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Data Analytics for Interactive Virtual Laboratories

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Data Analytics for Interactive Virtual Laboratories

Introduction

We have previously described the development and implementation of a set of *Interactive Virtual Laboratories* (IVLs) in thermodynamics.[1] Each *IVL* provides a set of activities to address targeted threshold concepts[2] via actively engaging students in a series of actions. The IVLs provide a less abstract and more intuitive access to students by providing a dynamic representation of phenomena at a molecular level. Students are expected to answer numerical questions and, when prompted, predict and explain the effects of macroscopic changes (i.e., pressure, temperature, composition, energy) based on observations of molecular phenonmena. Six IVLs are currently available for public use through the *AIChE Concept Warehouse*.

Through this study, we seek to explore ways to use gathered data from student answers to understand learning, supply formative feedback, and provide accountability. The study contains two parts. First, we audio recorded 10 students as they worked through one of two IVLs in an attempt to examine student thinking processes and determine rationale that commonly leads students to submit wrong answers. Second, we implemented the two IVLs in a large, junior level thermodynamics course. All responses were recorded and stored in the *AIChE Concept Warehouse*. In this paper we argue (and will show evidence) that sometimes even though the final answer was not normatively correct, there are still productive thought process behind the answers. One ancillary benefit of this study includes the development and implementation of an automatic grading system for the IVLs. Further improvements that were made to the IVLs are also described.

Background

It is commonly known that many students struggle to learn thermodynamics. Research studies confirm that key concepts of thermodynamics are commonly misunderstood because students develop non-scientific ways of thinking about things such as heat and work before they are introduced to these concepts in a classroom setting.[3-5] For example, van Roon, Sprang, and Verdonk[3] completed a three year study that examined freshmen chemistry students' understanding of heat and work in the context of thermodynamics. Students in this study often identified heat as a state function instead of a path function and routinely tried to conserve it using the First Law.[3] Because thermodynamic concepts are commonly misunderstood, there is a demand for ways to improve student learning. One such method of improvement over traditional lectures is active learning.

Students engage in chemistry and biology laboratories early in their science studies. Specifically, laboratories can promote inquiry-based learning where students engage in meaning making by solving problems, answering questions, or interacting with phenomena instead of didactically being presented with a concept to learn. Numerous studies demonstrate the efficacy of inquiry-based learning in science courses.[6-8] There has also been considerable research that ascertains students learn better with simulations than they do in traditional lectures.[9-11] Stieff and Wilensky[11] implemented computer simulations in undergraduate chemistry courses and interviewed students regarding their interactions with the software. According to their results, "all students took on increasingly more conceptual approaches to solving problems." [9,11]

There is also evidence that students perform better when a virtual laboratory (computer simulation) is used to supplement other learning.[12,13] For example, Zacharia, Olympiou, and Papaevripidou[12] implemented simulations in the form of “virtual manipulatives,” in an undergraduate physics course. The participants of the study were randomly assigned into two groups; one group used only physical manipulatives while the other group used physical manipulatives followed by virtual manipulatives. Conceptual tests that were administered before, during, and after the study showed that using both manipulatives in sequence improved the students’ conceptual understanding more so than using the physical manipulatives alone.[12] Virtual laboratories are also more flexible than physical laboratories and allow visual representations of phenomena not accessible in a physical laboratory – such as on the molecular scale.

The *Interactive Virtual Laboratories* used in this study were designed to help students master “threshold concepts” in thermodynamics.[1] According to Meyer and Land[2], there are four characteristics of a threshold concept: troublesome, transformative, irreversible, and integrative.[2] Troublesome refers to the difficulty of the concept and the fact that students often struggle with it. Transformative means it alters the way students approach the discipline and related knowledge. A threshold concept is irreversible in the sense that once students correctly understand it they will not return to the more simplistic or uninformed view that they held earlier. Integrative refers to how understanding a threshold concept allows students to make previously unseen connections between aspects of the course.

IVL Overview. The IVLs were constructed based on this active learning pedagogy and directed towards undergraduate thermodynamics students.[1] In the IVLs, students are guided through a set of *frames* where they are asked to respond to questions that ask them to predict, calculate, manipulate, observe, or reflect on phenomena related to the specific concept.

Figure 1 presents an example frame of the Work IVL, one of the six available IVLs. This frame includes the three main parts of a typical IVL frame, (i) a box containing the molecular simulation that students are asked with manipulating in certain ways - in this IVL, students place a block on a piston and observe as the system of gas molecules is compressed; (ii) a macroscopic, graphical representation of the simulated phenomena (located to the right of the molecular simulation) – the two graphs in Figure 1 allow students to check their answers they submitted on previous frames; and (iii) a box to read instructions and provide answers to questions (below the molecular simulation).

Each IVL begins with questions asking students to explain or define the threshold concept that the IVL targets. The students then predict what will happen when the system undergoes a process, such as supplying work. After students complete their calculations they interact with a simulation to see if their predictions are correct. Once students observe the simulation they are asked to explain how the results compare to their predictions. This pattern is progressively repeated until the end where students are prompted to reflect on the content of the lab and asked to define the threshold concept again.

There are a total of six *Interactive Virtual Laboratories* available on the *AIChE Concept Warehouse* and we focused on two IVLs for this study. We used the “Work Simulation” and the

"Heat Capacity Simulation." The Work IVL focuses on pressure-volume (Pv) work as an energy transfer process and covers the threshold concept of how pressure-volume work adds energy to a system. The Heat Capacity IVL examines the definition of heat capacity and the threshold concept for this lab is the difference between constant volume heat capacity and constant pressure heat capacity. Previous papers describe the development and implementation of the IVLs in more detail.[1]

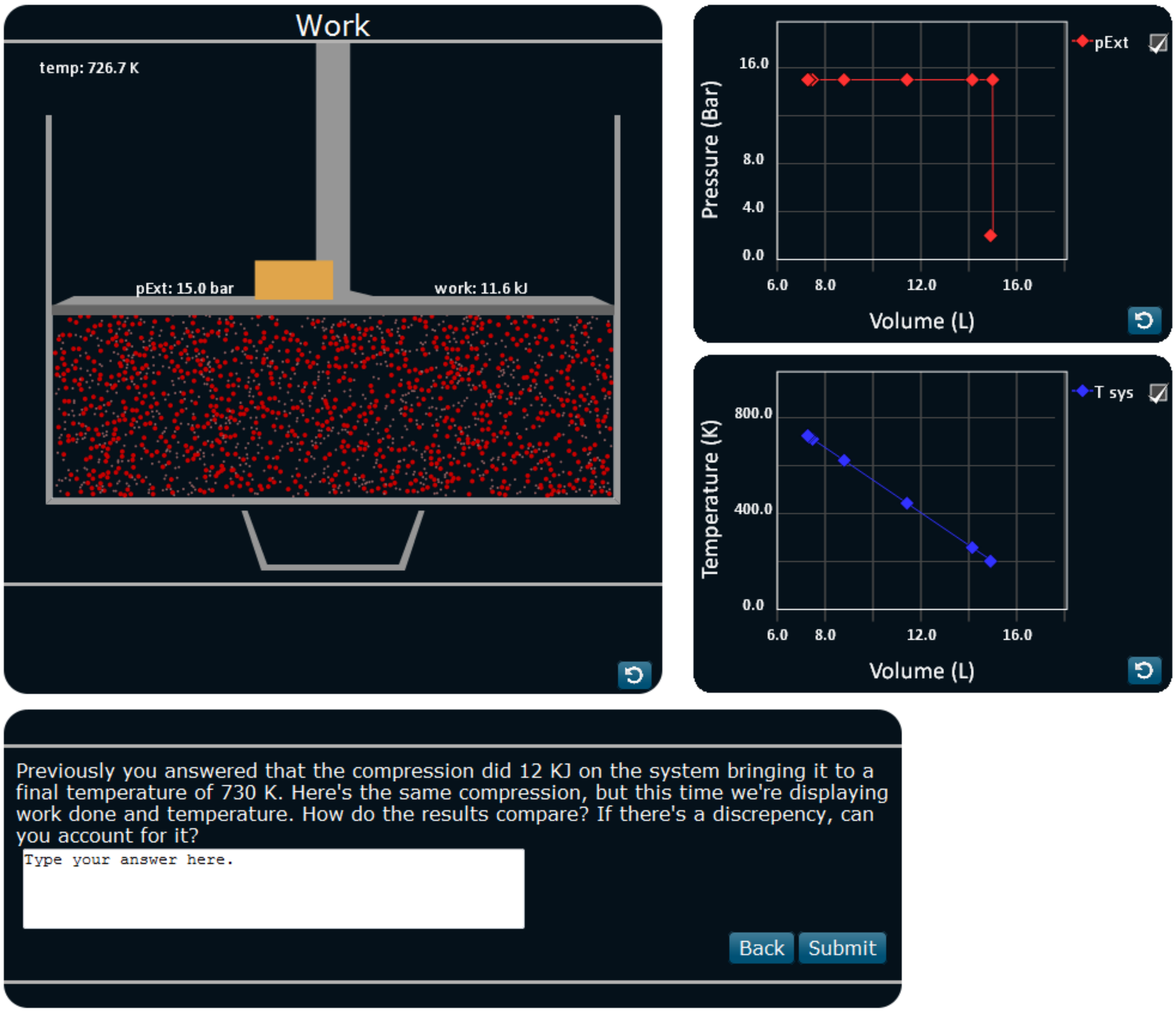

Figure 1. Sample frame from Work IVL

Methods

Participants. Participants in this study were enrolled in a junior-level engineering course titled "Thermodynamics" at a large, public university in the Northwestern United States. A total of 241 chemical, environmental, and biological engineering students participated. This is a required course for each of the three programs; main topics covered in the course include the first and second laws of thermodynamics, entropy, equations of state, and the thermodynamic web[14].

Context. The course consisted of two 50 minute, instructor-led lecture sessions on Mondays and Wednesdays as well as two 50 minute, graduate-student-facilitated studio sessions on Tuesdays and Thursdays. There were six different studio sections with an average of 40 students in each section. The lectures were used to introduce content whereas the studios allowed the students to apply what they learned in lecture to practice problems via an inquiry-based worksheet. The Heat Capacity was assigned during studio and therefore students completed it in groups. The Work IVL was assigned as homework and the students completed it individually.

Data collection. Based on the total number of students enrolled in the class and the number of questions in each IVL, slightly more than 7,000 student responses were collected.
In addition to the student responses from the general class implementation, 10 students agreed to be audio recorded as they completed the IVL using a think-aloud protocol. Data are only reported for students who agreed to participate and signed an informed consent form approved by the Institutional Review Board. The recordings were transcribed and each student participant was given a pseudonym to protect their identity.

For each of the three assigned IVLs, we collected two sets of responses. One response represented a stronger performing team and the other a weaker performing team; these designations were based on the answers the teams provided to the procedural questions. The stronger performing teams answered more procedural questions correctly than the weaker performing team did. An overview of the recording data we obtained is provided in Table 1.

Table 1. Recording data overview

IVL	Type of recording	Sets of responses	Total student participants
Work	Individual	2	2
Heat Capacity	Group	2	8

We did not provide specific conceptual prompts to the groups during data collection. Instead, we asked students to think aloud and talk with their group members like they would during a normal studio session. Because we recorded individuals working through the Work IVL, we occasionally asked them to explain why they used certain equations or how they got an answer if they did not elaborate on their own. Essentially, we played the role of a confused group member to better understand their thinking processes when they were not clear or explicit.

Data analysis. As part of our analysis on student answers to questions in the IVLs, we coded each question in the lab into one of four categories according to what type of thinking each question elicited: procedural, conceptual, prediction, and reflection.[15] Table 2 contains a brief explanation of the codes.

The codes allowed us to get an overview of what types of questions each lab asked. It also allowed for an easier comparison and analysis on student responses to a group of questions of a same type. Table 3 details the coding breakdown and total question count of each IVL.

We examined the transcripts of the audio recordings and identified the student thinking processes that led them to the answers they input in the IVLs. We especially tried to recognize (1) common misconceptions that led students to common wrong numerical answers of procedural questions; (2) productive discussion in conceptual questions regardless of whether answers to procedural

Table 2. IVL question coding descriptions

Thinking Elicited	
Procedural	Elicit computation or numerical graphical interpretation. The answers are typically numerical.
Conceptual	Elicit students' conceptual interpretation of data or information in order to explain complex phenomena. The answers are typically in text.
Prediction	Elicit students' anticipation about what will happen if they make a change to the system. The answers can be a mixture of text and number.
Reflection	Elicit student thinking back to previous problems and comparing how results differ due to changes. The answers can be a mixture of text and number.

Table 3. IVL question coding count

	Work	Heat Capacity
Procedural	9	3
Conceptual	6	4
Reflection	3	5
Prediction	0	1
Question Total	18	13

questions were accurate; and (3) reasoning that was canonical and also led students to arrive at the correct answers to procedural questions. For each incorrect procedural question that the groups or individuals submitted, we determined how the answer was reached and whether or not it was the result of a misconception or a calculation error. This analysis provided us a spectrum of student thinking and responses, in continuum, from wrong-answers with wrong-reasoning, to partially-correct reasoning, to correct-answers with correct-reasoning.

Results

In this section we present cases of students working through the Work and Heat Capacity IVLs. For each case, we include a detailed comparison of the student thinking processes as the individuals, or groups, worked through both a procedural and a conceptual question.

Work: Conceptual Questions. We recorded two individuals as they completed the Work IVL. An example of a conceptual question from the Work IVL is shown in Figure 2. The figure shows the third frame (out of total 18 frames) in the IVL.

Before this conceptual question students had answered two multiple choice conceptual questions. The first question asked the students to select an equation that best represented the work done in an adiabatic system. It included a problem statement with information about the system, 4 possible answer choices, and a diagram of the system to the right of the question. The correct answer choice states, in a symbolic format, that work (W) equals the product of minus external pressure (-P) and change in volume (ΔV). The question on the second frame presented students with several different versions of the First Law of Thermodynamics and asked students to choose which one correctly described the adiabatic system. The question contained a problem statement with relevant equations, 4 possible answer choices, and the same diagram as the first frame. The correct answer choice was n c_v ΔT=-P(external)ΔV, which indicates the equivalence between the change in internal energy and the work done (because no heat was transferred). Students could not progress to the third frame until they correctly answered both multiple choice questions in the first two frames. Both students (Gerry and Lucy) answered the questions correctly and moved on with Frame 3.

Figure 2. Conceptual question from Work IVL

The question on Frame 3 (shown in Figure 2) continued with the question students had chosen in Frame 2. Students were asked to manipulate a horizontal movable wall on top of the container and observe the change in the speed of a gas molecule in the container. They were then prompted to explain why this event would cause a temperature change in a system with numerous molecules. When responding to the question shown in Figure 2, Gerry thought out loud and made clear connections between what she observed in the simulation and the information included in the problem statement:

> **Gerry:** I think by changing the volume I can see the speed is changing in the simulation. Which means molecules' kinetic energy is changing and from this problem kinetic energy change will lead to temperature change so it makes sense that delta V is related to delta T.

Gerry then typed her answer to the question on the frame: "Volume change leads molecule's speed changes which leads temperature change." Gerry did not relate the increase in molecular speed to the molecule colliding with the moving wall; instead, she describes the overall volume change as the reason the kinetic energy increases. It appears that Gerry based her answer on observation but did not explicitly infer the cause, unlike Lucy.

In the audio recording, student Lucy talked about the idea of transferring momentum to the molecule from the moving wall:

> **Lucy:** Um, temperature is a measure of average kinetic energy… by transferring momentum from the wall to the molecules you speed them up, causing the temperature of system to increase.

Lucy was typing into the answer box while she was talking: "A transfer in momentum from the wall to the 'molecule.' Temp is a measure of average kinetic energy. By transferring momentum from the wall to the molecules, you speed them up causing the temp of the sys to increase."

Both students linked an increase in the molecule's speed to an increase in its kinetic energy, which would result in an increase in temperature. Lucy's response was consistent with the canonical explanation and both her reasoning and answer were considered correct when we coded them. Gerry did not directly associate the increased speed of the molecule to the collision between the molecule and the wall; therefore, we considered her reasoning and answer as partially-correct.

Work: Procedural Questions. After the students completed the conceptual question shown in Frame 3, they ran a simulation in which they virtually dropped a block onto a piston and observed the piston compress a system of many molecules. They answered two conceptual questions in Frame 5 relating to this simulation before they reached their first procedural question in Frame 6 (Frame 4 has no question. It is the explanation of previous simulation). For the question in Frame 6 (shown in Figure 3), students were also given a graph that displayed the changes in volume and pressure as the system is compressed. Students were prompted to calculate how much work the piston and the block did on the system. Both students recognized they needed to use the information in the graph to the right of the simulation. However, two different errors caused Gerry to submit the wrong answer:

> **Gerry:** This is insulated which means Q is zero. So, 'calculate the amount of work that the piston and block did on the system'. So as I can see in PV graph, this is [an] irreversible process, so the area under the PV curve will be the work that the piston did on the system. Since [the] system got the work, work will be a positive number. So I can just simply get the area under the curve which would be, I don't know, 15 times 15? So 225 approximately.

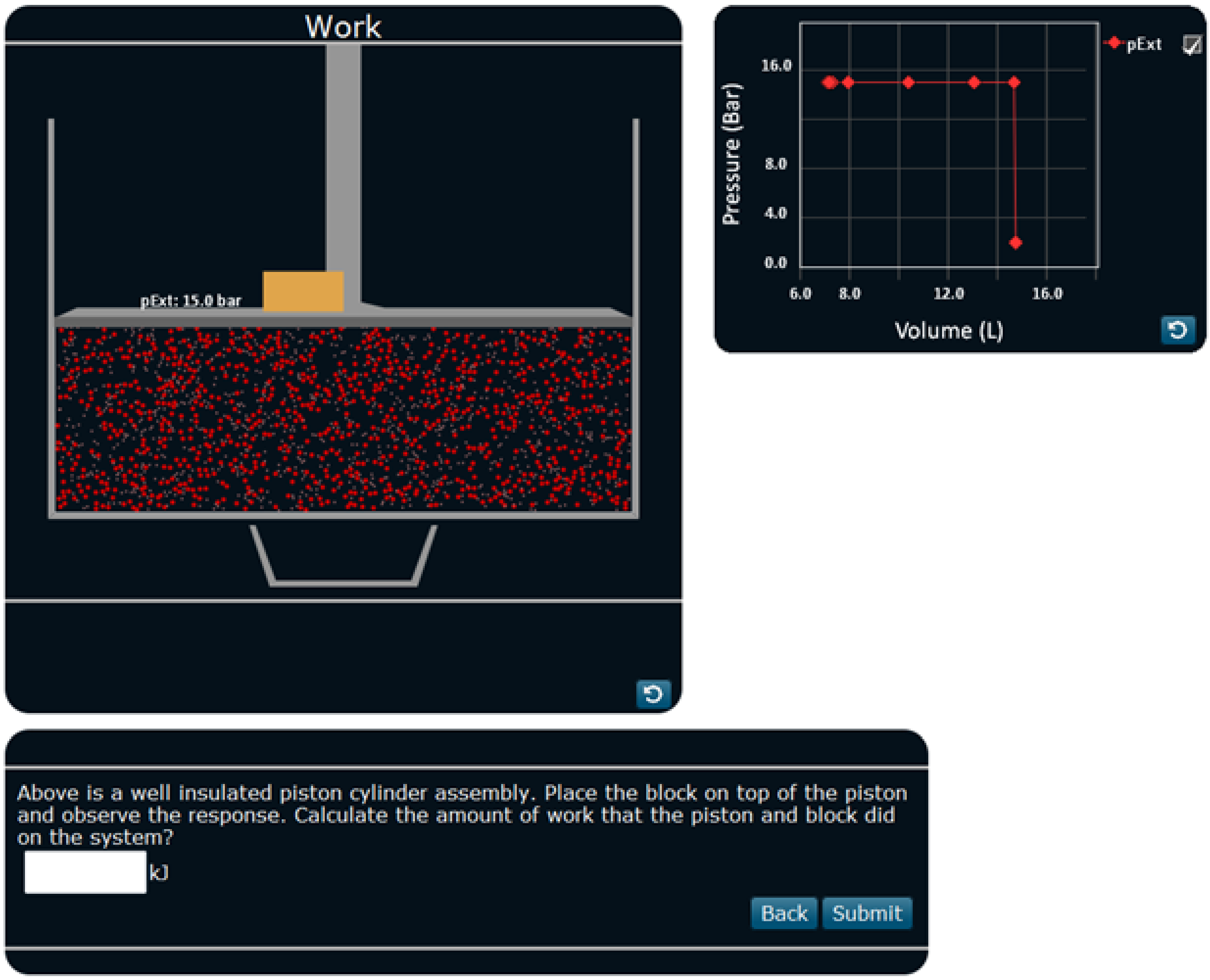

Figure 3. Procedural question from Work IVL

Gerry was correct that it is an irreversible process and that work is equal to pressure times the change in volume, but when she was getting these values from the graph she neglected to recognize that the volume axis did not start at zero. Therefore, she used the wrong value for her volume change. She also did not pay attention to units when she calculated for work.

By reading the graph more closely and converting her units, Lucy submitted the correct answer:

> **Lucy:** So I at first, I know that work is pressure times the change in volume and so on this little graph over here I see just that, except it's confusing because I don't know the volume change so I have to look at this graph to observe the volume change… All right, so about negative—minus 8 liters, so that's the change in volume I got, so that divided by 1,000 gives me meters cubed…15 bar, 15 e to the 5^{th}, times 0.008, and it was negative, too, but then negative and a negative makes a positive because energy is being done on me, the system, divided by 1,000 to get me in kilojoules, because I think you're going to ask for kilojoules. I hope this is right but it could be wrong. I'm going to say it's around 15- 12, I'm going to say it's around 12.

The individuals that worked through the Work IVL represent two different cases; responses from Lucy represent correct answers with correct reasoning for both the conceptual and procedural questions, whereas responses from Gerry represent partially-correct answer and partially-correct reasoning for the conceptual question and wrong answer with partially-correct reasoning for the procedural question. Although Gerry used the appropriate equation in her procedural calculation, she did not account for her units nor did she correctly read the graph when gathering values to use in her equation. This mistake represents procedural errors instead of a misconception.

Heat Capacity: Conceptual Questions. For the Heat Capacity IVL, Group 1 was the weaker performing group and Group 2 was the stronger performing group according to the scores they received in the on procedural questions. Although Group 1 answered the majority of the procedural questions inaccurately, they still answered the conceptual questions correctly. A conceptual question that highlights the threshold concept of the Heat Capacity IVL is shown in Figure 4.

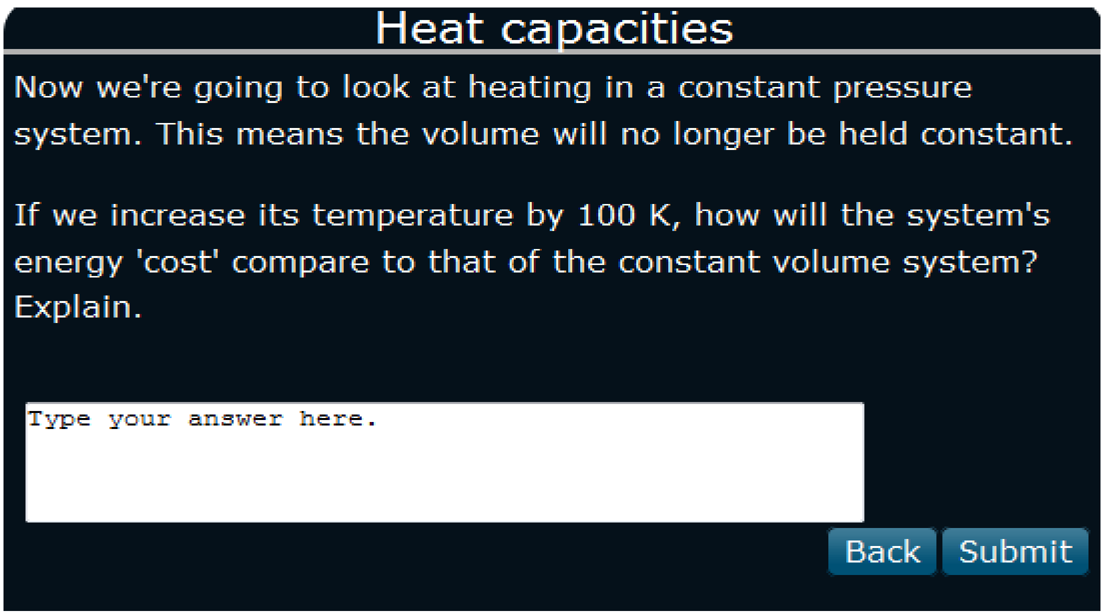

Figure 4. Conceptual question from Heat Capacity IVL

Figure 4 shows the screenshot of Frame 4 out of 10 total frames in the Heat Capacity IVL. In Frame 4 students were asked a conceptual question about *constant pressure* heat capacity, c_p. Before students reached this question they worked through previous frames about a *constant volume* system. In the first frame they were asked the question "Using your own words, how would you explain the concept of a heat capacity to a high school senior?" In the second frame they were asked “How much energy should heating this system by 100 K 'cost'?” The system in question contained 0.5 moles of an ideal, monatomic gas of a fixed volume. The third frame contained a simulation where they could pull a slider that simulates the switch of a heater to virtually “heat” a container of gas of a fixed volume (molecules represented by dots moving and bouncing around in the container) until the number on top of the frame that indicates the temperature achieved a 100 degree increase in temperature. This simulation allowed students to test their prediction from the second frame. They were instructed to observe how much energy was being used as they heated the system (the amount of energy used was also shown on top of the frame) and then describe how the total required amount they observed in Frame 3 compared to their predicted value in Frame 2 (more information about the frames are available on *AIChE Concept Warehouse* website).

In Frame 4 that follows, the question (shown in Figure 4) asks students to compare the amount of energy required to increase the temperature of a *constant pressure* system versus the energy required to increase the same degrees of temperature of a *constant volume* system (with which students had worked during the first three frames). Group 1 and Group 2 reached the same conclusion through two different ways of reasoning.

Below is the transcript of student discussion when Group 1 was working on this frame. April and Ben represent two students in this group.

> **April:** So c_p equals c_v plus R. So if we're keeping pressure constant instead of volume then we should require more energy. We need—so we're going to have more energy.
> **Ben:** That makes sense because you're probably also going to do work on the system.
> **April:** Yeah. So, we're putting that, we're going to put: the energy cost is going to be higher because the system has to do work to expand, um, to make the volume expand.

This excerpt shows that April started with the (correct) relationship between the heat capacity of a constant pressure system and the heat capacity of a constant volume system ($c_p = c_v + R$) and determined how the energy requirement varied. This excerpt is also an example of co-construction and shows the benefits of group work. Ben added his understanding of the relationship between the energy cost and the work done (more energy required because work was involved). April, when inputting their response, added the relationship between work and volume (the system has to do work to make the volume expand). April submitted the following written answer: "the energy cost is going to be higher because the system has to do work to make the volume expand." The response that Ben submitted was: "The energy will be higher due to the system requiring to increase the volume." The third student in Group 1, Donna, provided the following written response: "The system's energy cost should be higher than constant volume because the system has to do work to expand." All these showed the students' understandings of the concepts in thermodynamics related to the simulation. It is also interesting to note that it was Ben who brought up the notion of work, but he was the only one in this group who did not include "work" in his submitted answer.

Group 2 discussed the differences of energy requirement between the constant volume system and the constant pressure system in terms of the First Law, although they did not explicitly name it. Below is the transcript of the discussion of Group 2 when they were working on Frame 4. Leslie, Ron, and Chris represent the students in this group.

> **Leslie:** Okay, because for the previous—when we had a constant volume no work was being done. So you just had delta U equals Q. And now you have a –W, or negative work, like overall net work would be negative. Okay, I see what you're saying, because you were saying the energy cost would be higher. Internal energy is being kept constant, because for an ideal gas it only depends on temperature and we're increasing it a certain amount of temperature, right?
> **Ron:** The change in internal energy is the same here as in the last problem, you're saying?
> **Leslie:** Mhmm. And then it's just a matter of how much—
> **Chris:** How much heat you have to apply to get—
> **Leslie:** To get it to the same temperature

The conversation shows that the students know the First Law of Thermodynamics and can relate changes of internal energy (delta U), to heat (Q), and work (W). They also identify the relationship between temperature and internal energy for an ideal gas (that the internal energy of an ideal gas only depends on temperature) and the relationship between the gas's volume and the work done (that if the volume expands, the system has done a negative work). This thought process set the students up to correctly answer the procedural questions they encountered later in the IVL. The actual submitted answers from students in this group are shown in Table 4. The responses were basically consistent with their discussion.

Table 4. Group 2 student responses to the conceptual question in Heat Capacity IVL.

Student	Submitted response
Chris	The energy cost is higher in the constant pressure case because the internal energy given to the system via heat is lost through work. Thus, it will take a longer time to increase the temperature requiring more energy.
Leslie	The energy cost would be higher (i.e. more energy would need to be put into the system in order to reach the same temperature). If the energy cost is being defined as the heat put into the system, it would cost more, because in a constant pressure system the volume would change (expand in this case) and thus work would be done. By doing work, more heat needs to be put in to acheive the same change in internal energy
Ron	I am defining energy cost as heat transferred to the system in order to raise the temperature 100K. In a constant pressure system, the energy cost will be greater than it was in a constant volume system because the system will be doing work on the surroundings throughout the heating process. The work done results in a smaller increase in internal energy per unit of heat transferred.
Tammy	Its an expansion problem, Work is negative, Q is positive, Using nCpdeltaT to calculate work. Constant Volume no work is being done. Using equation deltaU=nCvdeltaT
Ann	The constant pressure system would be more costly. This is because when energy is added to the system the volume expands but this means work has to move the walls of the system. This work energy leaving the system means that for every unit of energy entering the system, some portion will leave as work. In the constant volume situation, no work energy left the system.

Group 1 approached the energy requirement question in Frame 4 by observing the relationship between c_v, or heat capacity of a constant volume system, and c_p, heat capacity of a constant pressure system. They knew that for an ideal monatomic gas $c_p = c_v + R$. Therefore, they determined that because c_p is larger than c_v more energy would be required in the scenario with the constant pressure system. They explained this increased energy requirement from a physical perspective; they thought about what would happen to the system if the volume wasn't held constant and the temperature were increased. They determined that the system would expand and thus work would be done. It is clear from their written responses that the students in Group 2, with the possible exception of Tammy (who seemed to reason through the conceptual question in a procedural sense via the application of equations), also have a deep conceptual understanding of the different energy requirements between a constant pressure system and a constant volume system.

Heat Capacity: Procedural Questions. Following the conceptual question in Frame 4 (shown in Figure 4) Frame 5 asked students to reflect what they have done in Frames 1 through 4. Frame 6 then contained two procedural questions as shown in Figure 5.

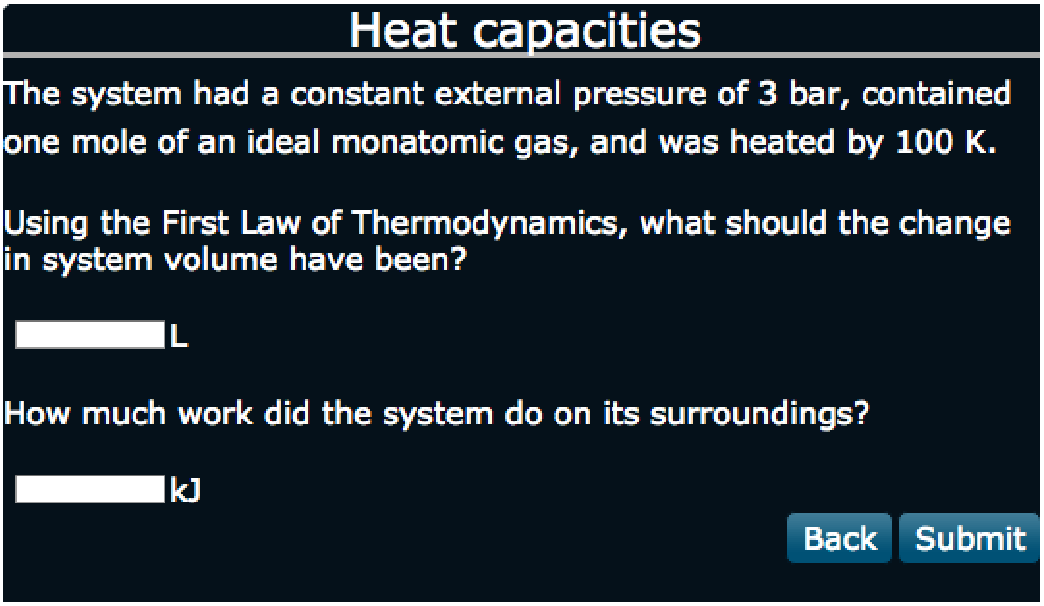

Figure 5. Procedural Questions from the Heat Capacity IVL

Group 1 had misconceptions related to the First Law that caused them to submit wrong numerical answers in Frame 6. Group 1 incorrectly set up the equation to calculate for the change in volume but used the correct equation to solve for the amount of work done on the surroundings. However, because their numbers from the first question were incorrect they did not achieve the correct answer for the second question either.

To solve for the first problem, Group 1 used the equation Q=W, or heat added to the system equals work done by the system.

> **Donna:** Okay, so then we can just solve for delta V. c_p delta T over P external, does that look right?
> **April:** Because it's just Q=W, that's just W and we want to calculate that. So how much work was done on the surroundings is just that [previous answer of ΔV] times 3 [the value of external pressure]…

They claimed all of the energy added to the system by heating it up was transferred to the surroundings in the form of work as the container expanded. This is a misconception; they did not account for the change of internal energy in their equation. Internal energy is a function of temperature, and thus, the change in internal energy was not zero for this process because it was not isothermal. The change in internal energy should be the same for both the constant volume and constant pressure systems because both were experiencing the same change in temperature. However, more energy needed to be added to the constant pressure system to achieve the desired temperature change because as the system expanded part of the energy was being lost to the surroundings in the form of work.

Because students in Group 1 did not include the change in internal energy in their equation, they did not get the correct answer for the first question (the change in volume). However, they still had some correct understanding of the relationship between heat, heat capacity, and change in temperature (that is, $Q = c_p \Delta T$). In answering the second question in this frame they also used the correct relationship between work and change in volume (that is, $W = P \Delta V$).

Group 2 correctly solved for the procedural questions displayed in Figure 5 by introducing enthalpy into their calculation.

> **Chris:** I used delta U equals n c_v delta T. Then you know delta H is equal to U plus PV and since you know delta U and you can find delta H since it's an ideal monatomic gas you have c_v and you can find c_p from c_v.
> **Tammy:** So you have delta U n C delta T and then H equals U plus PV?
> **Chris:** Yeah.
> **Tammy:** And then PV…
> **Chris:** You can solve for that. Because you know c_p is equal to R plus c_v
> **Tammy:** Oh, this should be c_p [delta U]
> **Chris:** No, that's c_v for delta U. And then c_p for delta H
> **Tammy:** Oh, okay, the same equation but c_p
> **Chris:** Yeah
> **Tammy:** And then you can solve for PV

Students in Group 2 used the definition of enthalpy, which states for a constant pressure system H=U + PV. They reasoned that the change in enthalpy was equal to the change in internal energy plus the product of pressure and (the change in) volume. They then stated that $\Delta U=n\ c_v\ \Delta T$ and $\Delta H=n\ c_p\ \Delta T$. After making these substitutions and rearranging Group 2 was able to correctly solve for the change in volume.

The groups that worked through the Heat Capacity IVL represent two different cases; responses from Group 2 represent correct answers with correct reasoning for both the conceptual and procedural questions, whereas responses from Group 1 represent correct answer and correct reasoning for the conceptual question and wrong answers and partially wrong reasoning for the procedural questions. Group 1 seemed to relate heat capacity to heat rather than a change in internal energy.

Discussion

Through this study we were able to examine student thinking processes as they work through these simulations. We also discovered errors and/or misconceptions some students have regarding thermodynamic principles. We were easily able to determine how many students might have shared the errors and/or misconception by looking at their numerical answers.

Using the information gained from examining the Work IVL recordings and looking at the bigger scale of student answers of 241 total students, we were able to identify students that made calculation errors similar to Individual 1 when they responded to the procedural question shown in Figure 3. Based on the student answers submitted for the Work IVL, 32 of the total 240 students who participated made a unit error in their calculations and 7 of those 240 students read the PV graph incorrectly. Thus, approximately 16% of the students who answered incorrectly did so most likely because of calculation errors as opposed to misconceptions.

By identifying and detailing the misconceptions Group 1 had in the Heat Capacity IVL it helped us to identify students with analogous misunderstandings in the future. For example, by examining the answers students submitted for the Heat Capacity IVL, we discovered that 24 of the total 237 students answered "6.93" for the change in volume We speculated with confidence that these other 19 students solved for the change in volume by using the same equation as the 3 students in Group 1: Q=W. Therefore, from this information we can assume that approximately 10% of the students have misconceptions involving internal energy.

Working toward the automatic grading system as one of our ultimate products of this project, we wanted to understand the thinking processes that led students to the answers they put in the boxes in the IVL. Since we have found that sometimes even students' final answers were not accurate, there are still productive ideas behind the answers. Therefore, the next challenge is to accommodate theses thought processes into the grading system.

IVL Improvements

Besides examining student thinking process and misconceptions, another related goal of this project was to inform instructors about student thinking and performance. The project allows instructors to gather data from the IVL labs and use that information to better inform teaching and thus improve learning. To fulfill this objective we developed an automatic grading system via an algorithm based off of student responses to questions in the IVLs. This grading mechanism will serve as a measure of student performance and allow the instructor to see specific areas where students are struggling. Because students will have access to this paper we will not detail how the questions are scored. The grading mechanism is currently being integrated into the *AIChE Concept Warehouse*.

We are also working on implementing a graphical display of student scores that will be visible to the instructor. This will provide the instructor with a quick overview of student performance for each IVL; without having to scroll through individual scores, the instructor will have an idea of whether or not students understood the concepts covered in each IVL based on a distribution of student scores. Based on the student answers we recorded during this study, Figure 6 shows an a mock-up of the instructor display.

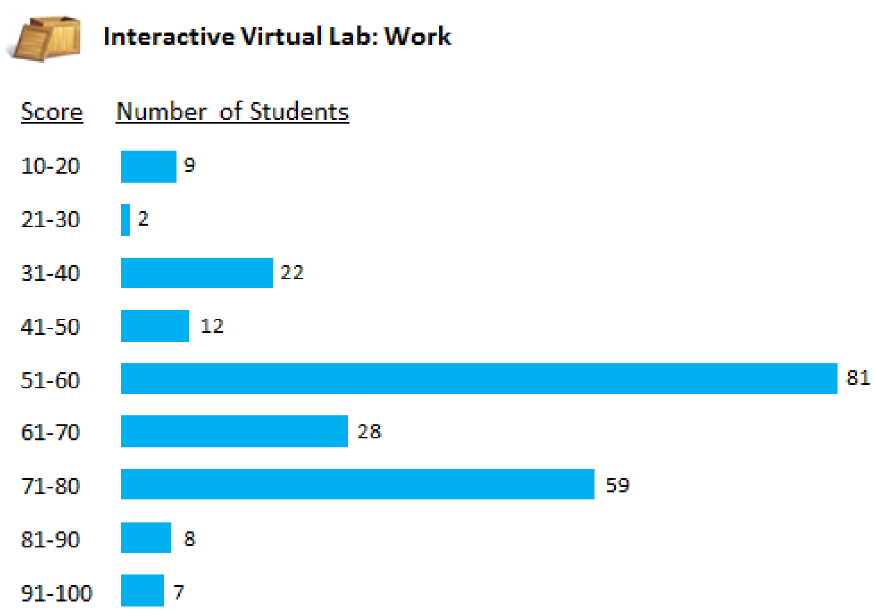

Figure 6. Mock-up of graphical distribution of student scores on the Work IVL (from class data)

Students working through the IVLs often commented on how it would be helpful if they had a measurement of how far into the simulation they were. To remedy this we are in the process of numbering each frame of the IVLs as well as displayed the total number of frames. Not only will this allow students to gauge their process but it also makes referencing frames in the IVLs more universal. For example, if a student is having a technical difficulty with a simulation they can now clearly articulate which frame they were on when the problem occurred. We are also in the process of implementing an interface that will allow students to submit any problems they had while completing the IVL. For example, if a student completes an entire IVL but when they hit submit they are directed back to the beginning and their answers are not saved they can submit an explanation of what occurred without their score being affected. The submitted problems will be available to the facilitator in charge of recording the scores as well as someone in charge of fixing IVL-related technical problems. Based on these improvements, Figure 7 shows a mock up with these features.

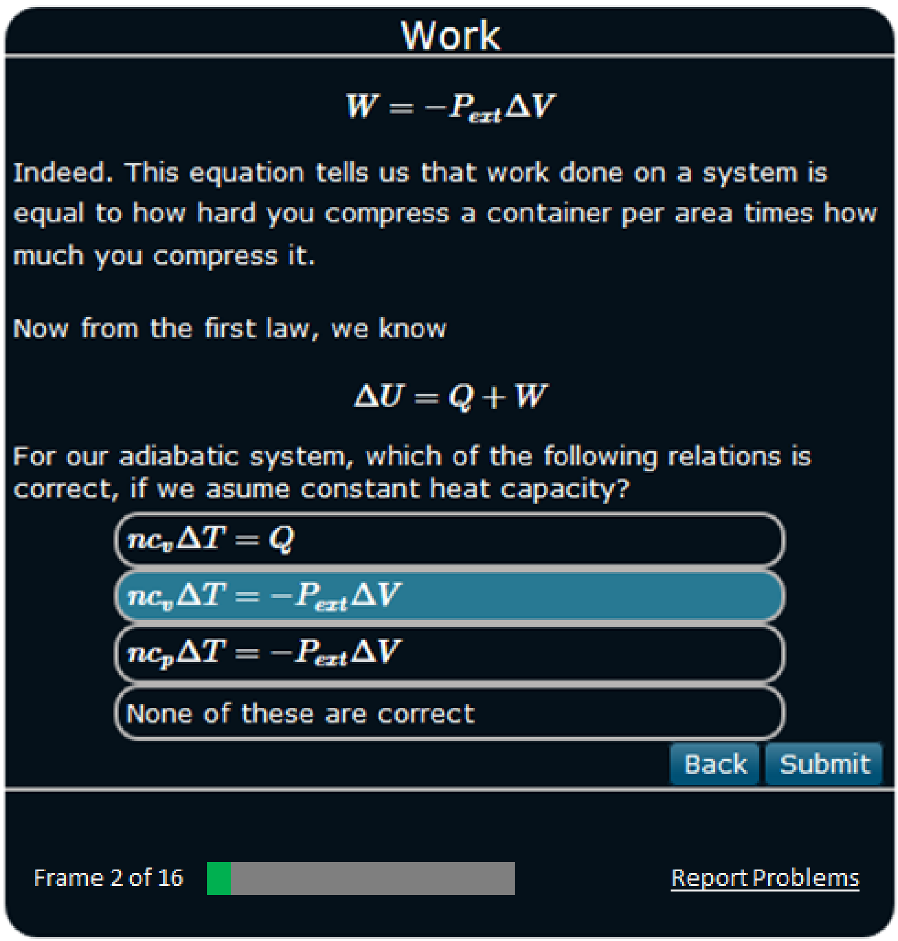

Figure 7. Mock up of progress display and link to submit problems (bottom)

We are currently creating a guide for IVL usage. This guide will function as a brief list of suggestions to help students run the simulations as smoothly as possible. For example, the guide will contain browser and device suggestions, such as no Internet Explorer and laptops are preferred. This guide will most likely be integrated into the *AIChE Concept Warehouse* where both instructors and students can access it. We will encourage instructors to advise students to read the guide before they use any of the IVLs. By creating this guide we hope to limit the amount of preventable errors that occur with the IVLs, such as students trying to use tablets and not being able to fully interact with the simulations.

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