Use of True-False or Multiple Choice Questions in Measuring and Improving Student Knowledge of Fundamental Concepts in Thermal Science Courses

Amir Karimi and Randal Manteufel
University of Texas at San Antonio

Abstract

Electronic devices such as I>Clicker or tools in Blackboard Learn are very useful instruments in large classes to take student attendance, give true and false quizzes, and keeping students alert by participating in active learning activities. These tools are also very helpful to measure and reinforce the understanding of the fundamental concepts in the technical subjects. Use of I>Clicker has been experimented in thermodynamics and heat transfer courses in the recent years. During the class period short true/false or multiple choice questions are given to measure student understanding of the fundamental concepts covered during a class period or in the previous class periods. Students answer questions using their I>Clicker devices. The results are evaluated instantaneously and lectures are continued by focusing on the areas of students' difficulties. Students are tested again at the end of the lecture or during the next period to gage the improvement in their understanding of fundamental concepts. Processes for the evaluation students understanding of the fundamental concepts in thermodynamics and heat transfer courses are described. These include the understanding of first law and second laws of thermodynamics, importance of such dimensional parameters as Biot, Fourier, and Reynold numbers. Few examples of questions used in the evaluation of student knowledge of fundamental concepts are included. The results of a survey conducted at the end of semester to get students' perception of using I>Clickers, the understanding the fundamental concepts, and the possibility of using I>Clickers in a "Flip Lecture" scenario are also presented.

Keywords

Fundamental concepts, thermodynamics, heat transfer, true/false/multiple choice questions, I>Clicker

Introduction

Many engineering students have difficulty explaining the fundamental concepts used in solving engineering problems. They succeed at algorithmic problem solving but have difficulty explaining the physical systems being described. This is reflected in low scores on concept inventory exams.[1,2] Continued poor performance in thermodynamics courses is linked to students not grasping the key concepts and failing to recognize how to apply relevant concepts in solving problems.[3] Even when students pass thermal and fluid science courses, many fail to achieve a deep understanding of the fundamental concepts. For example, students may be able to solve problems by neglecting kinetic and potential energies in the equations associated with the equations for the first law of thermodynamics, yet struggle to explain why these assumptions are justified. Likewise, they will assume steady-state behavior, but have difficulty to explain the reason. Students learn how to approximate the evaluation of thermodynamics fluid properties, but cannot provide reasonable justifications for the approximations. For example why the specific volume v (T, P), internal energy u (T, P), or entropy s (T, P) in the compressed liquid region can be simply be approximated by saturation properties, v_f (T), u_f (T), and s_f (T), respectively.

The mechanical engineering degree program at the author's institution requires a two-semester course sequence in thermodynamics, a course in fluid mechanics, and a course in heat transfer in the thermal-fluid area. In addition, the program offers several other courses in the thermal-fluid area. Understanding of the fundamental concepts presented in the four required course in thermal-fluid area is essential for students performing well in all technical elective courses in the area. A good understanding of the fundamental concepts in the first course in thermodynamics is essential for students performing well both in the second course in thermodynamics as well as a course in heat transfer. Also a good background in fluid mechanics helps students to better understand convection heat transfer. Our experiences indicate that students who have a sound understanding of the fundamental concepts in the first course in thermodynamics do well in the second course, as well as subsequent fluid mechanics and heat transfer courses.[4-6] Students who have a shallow knowledge of the concepts struggle in subsequent thermal-fluids courses. After teaching the first course in thermodynamics for several years, it is realized that many students have difficulties in grasping some of the fundamental concepts. The range of difficulties includes recalling definitions; selection of appropriate thermodynamic systems; distinguishing the differences between the extensive and intensive properties; evaluating properties; and applying general equations to particular systems. [4-6] Many difficulties can be traced to deep conceptual problems where student's intuitions about the system behavior are incorrect. In some cases, low performance in exams can be traced to the lack of students' effort in the course.[4,7] But for many students, it is a lack of conceptual understanding that present significant challenges to the instructor.

Areas of Conceptual Difficulties

Areas of conceptual misconceptions in thermodynamics include: distinguishing the differences between open and closed systems, evaluation of properties, state principle, internal energy vs. enthalpy, transient vs. steady state, realizing entropy is a thermodynamic property, reversibility, correct application of process equations vs. rate equations, distinguish differences between isothermal and adiabatic processes, realizing that temperature and pressure in the two-phase region are not independent properties, understanding why heat transfer or work are not thermodynamic properties, After the first few weeks in thermodynamics, students become familiar with retrieving property values from tables given values for temperature and pressure. Students begin to think of T and P as inputs, and finding other properties as the outputs. It becomes much more challenging when two different properties are used as inputs to evaluate other properties. Students often struggle to identify two properties (other than T and P), that can be determined for a given problem. One reason for this difficulty is that the tables of thermodynamic properties in the single phase regions are organized in terms pressures first, then of temperatures. It has been concluded that students need to develop a better grasp of the concept of the "state principle" and learn to identify two independent intensive properties to "fix the state" and subsequently determine other intensive properties. Students often are unfamiliar with the concept that there is a range of conditions where the ideal gas equation is applicable, and likewise a range of conditions where it isn't applicable. The concept needing to be grasped is that some substances are described as ideal gases (Air, O_2, N_2, He, Ar) but the same substances can also not behave as ideal gases under certain conditions. This is true at conditions near the critical point, and definitely when the substance condenses. Students should also understand that some substances rarely behave as an ideal gas (H_2O, Refrigerants), but in certain cases they can behave as ideal gases (superheated vapor at low pressures). It has been observed that some students will apply $Pv = RT$ when it is not justified, and fail to use it when it is justified.[4]

In heat transfer students have difficulty applying the boundary conditions correctly in solving boundary value heat conduction problem; under what condition the available equations for one dimensional heat conduction in a fin can be used (e.g., why Bi must be << 1); under what conditions the lumped capacity solution can be used for a transient heat conduction problem; or under what conditions in a transient heat conduction problem it can be assumed that the surface temperature is approximately the same as the convective fluid temperature. In convection heat transfer some students have difficulty to select a correct empirical equations that satisfies its range of application. For example for forced convection, most equations are accurate only within a range of Reynolds (Re) or Prandtl (Pr) numbers. Some students arbitrarily use an empirical equation to solve a forced convection heat transfer problem without first evaluating the Re and Pr numbers to see if they are within the range of application of the selected equation. Some students don't understand that the general Nusselt (Nu) number equations developed for laminar flow over flat plate is not valid for fluids with low Pr numbers (e.g., liquid metals). Most students cannot explain the physical significance of such dimensionless parameters as Bi, Re, Nu, Pr, Fo (Fourier), Ra (Rayleigh), and (Grashof) numbers.

Use of Multiple Choice and True/False Conceptual Questions for Instruction and Assessment

In recent years many studies have been conducted to examine the use of true/false or multiple choice quizzes in helping students to grasp fundamental concept or measure the students' understanding of fundamental concepts in math, science, or engineering courses.[4, 8-12] Multiple choice or true/false questions make grading easier for the instructors, especially in large classes. There is always a question whether the use of multiple choice questions in exams adversely affect the students' performance. A possible drawback of using multiple choice questions is that some students guess answers instead of solving a problem. One study compared student comprehension of introductory statics material by comparing the exam scores of students who are given both multiple choice questions with constructed response questions to see whether the type of exam question makes a difference in student performance and understanding.[8] The results showed little differences between the scores for the multiple choice and constructed response versions of questions on the exam results.

In general some students don't like multiple choice quizzes, because they might not receive partial credit for problems that require algorithmic solution. However, multiple choice questions can be designed to measure the understanding of the fundamental concepts without requiring algorithmic solution. For example, if a pressure and specific volume is given for water to identify the phase or phases of a substance (compressed liquid, superheated vapor, or a two phase system in equilibrium), there is only one correct answer regardless of the answers are given on the paper in a written exam, or it is marked on a multiple choice form to be graded by a device. In recent years we have tried to give multiple choice questions quizzes to test students' understanding of fundamental concepts.[4] Originally ParScore- Scranton were being used for these quizzes. This required that the ParScore forms be submitted to the university testing center to be graded. Therefore scantron forms are not very effective tools for active learning in the classrooms.

The use of electronic student response systems such as "clickers" are effective tools instructors can gain real-time feedback on student comprehension of the fundamental concepts.[13-16] Clickers are electronic handheld devices that communicate wirelessly with the instructor's laptop computer or a receiving device located in the classroom. They can be used in multiple-choice question or quiz. Students' responses by clickers are transmitted to the instructor computer or the receiving device and results are provided instantaneously in the form of a histogram. Students receive immediate feedback on their answers and the instructor receives immediate feedback on the students' understanding of the fundamental concepts. If the results are not satisfactory, the instructor can review the topics again and give the same or similar questions in a later date to see if there is an improvement on students' comprehension of the fundamental concepts.

Examples of Conceptual Questions for Active Learning Instruction and Assessments

The authors have been using the available concept questions in textbooks[16-20], as well as developing their own questions for a range of difficult topics in thermodynamics and heat transfer. These questions have increasingly been used as both formative and summative assessment tools. Most questions are relatively straightforward and are in a true/false or multiple-choice format. It has been observed that a student may do well on solving quantitative problems yet perform poorly on conceptual questions. After students were introduced to given topics in a chapter of textbook, homework problems were assigned and collected, multiple choice quizzes were given in class on the associated topics. Responses to multiple choice questions were submitted by students using there clicker devices. The results for each question were displayed on the classroom screen. In most cases less than 50% of students answered the questions correctly if the topic was introduced for the first time. Student could see the results on a bar chart and the correct answer was identified on the chart Therefore, students could see immediately whether their responses were correct. The instructor discussed the results with the class and provided additional information to resolve any misconception. The same or similar questions were given later during the class period or in the following lecture to see if there were any improvement on students' performance. The results showed drastic improvement, but never all students responded to questions correctly. Below are a few examples of questions used in thermodynamic and heat transfer courses.

Example 1: If the air pressure is 30 psi gauge, what is it in psi absolute? The multiple choice responses were given as: (A) 15 Pisa, (B) 30 Pisa, or (C) 45 Pisa.[13] The instructor asked students to round off to two significant digits, hence students had to round-off the atmospheric pressure to be 15 psi. Students had 30 seconds to respond using their I>Clicker, during which time the instructor was completely silent and students could discuss talk with other students. After students submitted their choices for answering the question, the results were displayed on the classroom projector screen as shown in Fig, 1. The figure shows that 22 students (or 29% of the class) selected (A), 19 selected (B), 35 selected (C) and one selected (D). The correct choice was (C) which is shown as a green bar in Fig.1. This example was based on one of the earliest lectures in the semester given by one of the authors in the first course in thermodynamics. A review of pressure was conducted prior to asking the above question. The emphasis of review was on atmospheric, absolute and gauge pressure. The results of responses by students is an example of a surprising observation which is revealed by classroom pooling: many students often don't understand the most basic points in a lecture. The instructor was initially surprised by the number of incorrect answers. This question was not intended to be tricky, but just the opposite. It was designed to be an easy "warm-up". The instructor often asked the same question on the following class period. It was intended to be an encouraging question which should have a very high number of correct responses. Yet results showed a significant part of the class (over 50%) answered the question incorrectly. The high number of incorrect responses to seemingly simple questions continues to surprise the instructor.

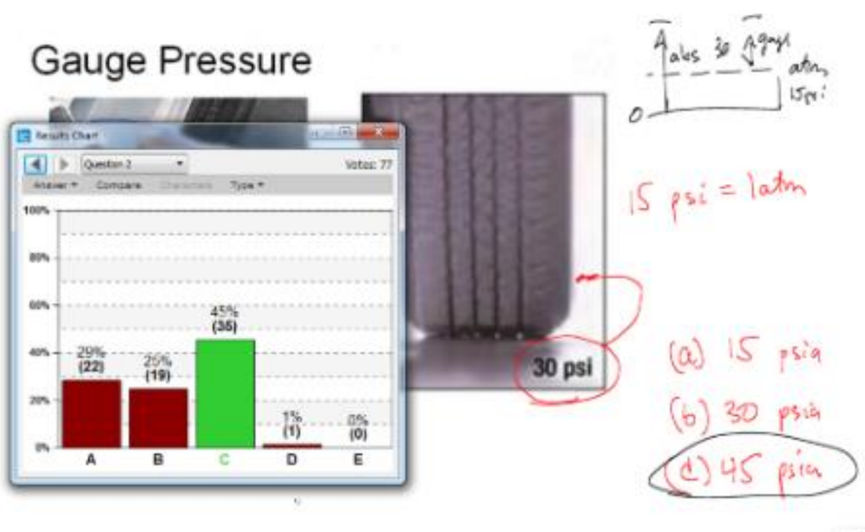

Figure 1. Typical use of clickers to assess student learning in the classroom. Question about the absolute pressure of the air in a passenger tire.

The following true/false questions were given near the beginning of semester in the second course in thermodynamics. They are based on the topics covered early in the first course in thermodynamics.

Example 2: Identify the following items as (A) True or (B) False

1. For a composite system consisting subsystems (a) and (b), the overall pressure is always expressed as $P = P_a + P_b$
2. For a composite system consisting subsystems (a) and (b), the overall enthalpy is always expressed as $H = H_a + H_b$
3. For a composite system consisting subsystems (a) and (b), the overall specific entropy is always expressed as $s = s_a + s_b$
4. The volume of a closed system cannot change during a process
5. A control volume is a special type of closed system that does not interact in any way with its surroundings
6. Heat transfer and work are thermodynamic properties
7. The change in specific entropy depends on the path of a process.

Figure 2 shows the results of students' responses. The correct answers are shown in green. The correct answer to question 3 is (E) The figure shows that more than 50% of students submitted wrong answers for question 3. It is clear that the majority of students who had passed the first course in thermodynamics, still did not realize the specific entropy is an intensive property and the specific entropy of the composite system cannot be obtained by simply adding the specific entropy of the system. Again, the majority of student submitted incorrect responses to question 5, not realizing that specific entropy is a thermodynamics property, hence the change of entropy is independent of the path of process.

Example 3: The questions in Fig 3 are related to heat transfer in steady state, one dimensional, heat conduction in fins and transient heat conduction. The correct answers are shown in green. The bar charts for the results of answers to the questions show that less than 50% students had a good understanding of the concepts behind Bi number, even though it was previously described in previous lectures. After the pop quiz, the instructor discussed the significance of Bi number in heat transfer and a similar quiz was given in the following class periods.

Students Feedback on Use of Clicker

During the last class period in the heat transfer in fall 2016 a survey was conducted to get feedback from student regarding the use of clickers. 27 out of 29 students in the course participated in the survey (2 were absent). The first questions asked if students are or were using I>Clickers in their other engineering courses. Not all students responded to this question; 19 responded yes and 1 student indicated that he/she was not or had not used clicker in any other courses.

Figure. 2 Results of student responses in second semester thermodynamics course to questions in Example 2.

The second question asked students including this class, in how many other courses that they have taken were I>Clickers used. Only 18 students responded to this question (obviously all were using their clickers in the heat transfer course). One student indicated one course, three stated two courses, one indicated 3 courses, eight answered four courses, four indicated five courses, and one stated eight course.

Items 3 through 14 on the survey asked students about their opinion about the specific statement on the survey questionnaire. Students had the following choices: strongly disagree (SD = 1point) disagree (D =2), Neutral (N=3), agree (A =4) and strongly agree (SA =5). Table 1 displays the statement on the survey instrument and the summary of responses by students for each statement.

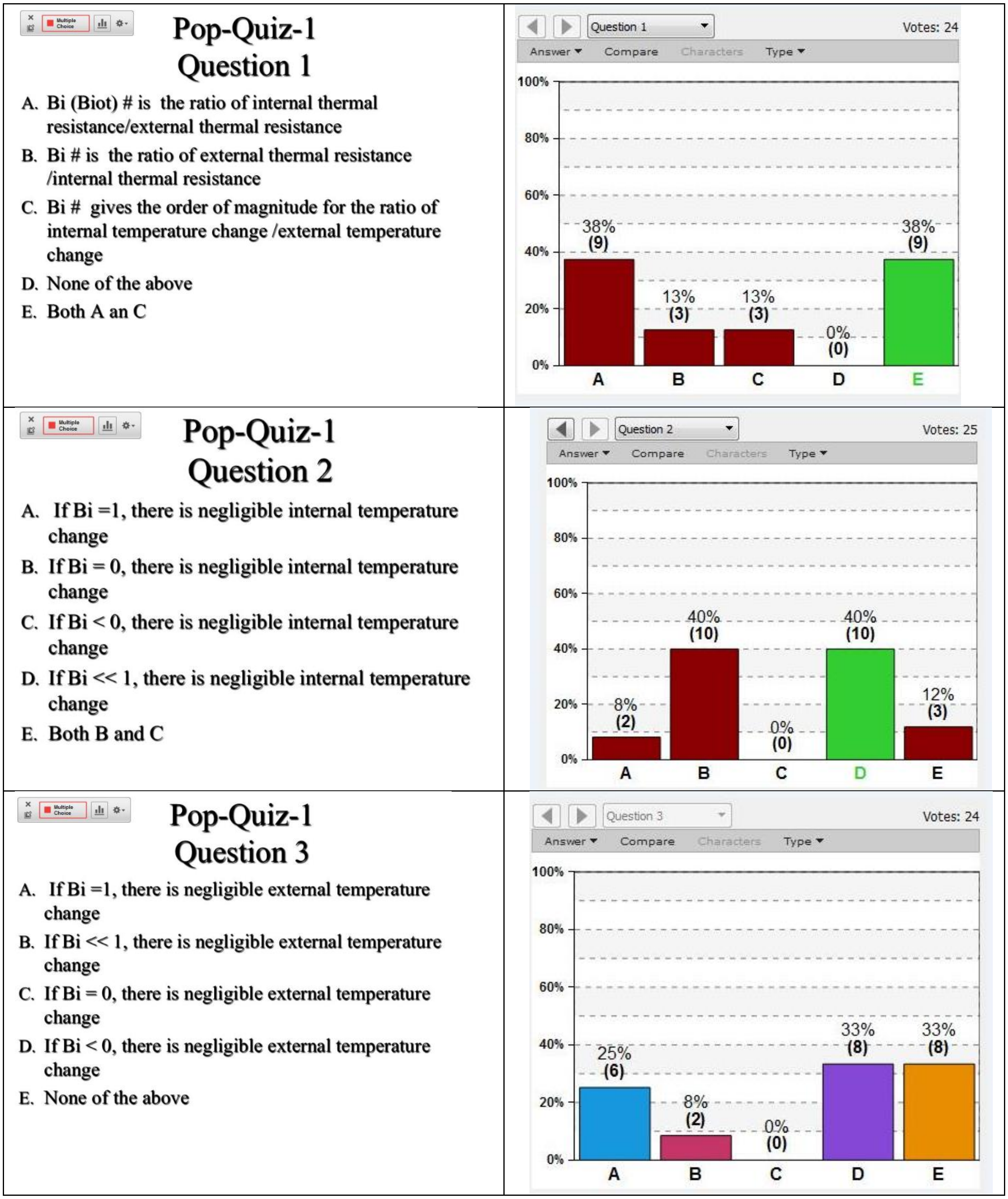

Fig. 3 Questions and the results of student responses to question in Example 3.

Table 1. End of semester survey

#	Statement	SD	D	N	A	SA	N	Average
3	I>Clicker is an efficient tool to take student attendance	2	1	2	10	12	27	4.1
4	I>Clicker is a good tool to assess student knowledge through true/false or multiple choice quiz questions	1	3	4	12	7	27	3.8
5	I>Clicker allows students to find out immediately if their answers to quiz questions were correct	1	0	1	8	17	27	4.5
6	Use of I>Clickers in this course helped me be alert in the class	2	1	0	13	11	27	4.1
7	Use of I>Clickers in this course helped me to participate in the class activities	1	2	1	11	12	27	4.1
8	Use of I>Clickers in this course helped me to enjoy seeing if my answers were correct	2	0	3	12	10	27	4.0
9	Use of I>Clickers in this course helped me to learn new concepts	2	2	5	14	4	27	3.6
10	Use of I>Clickers in this course helped me to attend class on regular basis	2	3	6	9	7	27	3.6
11	Should we continue using I>Clicker in engineering courses?	2	2	5	11	7	27	3.7
12	It is better to switch to I>Clicker-2?	7	6	10	3	0	26	2.3
13	Would you make sure to complete the reading or watching lecture video assigned prior to coming to class?	5	4	9	7	2	27	2.9
14	Will flip teaching help the learning process?	2	3	4	11	7	27	3.7

The super majority of students agreed (average > 4.0) that clickers: are an efficient tool to take student attendance; allows students to find out immediately if their answers to quiz questions are correct, the use of instrument helped them to be alert in the class, increase students participation in the class activities, helped s students to enjoy seeing if their answers were correct. Most students preferred not to switch to I>Clicker 2. The differences between I>clicker 1 and I>clicker 2 were explained at the beginning of the semester. I>clicker 1 which is discontinued can be used only to answer to true/false or multiple choice questions. I>clicker 2 is more advanced; it has all the functionalities of I>clicker 1, but students can enter text or numerical values to answer questions. At the start of semester, it was decided to use I>clicker 1, because many of students had already owned one.

Students' responses to question 13 was weak. They did not fully agreed that in a flipped classroom strategy they would make sure to complete the reading or watching video lectures assigned prior to coming to class. Wikipedia defines flipped classroom as: "an instructional strategy and a type of blended learning that reverses the traditional learning environment by delivering instructional content, often online, outside of the classroom. It moves activities, including those that may have traditionally been considered homework, into the classroom. In a flipped classroom, students watch online lectures, collaborate in online discussions, or carry out research at home and engage in concepts in the classroom with the guidance of a mentor." But there was more agreement that flipped teaching or flipped classroom helps the learning process.

Question 15 asked which version of I>Clicker they owned. Ten indicated I>Clicker-1 and 17 stated I>Clicker-2.

The survey encouraged students to include additional comments. The following is the list of few comments made by Students.

- I think it is great and the professor can see if his explanation helped students or if he needs to revisit that given concept. Should be used in all engineering courses
- Would like to have seen the I clicker used as a method of class to help students understand each step in order for approaching problems
- Longer time to answer questions
- Should be able to rent it for the course of my college career
- It is good
- I-clickers can be inconvenient, especially if one forgets to bring it to class and 50 quiz problems are decided to be asked
- I-clicker is helpful, but written quizzes there are partial
- Should be given a little more time to answer question, Sometimes there were few workout problems and it was tough make it in the given time for me.
- I-clicker 2s need more time for calculations

Conclusions

Electronic pooling has been used in multiple thermo-fluid classes and the instructional strategy has continue to evolve over the semesters. Repeatedly asking similar questions throughout the lecture and over multiple class meetings has been found to be effective and well-received by students. There also appears to be significant benefits to not assuming that students "get-it" after answering a question correctly once. Repeated quizzing is effective and electronic pooling allows this to be done rapidly and efficiently. A second conclusion is that electronic pooling should be used with adaptive questioning when a significant number of students answer question incorrectly. Instead of explaining the correct answer and grading the responses, the instructor spends more time asking additional simpler and focused questions, with the intent to lead students to the correct answer. Overall, having prompt assessment of student understanding has been found to improve student's conceptual understanding of the material.

References

1. Prince, M., Vigeant, M., and Nottis, K. "Development of the heat and energy concept inventory: Preliminary results on the prevalence and persistence of engineering students' misconceptions," *Journal of Engineering Education*, 101(3), 2012, 412-438.
2. Ngothai, Y. and Davis, M.C. "Implementation and analysis of a Chemical Engineering, Fundamentals Concept Inventory (*CEFCI*)," *Journal of Education for Chemical Engineers*, Elsevier, 7 (2012) e32–e40
3. Dukhan, N. and Mark Schumack, M. "Understanding the Continued Poor Performance in Thermodynamics as a First Step toward an Instructional Strategy," *ASEE-2013-8096*, *Proceedings of the 2013 ASEE Annual Conference*, June 23-26, Atlanta, Georgia
4. Karimi, A. and Manteufel, R., "Reinforcement of the Understanding of Fundamental Concepts in a Thermodynamics Course*," ASEE-2014-10626, Proceedings of the 2014 ASEE Annual Conference*, June 15-18, Indianapolis, IN.
5. Karimi, A. and Manteufel, R., "Assessment of Student Learning Outcome in an Introductory Thermodynamics course*."* ASEE-2012-5503, Proceedings of the 2012 ASEE Annual Conference, June 10-13, San Antonio, Texas.
6. Karimi, A., "An Approach in Teaching Applied Thermodynamics," IMECE2008-6812, Proceedings of ASME International Mechanical Engineering Congress and Exposition, November 2-6, Boston, MA
7. Karimi, A. and Manteufel, R., "Does Student Access to Solution Manual Pose a Challenge?" ASEE-2011-2753, Proceedings of the 2011 ASEE Annual Conference, June 26-29, Vancouver BC, Canada.
8. Peuker, J. M., & Brock, J. M., & Peuker, S., "*Effect of Multiple Choice Testing on Student Performance in an Introductory Engineering Course," ASEE 2013-5889*, Proceedings of the 2013 ASEE Annual Conference & Exposition, *June 23-26*, Atlanta, Georgia.
9. Biggerstaff, A. O., and Wambeke, B., "*Investigation of Probabilistic Multiple-Choice in a Structural Design Course," ASEE 2016*- 14674, Proceedings of the 2016 ASEE Annual Conference & Exposition, June 26-27, New Orleans, Louisiana.
10. Aden-Buie, G. A., & Kaw, A., & Yalcin, A., & Pendyala, R. "*Are Multiple-Choice Questions Suitable for a Final Examination in a STEM Course?,"* ASEE-2014-9042, Proceedings of the 2014 ASEE Annual Conference & Exposition, June 15-18, Indianapolis, IN.
11. Timmermann, D., & Kautz, C. H., "*Multiple Choice Questions that Test Conceptual Understanding: A Proposal for Qualitative Two-Tier Exam Questions,"* ASEE-2014-13350, Proceedings of the 2016 ASEE Annual Conference & Exposition, June 14-17, Seattle, Washington.
12. Wertz, R., Ross, M. C., Purzer, S., Fosmire, M., and Cardella, M. E., "*Assessing Engineering Students' Information Literacy Skills: An Alpha Version of a Multiple-Choice Instrument,"* ASEE-AC 2011-1273, Proceedings of 2011 ASEE Annual Conference & Exposition, June 26-29, Vancouver, BC.
13. Manteufel, R., Active Learning using a Classroom response System in Thermodynamics, Proceedings of 2016 ASEE-GSW section Conference, paper number 111.
14. Hung, W. P., "*Clicker Clicks It*,"ASEE AC-2011-1273, Proceedings of the 2011 ASEE Annual Conference, June 26-29, 2011,Vancouver BC, Canada.
15. Lapp, M., Ringenberg, J., Summers, K. J., Chivukula, A. S., and Fleszar, J., "*The Mobile Participation System: Not Just Another Clicker,"* ASEE-2011-2121, Proceedings of 2011 ASEE Annual Conference & Exposition, June 26-29, 2011,Vancouver, BC.
16. Falconer, J. L., deGrazia, J., and Weimer, A. "*The Use Of Clickers In The Engineering Classroom,"* Proceedings of 2005 Annual Conference & Exposition, June 12-15, Portland, Oregon.
17. Cengel, Y. A., and Boles, M. B, Thermodynamics, An Engineering Approach, 7th Edition, McGraw Hill, New York, 2011.
18. Moran M.J., Shapiro, H.N., Boettner, D.D, and Bailey, M.B., Fundamentals of Engineering Thermodynamics, 8th Edition, John Wiley and Sons, Inc.,New York, 2014.
19. Holman, J.P., Heat Transfer, Tenth Edition, McGraw Hill, New York, 2011
20. Bergman, L. B., Lavine, A.S., Incropera, F. P., Dewitt, D. P., Introduction to Heat Transfer, Sixth Edition, John Wiley & Sons, Inc., 2011.

Amir Karimi

Dr. Amir Karimi is a Professor of Mechanical Engineering at The University of Texas at San Antonio (UTSA). He received his Ph.D. degree in Mechanical Engineering from the University of Kentucky in 1982. His teaching and research interests are in thermal sciences. He has served as the Department Chair, Associate Dean of Academic Affairs of Engineering, and the Associate Dean of Undergraduate Studies. Dr. Karimi is a Fellow of ASEE, a Fellow of ASME, senior member of AIAA, and holds membership in ASHRAE, and Sigma Xi. He has served as the ASEE Campus Representative, ASEE-GSW Section Campus Representative, and served as the Chair of ASEE Zone III (2005-07). He chaired the ASEE-GSW section during the 1996-97 academic year.

Randall Manteufel

Dr. Manteufel currently serves as an Associate Professor of Mechanical Engineering at The University of Texas at San Antonio (UTSA). His teaching and research interests are in the thermal sciences. He has won several teaching awards, including the 2012 University of Texas System Regent's Outstanding Teaching Award and the 2013 UTSA President's Distinguished Achievement Award for Teaching Excellence.