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Decision based learning for a sophomore level thermodynamics course

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Decision based learning for a sophomore level thermodynamics course

Abstract

To meet the challenges of today's engineers, educators need to better understand and utilize teaching methods. These challenges and possible solutions are explored in Felder et. al. [1,2,3]. In this paper, decision based learning (DBL) is presented as a new pedagogy in an attempt to address some of these challenges. In decision based learning, a student is given a problem that they have never seen before. The student is asked to make a set of instructor decisions. When the student is unable to make a decision correctly, the instructor attempts to improve student understanding. This process continues until the student is able to solve the problem. While DBL shares characteristics of existing methods, it is unique in formulating sets of general to specific decisions. The instructor decision sets, student responses, and instructor feedback can easily be shared by instructors of different experience level. A long term goal of DBL is to allow students to solve novel and complex problems with minimal instructor support.

In this tutor, students were asked to draw a T-v phase diagram for a refrigeration cycle they had never seen before. At any point in the drawing process, students could submit their work to receive feedback. Upon submission, the tutor evaluated the student drawing to determine the most general/important understanding for which the student needed help. Rather than showing the correct answer, the tutor asked additional questions designed to assess the student's understanding. The tutor's response was contingent on the student's answers, potentially resulting in further assessments, instructional material, or returning to the problem at hand. The goal was to improve the student's understanding to the point where he or she could make a decision correctly. The decision making would, in turn, advance the student toward a correct solution. Students were asked to work at least 40 minutes on the activity.

Students completed a pre-tutor test and a post-tutor test to determine the impact of the tutor in furthering students' understanding regarding (P,T,v) property relationships for thermodynamic components. A significant amount of learning was demonstrated using DBL as suggested by a Cohen's d=1.77 for 88 students, where d>0.8 shows a large effect [4]. The pre-test results indicate that, on average, only 25% of students were able to identify all three relations for components prior to the tutor activity. Liquid gas separator, evaporator and condenser were the components that were most misunderstood by students. The post-activity test showed significant learning for component relations. As an example, 58% of the students had a misconception about pressure for heat exchangers. This was reduced to 18% using a single activity. More detailed analysis investigated how students learned using this activity.

Introduction

An intelligent tutoring system (ITS) was designed and used to study the effectiveness of a new pedagogy called Decision Based Learning (DBL) in thermodynamics. Most expert instructors have spent time with an individual student in office hours. Instead of showing the student the answer, the instructor might ask a series of questions that investigate the current understanding or misunderstanding of the student. Once the student misunderstanding is identified, the expert instructor may use an activity or some alternate representation. A sufficiently skilled instructor will be able to lead the student to the correct understanding needed to solve the original problem without directly showing the solution. DBL is a teaching pedagogy where the instructor decision sets and feedback are formalized throughout an entire course. A Decision Set is defined as a series of general to specific decisions that can be used to show understanding about a portion of the course material. The DBL pedagogy requires the development and use of enough decision sets that any problem in the course can be solved using instructor decisions. Once decision sets have been created, specific feedback can be formulated whenever students are unable to make a particular decision. The effectiveness of the feedback can be tested by investigating if the student's updated understanding is sufficient to make the original decision.

Many aspects of DBL already exist. A defining characteristic of Problem Based Learning (PBL) [5,6,7] is that students are given a problem before they have acquired the knowledge needed to solve it. This is also true for decision based learning. In PBL, students have to perform many tasks before solving the problem, such as trying to figure out what they need to know, researching the literature, and talking to experts. In DBL, students have a familiar set of decisions that helps them start on the unfamiliar problem. When students have trouble making a decision, they immediately know where their knowledge is lacking. They also know that improving this specific understanding is the key to solving this unfamiliar problem. The help that the students receive is very specific, and can directly target student understanding. DBL is intended to provide the structure needed to tackle problems at the edge of the student's ability. Contrast this with a more free form process like PBL, where students may form inexpert relationships that become difficult to correct. Using DBL, the correct relationships are clearly identified through the student's decisions. While DBL shares many characteristics with existing methods, it is presented here as a new pedagogy that has not been studied prior to this paper.

DBL has similarities to existing active learning methods [8-13], but differs in several important ways. First, a general to specific decision set provides the structure for solving novel problems. Second, students receive help with their understanding when they have trouble making those decisions. The goal of this method is to build expertise and to increase the chance that a student can solve novel and complex problems by:

1) Improving student understanding through the process of decision making
2) Improving the ability of a student to use their understanding while problem solving
3) Allowing students to solve novel problems without needing the instructor

Introduction to Decision Based Learning

Imagine a student sitting in a traditional classroom. The instructor presents material in a manner that many experts agree is the technically correct presentation of thermodynamic material. This includes expert language, definitions, and precise statements of understanding. This student is a novice and has little to no expertise in the subject matter. The novice will have difficulty accepting this information because it may differ from their current understanding and also because they have little prior knowledge to help internalize this expert information.

Instead, imagine a student in a classroom where the instructor understands the thought process of a novice as well as the relevant thermodynamic material. The instructor asks students to make simple decisions (Is there heat transfer in this problem?). Students, lacking expertise, may have trouble making this decision. The instructor could either remind the student of a prior problem where they made the correct decision or they could build the student understanding that heat goes from hot to cold.

DBL is based on the idea that students learn when:

1) They attach new information to existing understanding.
2) They modify existing understanding to accept new information.

Haile (1997-1998) [14, 15, 16] presented a series of papers that can be used to explain how students learn. While this work can help explain why existing methods are successful, it can also be used to explain why DBL might be beneficial:

1) The brain is not a storage and retrieval device. The brain only develops a propensity to reproduce neural firing patterns that have been found to be beneficial [17,18].
2) To be able to use what they know, students must learn cues that re-create useful patterns.
3) Learning can only begin from things the student already knows.
4) Intelligent thinking involves the identification of alternate attractors [i.e. patterns] and choosing from them. This cannot be done quickly.

As the student tries to make instructor decisions, the student is beginning with their current understanding. The instructor decision set creates useful cues that both provide structure for problem solving, and refer the student back to prior understanding based on previous decisions they have made with the same decision set. Feedback often consists of simply directing a student to something they already know.

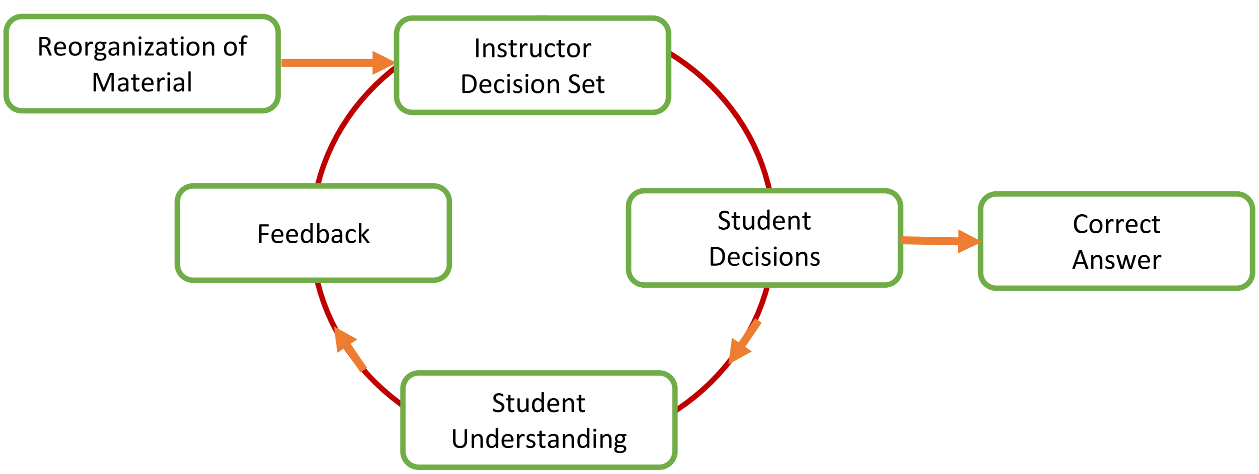

Figure 1 - The Decision Based Learning (DBL) process

The process of using a structured set of decisions with feedback to improve student understanding is called Decision Based Learning. DBL provides the interaction of active learning methods while retaining the structure of traditional methods. While the questions are simple, each new problem will be substantially different from prior problems. This process requires students to gain expertise as they combine pieces of understanding and apply the same decisions to unfamiliar problems. The ultimate goal of this process is to allow students to solve problems they have never seen before by using the instructor's decision set and their own understanding.

The DBL process depicted in Figure 1 has been formulated and refined by the primary author over 10 years of instruction and includes ~3000 successful students. As a practitioner, this method has shown that students can solve novel problems beyond the complexity of traditional textbooks without any memorization. Students solve problems and are tested without the use of equations sheets. Although this method is highly successful in practice and very popular with many students, it has been difficult to convince other instructors to adopt it because many expert instructors do not seem to be able to get past the "That's not the way I would do it" test. The goal of this paper is to study DBL in a very limited and controlled manner (drawing thermodynamic diagrams) to demonstrate the power of this method. The intent of this paper is not to prove the DBL is better than existing methods, but instead to show the promise of DBL and encourage researchers and practitioners to further investigate this method.

Perry (1968) [19], developed a model to show the change from dependent learning to independent learning to interdependent learning. At the independent level, a student should be able to identify the important factors for a given situation, recognize what they need to know, acquire any new knowledge, and apply their knowledge to successfully solve the problem. The authors present DBL as a framework that may allow students to succeed at the independent level.

Any teaching method must be accepted by the students or it is doomed to failure. Samples of student comments show that this method can be employed effectively.

Q1. How do students feel about a course using DBL?

"This class was very easy if you simply took the time to understand and work on his method. Going over problems in class was the most helpful to my learning as we could try our own hands at the problem with immediate feedback from him as to how successful we are at that method."

"The way that material was presented in this class was excellent. A basic understanding of how to solve the problems was developed early on and was very easy to pick up on. The way this instructor boils down information to what you need to know is fantastic."

"The material was presented in a way that required you to conceptually understand the material, and then use that understanding to derive the equations required to solve the problem. Much better than other classes that require you to memorize equations for certain situations."

"All thermo teachers should be required to sit through the first week of this instructor's class!"

Q2. Will students use the online tutor?

“I feel that once the Tutor software gets all of the bugs worked out and is completely interactive it will be a very powerful learning tool for future classes.”

“It’s a world of difference because it’s the first problem that we got that wasn't in class. It actually made me think about what I did. And it also made me think about what I was doing wrong. I Want MORE!!!!!!!!!”

Q3. What do students think about an instructor using DBL?

“Dr. Hagge’s simplistic teaching style, and requirement of understanding, not memorization.”

“Dr. Hagge's teaching style of thermodynamics forces you to learn the material, not just memorize equations.”

“Dr. Hagge is a fantastic teacher. Seriously the best teacher I have had at this university, give this guy a raise. The way he presents the material actually makes me want to go to class and he makes it interesting. I truly feel like I have a good grasp of thermodynamics, and it is all thanks to Dr. Hagge. No one else should even be allowed to teach thermo.”

The Tutor

An online tutor was designed to make DBL scalable to a large number of students. Students with internet access could log on to the tutor from anywhere using any major internet browser. The tutor is further described in reference [20]. The goal of the activity was limited to improving student understanding of property relations in thermodynamic components. Before using the tutor, students were sent to a pre-test that asked multiple choice questions about what happens to pressure, temperature and specific volume in each of the components in the tutor activity.

Students began by watching a brief video on how to use the tutor. After the video, students were sent to the workspace shown in Figure 2. The problem description is given on the left, and the student is asked to draw a diagram on the right. The student can hit the submit button whenever they want their work checked or whenever they need help.

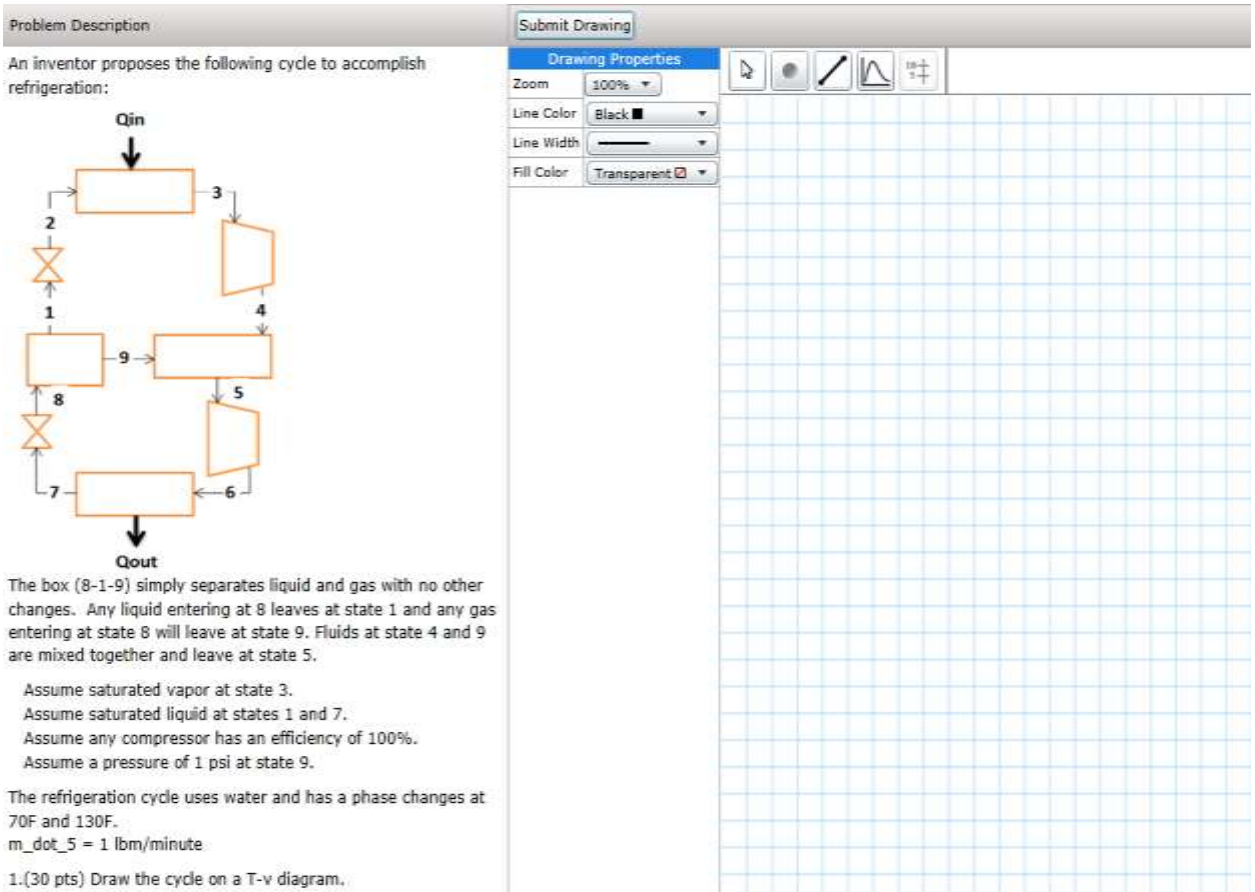

Figure 2 - The Tutor Workspace

The set of (general to specific) instructor decisions are as follows:

1) Is there a vapor dome?
2) Does the student know how many different pressures are in this cycle?
3) Does the student understand the relationship of T and v for a pressure line (i.e., horizontal inside the vapor dome, positive slopes outside)?
4) Are phase change pressures and temperatures properly labeled? (not implemented for the first set of students in this article)
5) Are all states present, each with a unique label?
6) Are the property relations (P, T, v) correct for each component?
7) Is problem specific information based on given data (actual state locations) used correctly?

A student is free to work as long as they wish without any enforced structure and may continue working with multiple errors. The student receives feedback only when the submit button is used. Note that this process limits tutor intervention to requests from the student, encouraging the student to solve the problem with the least amount of structure possible for their current abilities. When the student hits submit, the tutor assesses the seven decisions in sequence. Although the student may have multiple mistakes, the student is only given feedback on the most general (lowest numbered) decision. When a student makes an incorrect decision, they are given an additional question to determine if the student has understanding but needs a hint, or if they lack understanding to make that decision.

Let's assume a student draws a vapor dome with two pressure lines when the cycle actually has three different pressures. Failing decision #2, the student would be asked "How many pressures are there in this cycle?" as depicted in Figure 3.

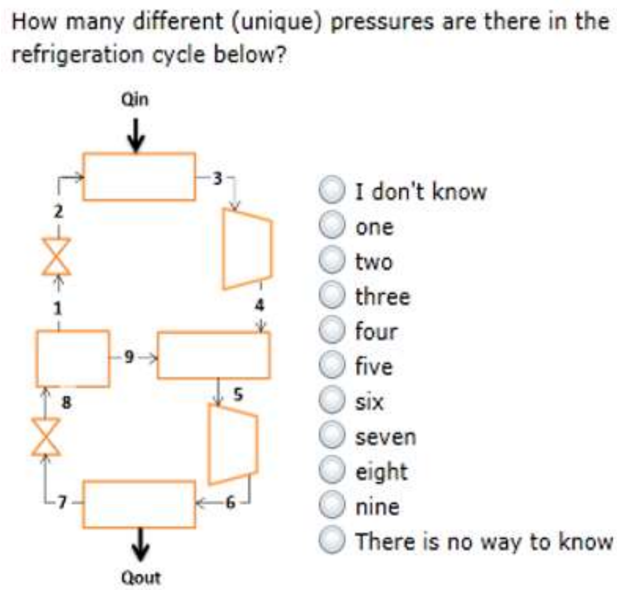

Figure 3 - The Number of Pressures Check

If the student answers correctly, they would be sent back to the activity and asked to draw the correct number of pressure lines. If the answer is incorrect, help is provided so that the student develops an understanding of how to determine the number of pressures in a cycle.

For help with the number of pressures, there is an entire activity that walks the student through each component of the cycle (see Figure 4). As shown below, the student is asked what happens to pressure in each component, and is subsequently shown a video about that component if they lack understanding. After watching the video, the student is again asked the same multiple choice question. Once the student has gone through all eight components, they can simply count the number of pressures to determine that this cycle has three different pressures.

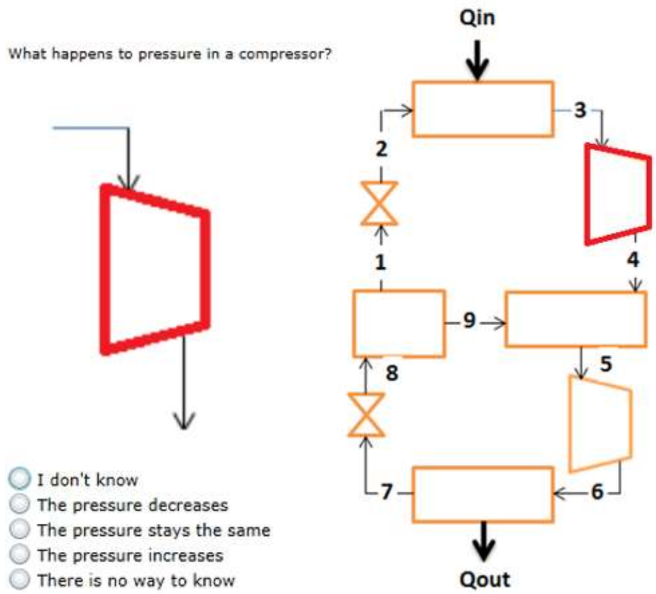

Figure 4 - The Pressure Activity

Now that the student knows the number of pressures, the student is asked to draw a diagram with the correct number of pressures. The student is also given the option of watching a video on how to correctly draw pressure lines. The third check will look to see that a student knows how to correctly draw the pressure lines (i.e., the student understands the relationship between T and v for a pressure line).

The fourth decision is labeling phase change temperatures and pressures on the diagram. This check was not yet implemented for this first group of students, so the tutor would proceed to decision #5, and make sure that the student had drawn all nine states on their T-v diagram.

At this point, the student has a T-v diagram for which the tutor can assess student understanding of components (e.g., Figure 5).

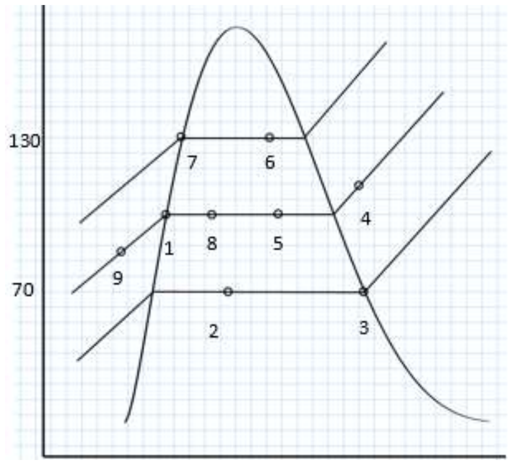

Figure 5 - A Sample Student Drawing

The tutor knows the correct P,T,v property relations for each component and now goes through the components one at a time starting with the expansion valve from 1 to 2. For this drawing, the student has incorrectly drawn a compressor from 3 to 4. The student has drawn a compressor with constant specific volume, when specific volume should decrease in a compressor. The student is told that they have a misconception about specific volume in a compressor. The student must now answer all three property questions about a compressor correctly as presented in Figure 6.

Question	Question	Question
What happens to pressure in a compressor?	What happens to temperature in a compressor?	What happens to specific volume in a compressor?
It increases.	It increases.	It increases.
It stays the same.	It stays the same.	It stays the same.
It decreases.	It decreases.	It decreases.
There is no way to know.	There is no way to know.	There is no way to know.

Figure 6- Component Multiple Choice Questions

If all three questions are answered correctly, the student is asked to redraw the compressor. If answered incorrectly, the student is sent to a video that describes how a compressor works. The student cannot fast forward the video, although they are allowed to close the video early. The student now has the option of watching the video to learn about the component, or closing the video and trying to correctly guess all three questions (1 in 27 chance if they eliminate the last response). Each time the student does not answer all three questions correctly, they are given the option to watch the video. The student is never told which answers are incorrect, so they must choose between brute force guessing and watching the video.

The component checks continue until the student has drawn all eight components correctly. The last check is the first time the tutor looks at the actual location of each of the states. A student may have all the correct property relations, but as an example, they may have drawn a point in the two-phase region when it should be in the liquid region. This final step was very crude, in that the tutor simply told the student where the point needed to be as depicted in Figure 7.

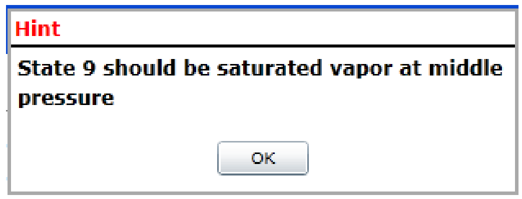

Figure 7- Crude Hint for Decision #7

If the student completes the drawing correctly, they are given a link to the post-test. If the student was unable to complete the drawing, they were given a link to the post-test in their assignment for the tutor activity.

Data was collected on a class of 88 students in a sophomore thermodynamics class. Students had solved a four component vapor compression refrigeration cycle with two pressures and a cascade refrigeration cycle with 4 pressures prior to this activity. Immediately before the activity, students took a pre-test evaluating their understanding on property relations in each component of the cycle. Sample question are shown in Figure 8.

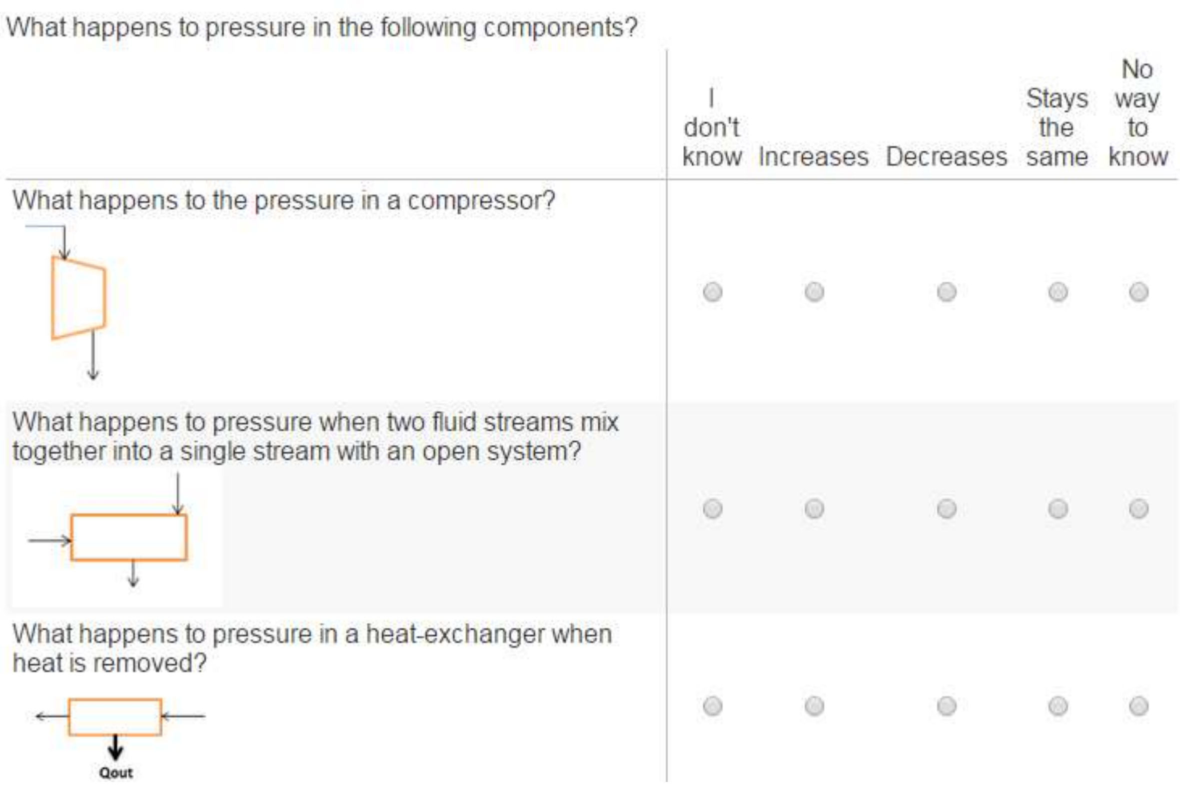

Figure 8 - Sample Pre/Post Test Multiple Choice Questions

Using the tutor, students were asked to complete a refrigeration cycle activity that they had not seen before. They were asked to spend about 40 minutes working with the tutor. Students responded to the same set of questions right after the activity in a post-test.

The tutor asked students to draw a thermodynamic phase diagram (temperature versus specific volume) for the refrigeration cycle. For each submission, the student drawings and feedback were recorded. The information from the drawing activity, in conjunction with the pre-test and post-test questions, provided a basis for an in-depth analysis of how student understanding connects to their drawing. Some of the findings are presented in the next section.

Results

The effectiveness of the DBL process can be seen by examining students' pre-test and post-test performance. Since the only activity in between the pre-test and the post-test is the tutor refrigeration problem, any improvements can be attributed solely to the activity. As depicted in Table 1, the post-test scores were significantly higher than the pre-test with a large effect size based on Cohen's d (0.2=small, 0.5=medium, 0.8= large)[1]. These results imply that by using a single thermo cycle activity in a DBL tutor, student's understanding about property relations can be improved significantly.

Table 1- Pre-test and post-test results for the 88 Thermodynamics 1 class. A paired t-test was used to indicate the difference. Cohen's d was calculated to observe the effect size.

	Pre-test average score	Post-test average score	t-test results	Effect size
Thermo 1	9.74 of 16.00	14.09 of 16.00	p<.0001	Cohen's d= 1.77

Two of the eighteen questions (6 components x 3 properties) were not included in the analysis because they were incorrectly worded. Results would have been nearly identical if the two poorly worded questions had been included. Students got 60.6% of the pre-test questions correct and 88.2% of the post test questions correct. The actual student learning is higher than these results indicate if student guessing and slip probability are included in the analysis. Slip is the probability that a student knows the correct answer but makes a mistake [21]. The slip and guess rate can be found by matching the pre- and post-test results with the fact that 6% of students answered a question correctly on the pre-test, but got this same question wrong on the post-test. Students had a 34% chance of guessing the correct answer and a 4% slip rate. Students were typically able to eliminate the first and last choice (see Figure 8 - only 1% of students picked the first or last choice for previously seen components) which supports the roughly 1 in 3 guess rate. When the guess and slip rates are included, the initial understanding was 43% and the final understanding was 87%.

Pre-Test Results:

$$(43\% * 96\%) + (57\% * 34\%) = 60.60\% \text{ correct on pretest}$$

$$\text{Have understanding and no slip} + \text{No understanding and guess correctly} = \% \text{ correct}$$

Post-Test Results:

$$(\mathbf{87\%} * \mathbf{96\%}) + (\mathbf{13\%} * \mathbf{34\%}) = \mathbf{88\%}\ \boldsymbol{correct\ on\ pretest}$$

$$\boldsymbol{Have\ understanding\ and\ no\ slip} + \boldsymbol{No\ understanding\ and\ guess\ correctly} = \%\ \boldsymbol{correct}$$

An important goal of DBL is to find and remove misconceptions. A common misconception about pressure is that heating or cooling an open system will raise or lower the pressure. This is a misconception because heating or cooling a closed container will raise or lower the pressure. Student pre-test results showed that 38% of students had correct initial understanding of pressure in a heat exchanger while 53% of the students had this misconception. This misconception was so strong that more students had this misconception than the correct understanding. At the end of the activity, the post-test showed that 80% of the students had the correct understanding of pressure while 16% of the students still had this misconception.

Component understanding for combined (P,T,v) property relation are shown in Table 2. While student understanding increased, they still had problems with some components.

Table 2 - Combined (P,T,v) propertyrelations in each component for pre-test and post-test.

Component	Pre-test Understanding	Post-test Understanding
Compressor	53.41%	88.64%
Condenser	17.05%	59.09%
Expansion valve	37.50%	77.27%
Liquid gas separator	6.82%	62.50%
Evaporator	15.91%	42.05%

If a student truly understands a component, they should be able to get all three property relations correct. Students were able to do this for only 25% of the components in pre-test and 70% on the post-test. If the effects of guessing are taken into account, students may have been able to correctly understand only 7% of the components prior to the DBL activity, while they understand 70% of components after the tutor activity.

So far, the results show both improved understanding and the reduction of misconceptions using DBL. Another goal of DBL is to get students to solve problems using their own understanding and to reduce their reliance on previously seen problems and memorization. By matching up student drawings with pre- and post-test data, we can find how closely correlated their drawings are to their understanding. On average, students' initial drawings matched up with 62% of the understanding as shown on the pre-test. At the end of the activity, student drawings matched up with 78% of the understanding as shown on the post-test. Because of the guidance that the tutor provides, we can't claim that the closer match between drawing and understanding is purely attributed to students using their knowledge in problem solving. We hope to investigate this further when the tutor is extended to multiple cycle problems.

The benefits of this initial dataset led us to study seven more sections of thermodynamics for a total pool of four different instructors and almost 500 students. The tutor was scheduled at the convenience of the instructor, which means that each group of students may have had a different amount of coverage of refrigeration cycles prior to using the tutor. For every group, the students were significantly different ($p < 0.0001$) after the activity and showed a large amount of learning ($d > 0.8$). Figure 9 shows this improvement for all seven groups of students.

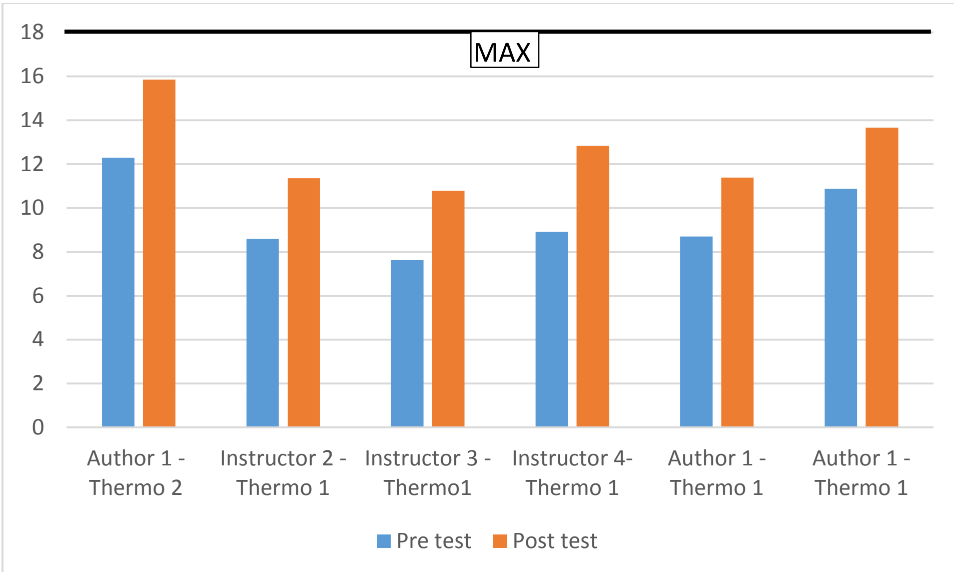

Figure 9 - Pre-test and Post-test average scores for 7 different classes of Thermodynamics 1 and 2, with 4 different instructors. Scores are out of 18 possible points. Regardless of the instructor, students' undertsanding of P,T, v relations in components improve after the activity.

Conclusions

Decision based learning appears to be a powerful teaching method. These results were obtained without any individual model or information about a student. Student understanding was improved and misconceptions were reduced. In this activity, the student population gained twice as much understanding in a single 40 minute activity. One of the traditional challenges of teaching is finding a way to teach to a group that has different levels of understanding. Evaluation of the entire set of ~500 students shows that the students needing the most help learn the most with DBL. If the trends from a single activity continue through multiple problem sets, it should be possible to take students of different initial understanding and allow them to achieve mastery with a DBL tutor system with a relatively small set of problems. Even better, early evidence indicates that the DBL tutor can be used regardless of the preferred teaching style of the instructor, and with minimal instructor time (~5 minutes of class time to send students to the tutor).

The present tutor system is very limited in scope. If decision based learning is implemented throughout a course, students will have understanding at multiple levels and through multiple decision sets. As an example of a second decision set, students can make three simple decisions that allow them to explain why the components of a refrigeration cycle (or power or heat pump cycle) are needed. Students following this process would make decisions that allow them to determine the needed components of a refrigeration cycle, without anyone showing them the components of a refrigeration cycle. A third level of understanding would involve letting students make decisions about what is happening with mass, energy, and entropy in each component. For all three of these decision sets, students would be refining much of the same set of understanding in new ways.

As a word of caution, decision based learning is an advanced teaching method because it requires the instructor to reconfigure an entire class into sets of simple decisions, to understand how students think, and to have simple explanations that improve student understanding. The instructor needs to be able to explain things at multiple levels of understanding because the instructor language will change (boiling temperature→ phase change temperature → saturation temperature) as student expertise increases. An instructor can begin this process by introducing students to a problem they have not yet seen, and asking them to make simple decisions. The instructor does not tell students the answer. Instead, the instructor finds out how students think, and explores different explanations until they can find one that taps current understanding and allows students to explain something new. As students practice decision making, the instructor tries to come up with a universal set of simple decisions, starting with the most general decisions and finishing with specific decisions. Alternately, experienced instructors can share decision sets and feedback to allow new instructors to use this advanced teaching method.

Future Work

The next steps are to implement multiple problems, track student understanding over time using Bayesian Knowledge Tracing, and to create a student model that allows intelligent tutoring (customized feedback). DBL in a tutor environment provides such a rich understanding of students that patterns of cheating, random guessing, learning styles, or other behavior that require individualized tutor actions may be detectable. Instructor tools need to be developed that clearly communicate to instructors what their students are doing well and what they need to work on. Imagine an instructor sending their students to a tutor, learning about their students, and adjusting the teaching at the next class period based off tutor suggestions. While implementing DBL is non-trivial, imagine the possibility of automatic grading and mapping of course outcomes over time, with relatively little instructor effort.

A second step is to provide additional decision sets that layer similar student understanding in multiple ways. The understanding gained from this property tutor should help students make decisions about energy equations, about why these components are needed, about what is happening at the molecular level, as well as decisions about component and cycle performance.

The authors believe that DBL with intelligent tutoring may be a disruptive technology, in that it could change the way we teach on a daily basis. It will not be long before tutor systems will have enough information to quantitatively determine what teaching methods work best for each student, and how instructors can improve their own instruction. Educators will have the choice of using fully automated or instructor assisted tutor systems.

Acknowledgments

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