USE OF CONCEPTESTS AND INSTANT FEEDBACK IN THERMODYNAMICS

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Many studies have emphasized the fact that cooperative learning can improve engineering education.[1,2] One form of cooperative learning in physics and chemistry departments is in-class ConcepTests[3,4]—multiple-choice conceptual questions posed to the class. After all the students respond with an answer, they are asked to discuss the answers among themselves (peer instruction) and are given the opportunity to change their answer.

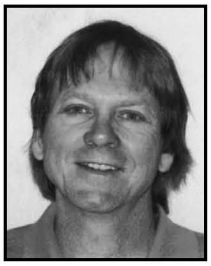
Mazur[3] showed a lack of correlation between students' conceptual understanding of physics and their ability to do quantitative problems. They could do quantitative problems better than conceptual problems that used the same concept. He found that students memorized algorithms for solving the problems without understanding the concept, and thus had difficulty when a problem they had to solve was different from ones they have previously solved. He reported a gain in student performance with the use of ConcepTests. The students' conceptual understanding increased because they were better able to explain concepts to one another than their teachers could. The percentage of students with the correct answer always increased after they discussed the question with their peers.

This effectiveness of ConcepTests can be further improved if students are graded on their answers because it increases both their participation and their motivation. The grading is done with IR transmitters and receivers, as described below. My experience in a thermodynamics course showed the following advantages:

- *Students liked using ConcepTests and getting instant feedback on how well they understood material as it was presented to them.*
- *The instructor obtained instant feedback on how well the class understood a concept.*
- *Students were more motivated to be prepared and thus learned more in class.*
- *Attendance in class was higher than in previous semesters when ConcepTests were not used. (Although statistics were not obtained for the previous semesters, attendance was over 90% when ConcepTests were used and graded.)*
- *Everyone participated in class.*
- *The discussions among students were quite lively. Students interacted, teaching and learning from their fellow students. This creates a more engaged class and students hear more than one explanation. This increases learning.*

Although ConcepTests were a small part of the course grade, grading them motivated the students. For the thermodynamics course, the lowest five days of grades were dropped to allow for sickness, outside activities, etc. The ConcepTest grades then counted either 5% or 10% of the final course grade. The higher of the two grading methods was used for each student. Since the average on the ConcepTests was 88%, almost all students counted the ConcepTests as 10% of their grade. An important aspect was the use of an absolute grading scale for the course. This encouraged students to cooperate; they were also required to do homework in groups.

This brief article describes ConcepTests and the relatively



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inexpensive technology available that significantly improves their application. Both the technology and ConcepTests have been in use for some time in physics and chemistry departments. The purpose of this article is to indicate that they are also effective in chemical engineering courses, particularly those courses that require significant conceptual understanding, and that inexpensive technology exists for implementing the test and getting instant feedback.

Examples used during the Fall 2002 semester for a junior-level chemical engineering thermodynamics course will be presented here. Grading and instant feedback were accomplished by installing IR detectors in the classroom and requiring students to purchase IR transmitters (clickers) manufactured by H-ITT.[5] There were fifty students in the class.

EXPLANATION OF CONCEPTESTS

The ConcepTests with transmitters (clickers) works as follows:

1. The instructor poses a conceptual question and presents possible answers (multiple choice).
2. Each student picks an answer by selecting A,B,C,D, or E on a clicker.
3. The instructor displays a histogram of answers for the class to see. If most answers are correct, a short explanation is given and the next topic is started.
4. If many of the answers are incorrect, students are told to discuss the question with their neighbors. This peer instruction is a critical aspect of ConcepTests and learning. It fosters student involvement and engagement.
5. Students are allowed to change their answers after the discussion. As a result, most of the students end up with the correct answer and a better understanding.
6. If most students have the correct answer, a brief explanation is given. If not, the question is discussed further, and the instructor provides additional ideas to help the students learn the concept.

Three receivers were mounted high on the walls in the room for a class of fifty students. The receivers are small (3.5 x 2.5 x 1.5 cm) and are daisy-chained together by cables. The cost of 3 receivers and cables was around $600. The receivers collect the signals and send them to a PC running acquisition software, which can be downloaded free from the H-ITT web site.[5]

Each student has their own hand-held transmitter (clicker), purchased from the bookstore for $30. The H-ITT hand-held IR transmitter, similar to a TV remote control, has a unique ID number. It is slightly larger than a pen and is battery operated. Each student responds to the multiple-choice questions by aiming the clicker at a wall-mounted receiver and pressing A, B, C, D, or E. The H-ITT acquisition program display is also projected onto a screen for the entire class to see. The ID number (or the student initials) of each clicker is displayed, indicating that the student response has been successfully collected, but it does not show the student answer. The H-ITT acquisition program summarizes the data and displays the class responses in histogram form.

After class, a separate program associates student names with the remote ID numbers and grades the responses instantly. It allows the instructor to assign point values to each answer for each question (*e.g.*, 3 points for a correct answer and 1 point for an incorrect answer). The software also allows a list of the student names and point totals to be quickly exported into a spreadsheet.

EXAMPLES FROM THERMODYNAMICS

Several examples from the thermodynamics course are presented here. Many students initially had problems answering these types of questions since some of them require higher levels of Bloom's taxonomy. The examples are presented to give the reader an idea of how ConcepTests are applied in class. Similar problems were then used on the course exams, but without the multiple-choice options and with the requirement that the students explain the reason for their answers.

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1. Components (A and B) are in vapor-liquid equilibrium. One mole of liquid ($x_A = 0.4$) and 0.1 mol of vapor ($y_A = 0.7$) are present (see Figure 1). When 0.5 mol of A is added and the system goes to equilibrium at the same T and P, what happens?

   A. The amount of liquid increases.

   B. The amount of liquid decreases.

   C. The concentration of A in the gas phase increases.

   D. The concentration of A in the liquid phase increases.

2. Is the fugacity of water at 150°C and 100 atm closer to

   A. 1 atm

   B. 5 atm

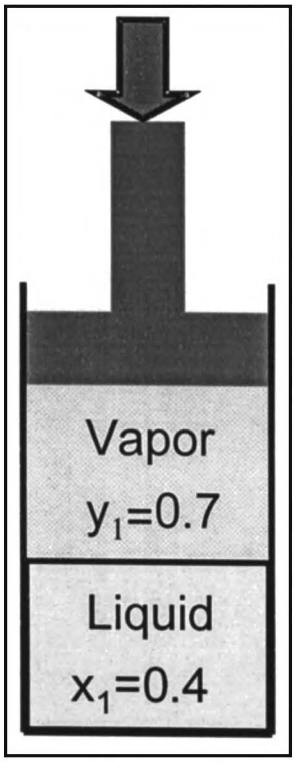

Figure 1. *Two-component vapor-liquid phase equilibrium in a piston/cylinder at constant pressure equilibrium.*

C. 50 atm

D. 100 atm

3. For the H-x_A diagram at 80 °C in Figure 2, what is the maximum value of the partial molar enthalpy in cal/mol of component A?

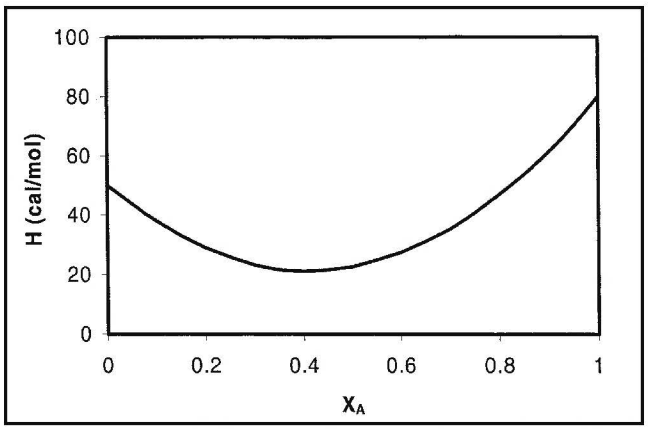

Figure 2. *Enthalpy of a binary mixture versus mole fraction of component A.*

A. 50

B. 22

C. 85

D. 100

E. 0

4. Two identical flasks at 45 °C are connected by a tube. One flask (A) contains water and the other (B) contains the same amount of a 95/5 mixture of water and salt. After five hours

A. Beaker A has more water.

B. Beaker B has more water.

C. The amounts of water do not change since they are at the same temperature.

D. All the salt moves to beaker A.

5. Consider the reversible reaction and the indicated number of moles present at equilibrium:

$$CaCO_3(s) \leftrightarrow CaO(s) + CO_2(g)$$
$$10\ mol \quad 0.2\ mol \quad 10\ mol$$

If we push down on the piston (see Figure 3) to decrease the volume to half and keep the temperature constant, what happens at equilibrium?

A. The CO_2 pressure almost doubles.

B. CaO and CO_2 react, so the CO_2 pressure does not change.

C. The system is at equilibrium, so nothing changes.

D. All the CO_2 reacts.

6. 6 mol A and 4 mol B are in equilibrium at 100 °C and 3.0 atm. A and B are completely immiscible in the liquid phase. Their vapor pressures at 100 °C are

$P_A^{sat} = 2.0$ atm

$P_B^{sat} = 0.5$ atm.

What phases are present?

A. Liquid B and vapor of A + B

B. Two liquids

C. Two liquids in equilibrium with vapor

D. All vapor

E. Liquid A and vapor of A + B

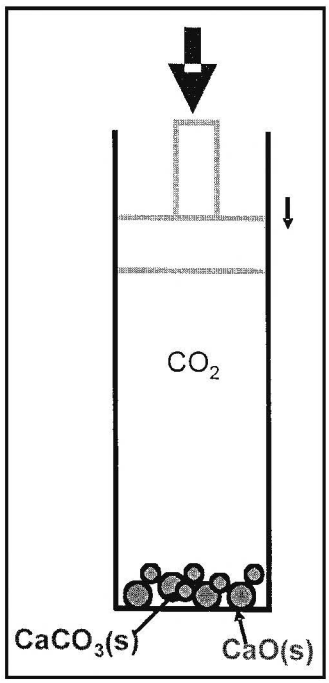

Figure 3. *Gas-solid chemical equilibrium in a piston/cylinder.*

7. Water alone is present and is in VLE at 1.2 atm in a piston/cylinder. You inject 5 cm^3 of air into the system, but keep P and T constant. What happens?

A. All the water vaporized.

B. All the water condenses.

C. Some water vaporizes.

D. Some water condenses.

FEEDBACK FROM THE FALL 2002 THERMODYNAMICS CLASS

At the end of the Fall semester, students turned in an anonymous typed course evaluation to the TA. These evaluations were given to the instructor after course grades were posted. One area that the students were asked to address was the use of clickers and ConcepTests. Partial comments from fifteen of those evaluations follow. Almost everyone in the class liked the clickers and ConcepTests.

- The greatest part about it was that you made thermodynamics a fun class to attend. The IR transmitters did not follow a straight lecture and I found they are a good idea, and I found them to be quite useful in understanding the ConcepTests.
- There was one thing in particular that I really enjoyed, and that was the clicker questions.
- As for the instant response clicker system, it was generally a big help. I think it is essential to

teaching such technically difficult material as we study in thermodynamics. Being able to immediately apply what we were learning to a problem and receive instantaneous feedback on our understanding, as a class, was fantastic.

- Although I was a bit skeptical of the transmitters at first, I found that I actually liked them a lot. It kept the class interesting to be able to participate every day.
- The transmitters were very effective in adding to the class as a learning experience. They gave support to myself in times when I felt unwilling to ask a question for fear I was the only one who didn't understand.
- The ConcepTests were extremely helpful in getting a grasp on what is happening. I also liked the use of the transmitters.
- I thought the clickers worked well in class. These questions were very useful at helping me grasp the conceptual part of the course.
- I thought the overhead ConcepTests were a great idea, and a good usage of the clickers.
- I felt the use of the transmitters greatly enhanced my understanding of the topics we discussed.
- The IR transmitters receive two thumbs up. I was skeptical of them at first, but they really help in making sure that not only I but the majority of the class understands what is being taught.
- I also liked the concept questions.... I thought the IR transmitters worked very well and were used well. The IR transmitter is good because there is no peer pressure factor when you're answering the question for the first time, and you can get a good idea of the class understanding of the concept.
- My favorite parts to this course were the supplements in the notes and the IR transmitter...I felt the IR transmitter and the ConcepTests were a valuable tool to this class.
- I thought the best aspects of the course were the transmitters, the reviews, and the homework help sessions. The transmitters were definitely a good way to get people to participate.
- I felt the IR transmitter and ConcepTests were a valuable tool in this class.
- Ultimately I found that the clicker really helped my learning. It also keeps you involved with the lecture, rather than just mindlessly copying down notes.

The concerns expressed by the students were small. The biggest concern was that they had to spend $30 to purchase a transmitter they could use only in one course. Since they should be able to sell their transmitters to students in next year's class, that should become less of a problem. Some students were concerned that the grading in every class forced them to come to class more often. Two students did not like the transmitters or the ConcepTests.

The purpose of this article is to indicate that [ConcepTests] are also effective in chemical engineering courses, particularly those courses that require significant conceptual understanding . . .

SUMMARY

Even though students could work numerical problems, many did not have a good grasp of the thermodynamic concept involved. For example, they could calculate the vapor pressure at a given temperature with Antoine's equation, but a large fraction of them did not understand the concept of vapor pressure well enough to answer questions such as #7 above.

For many of the ConcepTests used, more than half the class initially answered incorrectly, but the percentage of correct answers increased, usually dramatically, after discussions with other students.

The H-ITT software was easy to use in class, and the students could readily see their clicker ID number on the projected display. Since their ID number always appeared in the same location on the screen, it was easy to find. We have since installed the detectors in a second room in the engineering building, and two other faculty members have indicated they will use the clickers in their classes in the future.

ACKNOWLEDGMENTS

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