Interactive Simulations combined with Screencasts and ConcepTests

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Introduction/Project Overview

We propose to prepare interactive *Mathematica* simulations that focus on important concepts for chemical engineering thermodynamics, a junior-level course that will have a total enrollment (2 sections) in fall 2015 of about 190 students. These simulations will be incorporated into ConcepTests that will be used in class with clickers and peer instruction. The simulations will also be posted on our web site, and short screencasts that describe the simulations and how to use them will be prepared so students can use the simulations on their own. We hypothesize that integrating interactive simulations into ConcepTests and providing screencasts to help students use the simulations will improve understanding of the important concepts in thermodynamics. Each simulation and its accompanying screencast will be posted on a separate web page so a student can use a simulation while simultaneously playing the screencast. If our assessment indicates that this approach is successful, we plan to extend it to other chemical engineering courses (and courses in other engineering departments), and this initial effort would provide a strong base for obtaining outside funding.

ConcepTests and peer instruction have been shown to significantly improve student learning of concepts [1-7]. We have used this approach in chemical engineering thermodynamics since 2002, and we have prepared more than 500 ConcepTests for this course. We have prepared screencasts for chemical engineering courses, starting in 2009, and the student response has been overwhelmingly positive as indicated by anonymous comments from end-of-the-semester feedback: "Screencasts are fantastic", "Screencasts are amazing", "I love screencasts", "I think screencasts were unbelievably effective".

More recently, we started preparing interactive *Mathematica* simulations and introduced a few of them into the thermodynamics course in fall 2014. On the anonymous feedback collected as the last assignment in the fall semester, students were asked about the simulations. The student response was positive: 77% of students on an anonymous feedback form thought they were useful including comments like: "The interactive simulations were the best thing that I could even imagine", "The interactive simulations are incredibly useful", and "Really liked the simulations. You should use more of these". Many of the remaining students though they were useful, but indicated that they sometimes had trouble knowing how to use them, and thus we think that short screencasts that help students use the simulations will allow students to more readily use them on their own.

The proposed simulations will be prepared using *Mathematica* because it has built-in functions to make simulations interactive, and the resulting simulations can be saved in a format that does not require a *Mathematica* license. These simulation will focus on concepts that students struggle with and on diagrams that are used extensively in the course. System parameters will be changed with sliders or buttons (not by typing values into the program), and the output will be plots, bar graphs, and/or animated visual representations. The objective is to make the simulations easy for students to use on their own. One key feature of these simulations is that the calculations are done in real-time as input parameters are manipulated through user-friendly controls, and the graphical output appears almost instantaneously.

Background/Literature Review

An effective method to demonstrate complex system behavior to students is to use interactive simulations[1], which allow the user to manipulate parameters and receive instant feedback on how these changes affect the system. Podolefsky et al. showed that they promote self-directed inquiry and exploration.[9] They essentially allow students to conduct experiments that otherwise are not practical because of expense and time scales. Students can slow down or speed up processes so they can observe behavior that would be hard to observe in real time[8]. Interactive simulations have been used extensively in physics education [10,11] and more than 130 PhET simulations (phet.colorado.edu) have been developed in the Physics Department at CU. As pointed out by Wieman et al.[10], students using one of the PhET simulations for a two-hour exercise had higher mastery of the concepts than students who did a laboratory exercise. In another example they found that 80% of students mastered a concept using a simulation in a quantum course, whereas only 20% mastered the concept in a course with traditional instruction. They found that when something unexpected was observed in a simulation, students question their understanding, and this motivated them to change parameters and observe how the simulation behaves. Other students have also shown that students' interactions with simulations have positive effects on learning.[12-14]

Discovery learning follows the same steps as scientific reasoning, and simulations based on discovery learning have the potential for a high impact on student learning.[15] In interactive simulations, students get immediate feedback when they change a parameter and they can experiment. However, some students may have difficulties evaluating simulation results and using the simulation systematically.[16] Creating short screencasts that demonstrate how to use the simulations can improve their effectiveness. Rieber et al. showed that students who were given interactive simulations with short explanation videos scored better than students who were given just interactive simulations.[15] Furthermore, Bodemer et al. showed that by first studying static representations followed by exploring dynamic visual simulations, student performance and understanding improved.[16] Because users manipulate the simulation at their own speed, fewer demands are placed on the user's working memory and students can focus on understanding.[17]

Study Design and Methods

We propose to prepare 10-15 interactive simulations, the same number of screencasts describing them, and 30 or more ConcepTests that use these simulations. The proposed simulations will be prepared using *Mathematica* because *Mathematica*-based interactive simulations have many of the advantages that have been demonstrated for the PhET simulations: encouraging scientific inquiry, showing visual models, presenting multiple representations, giving users guidance, and providing interactivity. However, they are less expensive to prepare than the more-sophisticated PhET simulations. A single PhET simulation can take several months to make[2] and each one costs about $60,000. The much smaller number of students taking chemical engineering courses (compared to basic physics and chemistry courses) means that a more cost-effective approach is needed for engineering simulations.

These proposed simulations will demonstrate a concept or explain how to use a diagram. They solve equations that model a system and present the results in animated graphics, plots of dependent variables versus independent variables, bar graphs, and/or simple representation of physical systems. Numerical values of parameter are changed with sliders (instead of typing numbers into the simulation), and in some cases parameters are changed by selecting buttons. Different displays (different plots or a plot versus a physical representation) are selected with buttons also. The goal is to make simulations that are easy to use and focused on one concept.

Sliders and buttons are created in *Mathematica* with simple commands. An example of an interactive *Mathematica* simulation that we created for chemical engineering thermodynamics is shown in Figure 1. The temperature versus mole fraction graph represents vapor-liquid-liquid equilibrium for a binary system in which the two liquids are only partially-miscible. The black dot represents the current state of the system, and its location can be changed by changing the mole-fraction slider or the heat-added slider. The phases and their relative amounts that exist at equilibrium at the conditions of the black dot are shown in the bar graph on the right. Because the amounts of phases present can change by adding heat, without the temperature changing and thus without the black dot changing location, understanding these diagrams can be difficult for students. The simulation allows the user to readily see which phases exist at a given condition.

A second example of a simulation prepared for thermodynamics is the refrigeration cycle in Figure 2. The cycle is shown in a pressure-enthalpy diagram on the left, and as the upper and lower pressures are changed with sliders, the cycle diagram is redrawn, and a new coefficient of performance is calculated.

Clicking on the button on top right of this this simulation displays a temperature-entropy diagram for the same cycle. The pull-down menu in the upper left corner displays a schematic of the cycle, as shown on the right of Figure 2. This simulation allows students to better understand how the pressures chosen for system operation affect the overall performance.

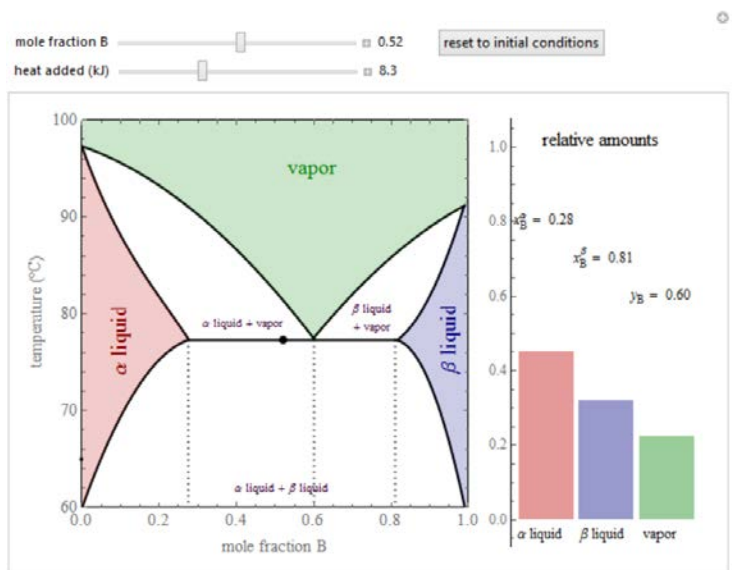

Figure 1: Interactive simulation for vapor-liquid-liquid phase equilibrium. http://demonstrations.wolfram.com/VaporLiquidLiquidEquilibriumVLLE/

We propose to prepare additional simulations for thermodynamics so that all the important concepts are represented in interactive simulations. We also propose to prepare short (2-4 minute) screencasts that describe how to use each interactive simulation. The screencasts will be prepared using Camtasia software and processed to remove dead times and also to check for errors. Each screencast and its corresponding simulation will be posted together on a separate web page, so that the screencast can play at the same time that the simulations runs. The simulations will be introduced in the course by preparing multiple ConcepTests for each simulation. A graphic from the simulation will be incorporated into the ConcepTest, as shown in the example in Figure 3. This ConcepTest utilizes a simulation that we prepared on unstedy-state energy balances. This ConcepTest would be presented in class, and students would be required answer on their own with clickers. They would then discuss the question with their neighbors (peer instruction) and they would be allowed to change their answer. A class-wide discussion would follow where student would explain why they believe their answer is correct and why other answers are wrong. The simulation would then be shown in class and the sliders manipulated to represent different conditions to better explain the system

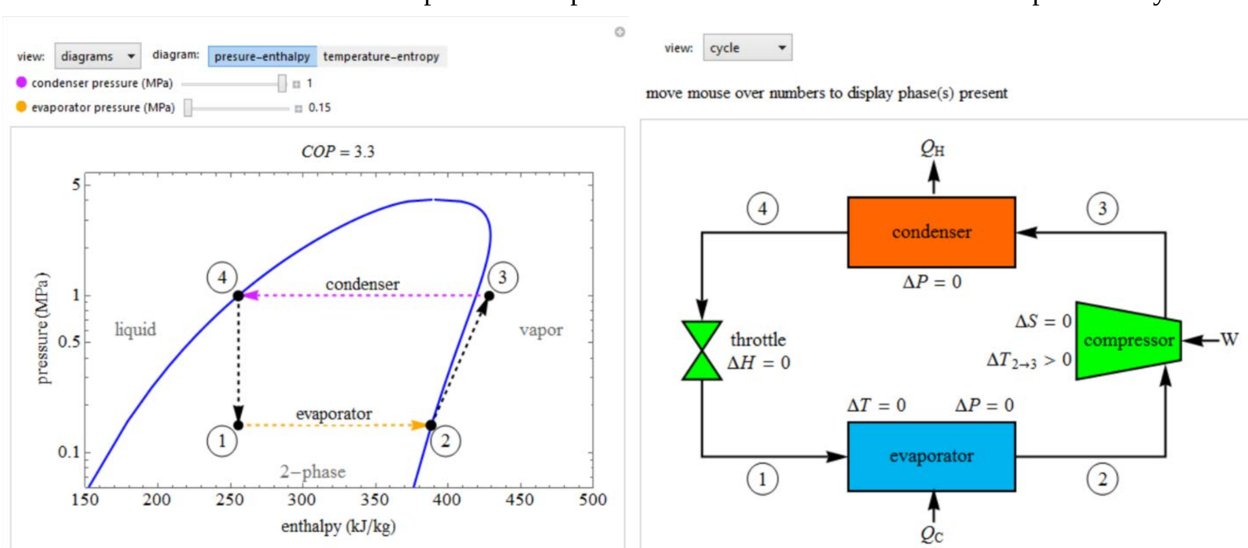

Figure 2: Interactive simulation for vapor compression cycle. This simulation is located at: http://demonstrations.wolfram.com/OrdinaryVaporCompressionOVCCycleForRefrigerantR134a/

behavior. Links to the simulation and accompanying screencast would be provided on D2L so student can use them on their own.

Consider superheated steam flowing through a pipe at 200°C and 10 bar pressure (the saturation temperature at 10 bar is 180°C). When the a valve is opened to an insulated tank that contains a vapor-liquid mixture of water at 4 bar and 144°C, which is the most likely temperature when the tank pressure reaches 10 bar?

A. 144°C

B. 172°C

C. 180°C

D. 200°C

> 200°C

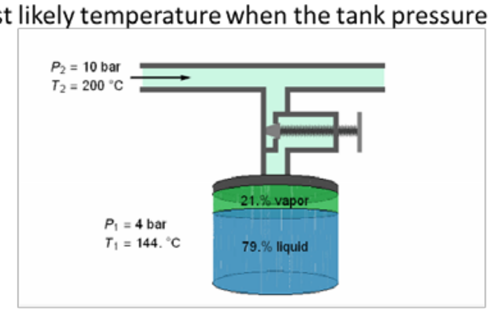

Figure 3: Thermodynamics ConcepTest for unsteady energy balance

Assessment

Assessing the effectiveness of the combined ConcepTests/interactive simulations/screencasts will be done by comparing student performance on conceptual questions on the final exam. The objective will be to determine if student performance improves when interactive simulations and screencasts are added to ConcepTests. Since this course was taught using ConcepTests and clickers in fall 2014, comparisons will be made to student performance on the conceptual questions on the fall 2014 final exam. The conceptual question were about 40% of the total exam points. The student solutions to this exam were saved. The average performance on each question will be calculated and then compared to student performance on conceptual questions for the fall 2015 course. Student performance on questions on the same concept, with and without interactive simulations, can be compared to determine if the simulations increased student understanding. The conceptual questions on the exam are not multiple choice, but are short answer and thus provide a good measure of student understanding. Although this comparison is not an extensive assessment, it should provide an indication of the value of the interactive simulations, and with the limited budget, it is the only realistic assessment possible.

Timeline

The interactive simulations and screencasts will be prepared during the summer so they are complete at the start of the fall semester and can be used in the chemical engineering thermodynamics course. The ConcepTests will be prepared during the summer and fall and incorporated, along with the simulations, into the class. Student performance on conceptual exam questions will be evaluated during the fall semester after each of the two exams and the final. The analysis of student performance will be compared to the fall 2014 semester in the spring semester, 2016 and a report will be prepared at that time.

Outcome/Impacts

The objective of ConcepTests that utilize interactive simulations and the corresponding screencasts is to actively engage students in their learning. The ConcepTests in class utilize peer instruction, and after student predict the behavior, the interactive simulation will be shown in class. The simulations are more general than just the specific ConcepTest, and students will be able to watch the simulations on their own schedule, using the corresponding screencasts to help them utilize the simulations effectively. If this approach improves student understanding of important concepts in thermodynamics, it can be extended to other courses in chemical engineering and other engineering majors, and we would submit proposals to outside agencies for funding.

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Budget Justification

The interactive Mathematica simulations will be programmed by Rachael Baumann, who graduated in chemical engineering from CU last year and has been developing interactive simulations. She is an experienced Mathematica programmer who had been funded partially by an NSF grant and partially by some unrestricted funds that Professor Falconer has. However, to continue to pay her so that this proposed project could be carried out to completion, funds are needed for her salary. She would develop the simulations during the summer 2015. Katherine McDanel is supported by an NSF grant to develop screencasts for chemical engineering courses. She has a Master's degree in chemical engineering and has processed screencasts and ConcepTests for the last two years. She would devote part of her time during the summer processing the screencasts (removing mistakes and deadtimes, checking for accurcy and clarity, adding annotations, converting to MP4 format, adding to YouTube, creating links from our website to the Youtube screencast, and embedding the Mathematica simulations into web pages)

Budget

Rachael Baumann, research associate	100% time, 3 months summer	$7,500
Katherine McDanel, research associate	25% time, 3 months summer	$2,500
Total		$10,000