
- 4) The software is extremely easy to use; the controls are similar to those of a DVD player.
- 5) Because the program is “hard-coded” in Adobe Flash Action Script, there is an abundance of control in the advancement of the software package.
- 6) The cost and time of development is relatively low because all images may be duplicated directly from the textbook.
- 7) The animation program is unique in that each animation is linked to a homework problem or case study; students unanimously support this way of utilizing the software.

A closed polytropic process of a piston/cylinder system has been chosen to test the concepts of the software and will be described in this paper. Many additional problem types are intended to be developed in the future.

Software Intent and Audience

It must be emphasized that this software is not intended to eliminate the grading of homework for the professor. The primary objective of the software is to increase the engineering student’s fundamental understanding of the subject of *Thermodynamics* via a user friendly, cost effective, and readily available web-based interface.

The principal audience is composed of educators who wish to enhance their students’ overall comprehension of *Thermodynamics* via simulations.

Explanation of the Software

The software functionality will be discussed briefly in this section. If the reader is interested in the details of the animation software, he or she may reference[7,8,9,10,11,12].

The main problem page has three sections (Figure 1). The top displays the problem, exactly as it appears in the text. The middle of the page is the setup, which contains the individual steps that are required of the student. The bottom holds the animation, specifically developed for the problem.

Each animation may contain between one and three objects. In the given problem, the only object is the piston/cylinder arrangement.

Each object has INPUT variables which may be changed by the user. INPUT variables with a white background must be changed by the user (in this problem, the variable is the initial volume V_1). INPUT variables with a light grey background already have the correct input values entered. These values may be changed by the user, if desired, for “what-if” analyses (in this problem, these variables are: the initial pressure P_1 , the mass of the gas m , the cylinder diameter D , the initial position of the piston X_1 & Y_1 , the polytropic coefficient n , the specific heats of the gas C_v & C_p , and the constant heat transfer rate \dot{Q}). INPUT variables may also have a dark grey background, which cannot be changed by the user (none of these INPUT variables are included in this problem). All variables are color coded. For instance, variables associated to the particle’s position are black, those related to the pressure are blue, those associated with the internal energy are purple, and so on.

When the user hovers the mouse over an INPUT variable, pop-up balloons indicate the variable definition, the units, and the range of allowable values. If the user wants a pictorial representation of the variable, he or she may click on the variable and a pop-up box will provide this information.

Just to the right of the INPUT values are the OUTPUT variables. The OUTPUT variables, chosen specifically for this problem are: the gas temperature T , the cylinder pressure P , the volume & change in volume Vol & ΔVol , the initial, instantaneous, and change in internal

energy U_1 , U , & ΔU , the heat transfer Q , and the work W . As with the INPUT variables, the variable definition and units are displayed when the user hovers the mouse over the given variable.

If the user would like to add or delete OUTPUT variables, he or she can click on the OUTPUT button and a pop-up screen appears. Several options are available to the user; these can be viewed and changed by clicking the OPTIONS button. And finally, the controls of the animation are familiar to any user; they are

similar to those of a modern DVD player.

General Problem Solving Methodology

Following is an example of how a student can use the software to solve the problem shown in Figure 1. Given the conditions in the problem statement, the student must solve for the OUTPUT values when the pressure in the cylinder reaches 200 kPa (i.e. the work done on or by the system W , the heat transfer to the system Q , and the final temperature T and volume V of the gas).

Polytropic Piston/Cylinder Problem: Find Work, Heat Transfer, T, V

A piston/cylinder device contains a gas with specific heats of $C_p = 1.04 \text{ KJ/kg}\cdot^\circ\text{K}$ and $C_v = 0.743 \text{ KJ/kg}\cdot^\circ\text{K}$. Its initial temperature, pressure, and mass are 700 K, 500 kPa, and 1 kg, respectively. Heat is transferred to the device at a constant rate until $P = 200 \text{ kPa}$. The gas undergoes a polytropic process with $n = 1.3$.

- 1) Calculate the work done on/by the system.
- 2) Calculate the heat transfer to the system.
- 3) Calculate the final temperature and volume of the gas.

PROBLEM STATEMENT

Polytropic Piston/Cylinder Setup: Find Work, Heat Transfer, T, V

STEP 1: Calculate the initial volume of the cylinder (by the ideal gas law) and enter it into the corresponding INPUT box (V_1) of the animation. (NOTE: INPUT variables that must be changed by the user have a white background; $V_1 = 0.5 \text{ m}^3$ is a default value.)

STEP 2: Calculate the heat transfer, work, final temperature, and final volume by hand.

STEP 3: Run the animation until the pressure of the gas reaches 200 kPa and validate your calculations.

STEP 4: Print out the web page, which is paused at STEP 3.

STEP 5: Hand in the web page printout and supporting hand-calculations. Please circle the answers on both the web-page printout and the hand-calculations.

PROBLEM SETUP

TIME:

INPUT	OUTPUT
P_1 : 500	T : 841.7508
V_1 : 0.5	P : 500
m : 1	Vol: 0.5
D : 1	ΔVol : 0
X_1 : 3	V : 0.5
Y_1 : 2.5	U_1 : 625.4208
n : 1.3	U : 625.4208
C_v : 0.743	ΔU : 0
C_p : 1.04	Q : 0
Q : 100	W : 0

● RESET

OUTPUT VALUES

PISTON/CYLINDER ARRANGEMENT

ANIMATION

CONTROLS

OPTIONS

TIME STEP: 0.001

ZOOM

Figure 1 Screen Shot of the Animation Program.

The initial volume and the OUTPUT values must first be calculated by hand. The initial volume is then entered into the appropriate INPUT box of the animation. The student runs the animation and clicks the pause button at the appropriate time in order to validate his or her answers. The deliverable is the printout of the web page printout (paused at state #2), along with the supporting calculations.

Solving of the Problem

Forty students in two sections of *Thermodynamics* solved the problem shown in Figure #1 during the fall term of 2009. The students were given a brief 10 minute overview of how to use the software before they were asked to solve the problem. The following is the process that was followed by the students:

The student is given the following conditions at state #1: $T_1 = 700^\circ\text{K}$, $P_1 = 500 \text{ kPa}$, and $m = 1 \text{ kg}$. With this information, the ideal gas law is used to solve for the initial cylinder volume V_1 , which is calculated to be $V_1 = 0.4158 \text{ m}^3$. The student enters this volume in the corresponding INPUT box in animation program, as shown in Figure 2. After the student enters this value, the following transpires:

- 1) OUTPUT variables T and P change to 700°K and 500 kPa , respectively. The student compares these values to those of the problem statement and validates that V_1 has been calculated correctly.
- 2) The text of the INPUT variable V_1 changes to brown. The brown color indicates that V_1 has been changed from its default value.
- 3) The color of the gas in the cylinder and the color of the OUTPUT variable T change to represent the gas temperature. This temperature color varies from white (absolute zero), through varying color combinations of blue and red, and finally to black (extremely high temperature).

The student then solves for the work done on/by the system W, the heat transfer to the

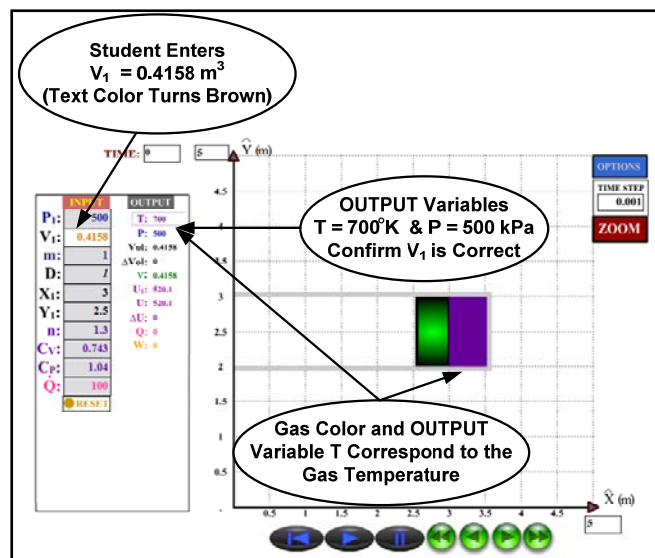


Figure 2 Screen Shot of the Animation: State #1.

system Q, the temperature T, and volume V of the gas when the cylinder pressure P reaches 200 kPa. These are calculated to be:

$$Q = 32.9 \text{ kW}, W = 132.1 \text{ kW}, T = 566.7^\circ\text{K}, \text{ and } V = 0.841 \text{ m}^3$$

In order to validate his or her calculations, the student hits the play button (Figure 4) and runs the animation until P lowers to 200 KPa. (Because no heat transfer rate is indicated in the problem statement, a constant heat transfer rate \dot{Q} of 100 kW is the default value. (In reality, any positive \dot{Q} would eventually yield the required conditions at state #2.)

To give the reader an idea of how the animation progresses, Figure 2 is a screen shot of the animation at state #1, Figure 3 is a screen shot about $\frac{1}{2}$ way (in time) between the state #1 and the state #2, and Figure 4 is a screen shot at state #2. Note that the arrows, which correspond to the work W and the heat transfer Q, are scaled accordingly as the program progresses.

The student verifies that his or her work is correct. As stated earlier, the deliverable to the professor is the screen shot at state #2 (Figure 4), along with supporting calculations.

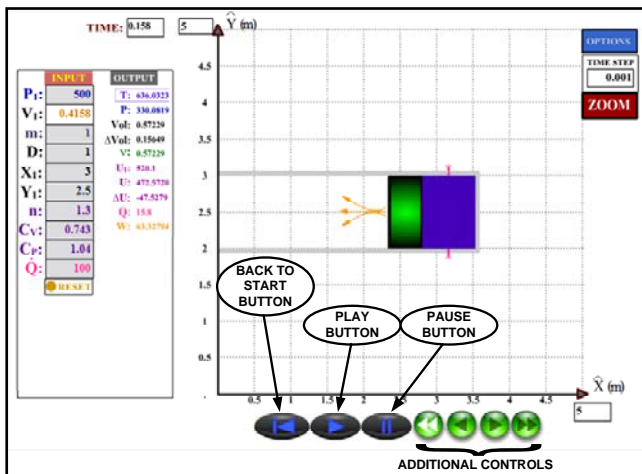


Figure 3. Screen Shot of the Animation: In Between State #1 and State #2.

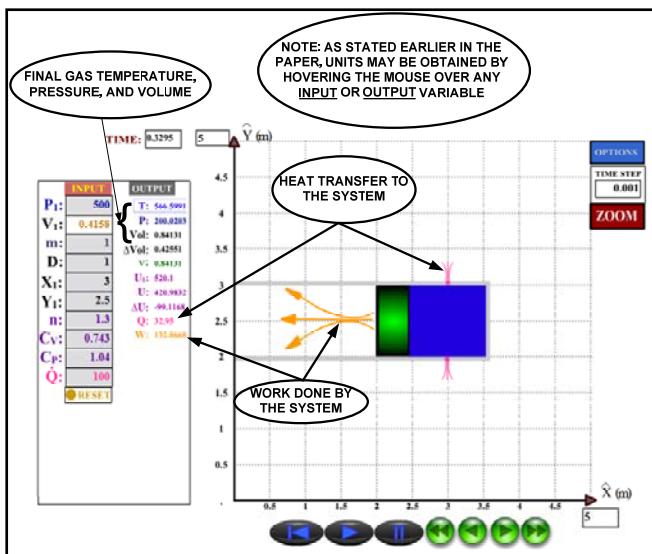


Figure 4. Screen Shot of the Animation: State #2.

Student Success Rate

Over 90% of the students answered the question correctly. This is no surprise, because the problem is relatively basic and it was given to the students after they had been exposed to over 80% of the *Thermodynamics* course material.

Student Surveys

The animation software was used in two sections of *Thermodynamics* at Kettering University (Flint, MI) during the fall term of 2009. A total of 40 students were surveyed at the end of the term regarding the effectiveness of the software. The students surveyed were assured that their answers would remain anonymous.

Student Surveys: Pedagogical Implications

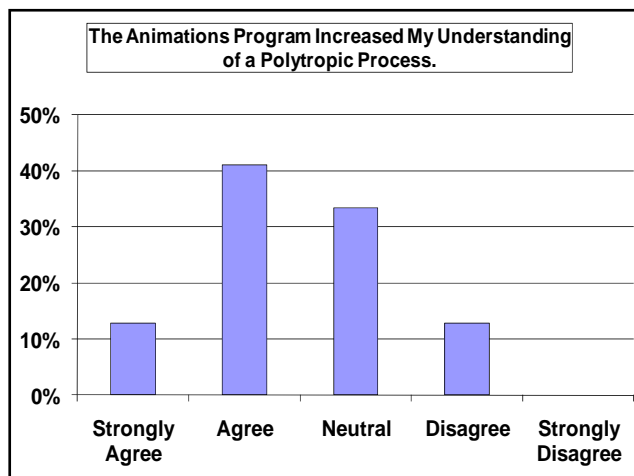


Figure 5. Student Survey: Software Increased Understanding of a Polytropic Process.

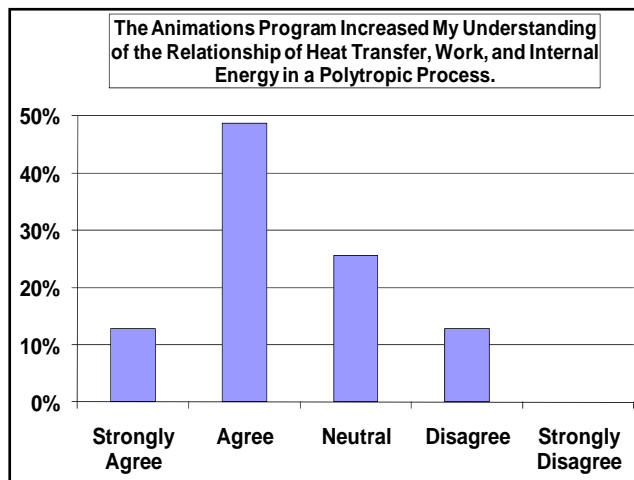


Figure 6. Student Survey: Software Increased Understanding of Energy Relationships of a Polytropic Process.

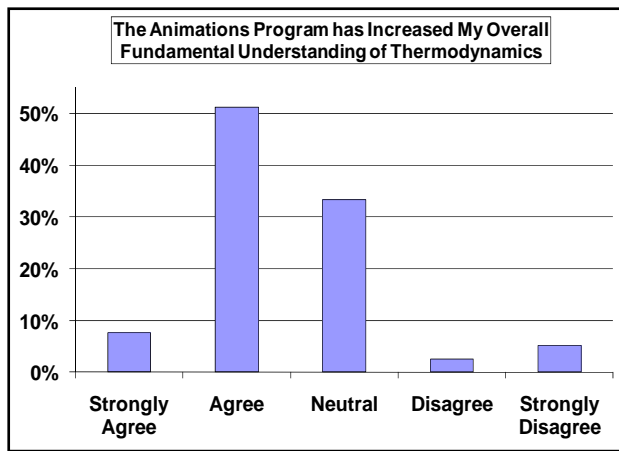


Figure 7 Student Survey: Software Increased Overall Understanding of Thermodynamics.

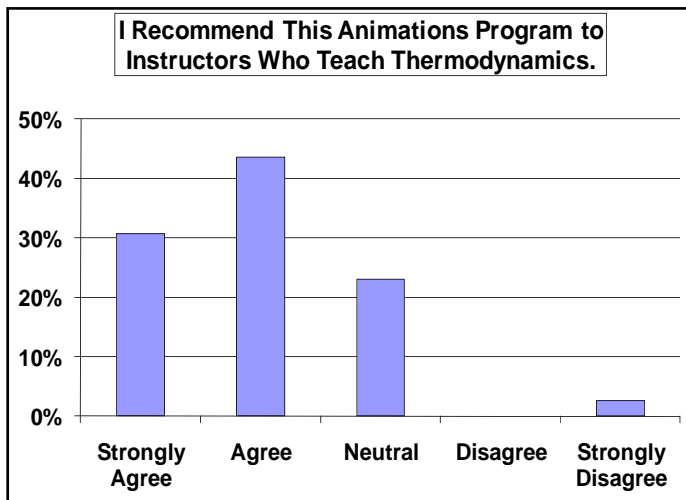


Figure 8. Student Survey: Percent of Students Who Recommend the Animation Software to Professors.

According to Figures 6-8, ~55% to 65% of students think that the animations increased their understanding of *Thermodynamics*, ~25% to 35% are neutral, and between 10% and 15% do not believe that the animations were useful. The students were only exposed to a single animation, and not a series of them. It is the authors' opinion that exposure to more various *Thermodynamics* animation types would increase their opinion that the animation program is beneficial.

Survey Results: General Opinions

According to the survey, over 93% of students consider themselves as visual learners. They

also think that the software is easy to use and believe that linking the animation to a homework problem is an effective way to use the software. This is in agreement with the previous surveys of students who used the software in *Dynamics*[7,8,9,10,11,12].

About 75% of the students surveyed recommend the animation program to instructors who teach *Thermodynamics*, while about 23% are neutral (Figure 8). In contrast to this, 95% of students who used the software for *Dynamics* recommend the software to *Dynamics* professors[7,8]. There may be a couple of reasons for this considerable difference.

- 1) The *Dynamics* software was used throughout the term and covered many *Dynamics* concepts, so the students had time to absorb the usefulness of the software. The *Thermodynamics* students were only given a single problem at the end of the term, so their exposure to the possibilities of the software was quite limited.
- 2) The subject of *Dynamics* is “dynamic” in nature, so animations will naturally enhance a student’s understanding of the material. Although it is envisioned by the authors that many *Thermodynamics* principles can be better understood via the animations program, the students who claimed that they were “neutral” may not have shared the same insight as the authors.

It is the opinion of the authors that most *Thermodynamics* fundamentals can be integrated into an animation in some way. Even a steady state, steady flow problem can be visually illustrated via simple streamlines that can illustrate the movement of the gas or liquid.

Additional Software Features

The animation program has the following additional features available, some of which have been explained in previous papers:

- 1) Sound effects can be incorporated into the program.
- 2) Realistic clip-art and backgrounds can be included as part of the animation.
- 3) The problem statement can contain pseudo-random variables, which are seamlessly passed into the animation[9,10].
- 4) The user may download tab-delimited data of time-based and/or perform parametric studies of any of the INPUT or OUTPUT variables. Graphs can then be automatically generated and formatted via an EXCEL Visual Basic Applications (VBA) macro.
- 5) The user can add or subtract various OUTPUT variables, as desired[7,8].

Additional *Thermodynamics* Problem Types

The following is a partial list of some of the *Thermodynamics* principles that can be augmented by animation software:

- 1) Refrigeration and Heat Pump Cycles
- 2) Constant Volume Processes
- 3) Property Evaluation via a Constant Volume Process, or Other Processes
- 4) General Piston/Cylinder Processes
- 5) Steady State and Transient Mass Balances
- 6) Nozzels and Diffusers
- 7) Turbines
- 8) Compressors and Pumps
- 9) Heat Exchangers
- 10) Throttling Devices
- 11) The Integration of Entropy and the 2nd Law into Thermodynamic Power Cycles
- 12) Refrigeration and Heat Pump Cycle Performance
- 13) Irreversibility and Efficiency
- 14) The Carnot Cycle
- 15) The Otto, Diesel, Brayton, etc. Cycles

Conclusions

The basic functions of the animation program have been explained in this paper, along with an example of how the software can be used. The results of anonymous student surveys show that

most students consider it is a valuable tool in the teaching of *Thermodynamics*.

The *Thermodynamics* animation software is currently at the conceptual level. This publication represents the results of a single problem solved by students at the end of a term. Many software enhancements and additional problem types are foreseen to be included in the software package as it is developed.

The following are some additional conclusions about the animation program for *Thermodynamics*:

- The transient nature of *Thermodynamics* concepts, which may difficult to explain on the blackboard, can be better understood when viewed in the animation program.
- Although most students agree that the software enhanced their understanding of *Thermodynamics* principles, it is believed that the vast majority of students will receive benefit from the software once it matures past the conceptual level.
- Most students recommend the software to professors who teach the subject of *Thermodynamics*.

Future Considerations

- 1) Studies will be conducted with peer institutions and/or separate groups of students that objectively measure the student's performance with and without the use of the software.
- 2) At the request of a Kettering University student, a "legend" key will be added to the blank area just to the right of the animation (under the "ZOOM" button). This legend will give the user quick hints regarding the software functionality.
- 3) "Hints" will be added to the problem statement. These hints will be intended to help the student solve the problem. The professor will have the ability to limit the access to these hints, if desired.

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Biographical Information

Dr. Richard Stanley has been a faculty member of the Mechanical Engineering Department at Kettering University (Flint, MI) since July of 1999, where he holds the rank of Associate Professor. He earned his BSME from The University of Michigan in 1990, his MSME from Wayne State University in 1996, and his Ph.D. from Wayne State University in 1998. His primary interest is to develop web-based internet animation software, which can be used to enhance the engineering student's understanding of mechanics principles. He is also the karate and jiu-jitsu instructor at Kettering University, where he incorporates many of the martial arts principles and methods in the classroom.

Professor Gianfranco DiGiuseppe joined Kettering University in 2005 and now teaches in the Mechanical Engineering Department. His teaching interests are in Thermodynamics, Fluid Dynamics, Heat Transfer, and fuel cell courses. His research interests are in fuel cells and batteries with an emphasis on Solid Oxide Fuel Cells with over 15 years of experience. He is responsible for Kettering's Solid Oxide Fuel Cell research facility and is focused on research related to improved cell durability, improved thermal management, geometric optimization for increased power density, and to develop more robust cell designs that are less sensitive to operating environments.