Toward the effective use of voting machines in physics lectures

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A ''voting machine'' is a generic name for wireless-keypad in-class polling systems used by students to answer multiple-choice questions during lectures. We present our experiences gained while distributing and using voting machine modules. Using voting machines with carefully designed sets of multiple-choice questions and instantaneous voting summaries improved classroom dynamics and provided students with several opportunities per concept to test their understanding. Three question sets developed for the electricity and magnetism quarter of a year-long introductory physics course are included as examples.
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I. INTRODUCTION

A ''voting machine'' is a generic name for in-class polling systems used by students to answer multiple-choice questions during lectures.[1,2] Some of these machines are offered by publishing companies as a teaching aid in support of their textbooks. It has been demonstrated that the use of voting machines improve classroom dynamics, in particular, student–lecturer interactivity,[3] but little has been published concerning the development of research-based strategies for their use. We report an initial study in which carefully designed question sets improved classroom dynamics and gave students rapid feedback regarding their understanding of selected concepts.

It has long been understood that traditional forms of lecture instruction are not optimal for teaching concepts. More than 20 years ago, Peters illustrated this point while studying honors students with conceptual difficulties.[4] Since then, Mazur,[5] Crouch and Mazur,[6] and others have contributed to the development of new approaches. Price and Driscoll inquired into the spontaneous transfer of problem-solving skills and suggested the importance of feedback.[7] Yager reported on the effectiveness of using a constructivist learning model to minimize cognitive loading.[8] The basis for this model is that understanding is ''constructed'' by the learner, who has as much impact on his/her understanding as the instructor. Therefore, instructors need to seek out student ideas and encourage discussion. Mayer *et al.* showed that a series of small visual steps is more effective in learning than a single comprehensive presentation.[9] VanLehn *et al.* found that learning is enhanced if students reach an impasse sometime during the assimilation process.[10] Dykstra *et al.*[11] outlined a strategy in which students are exposed to phenomena that induce a conflict with previous conceptions, and then participate in a ''town meeting'' discussion to resolve perceived discrepancies.

The proper use of voting machine questions in lectures includes all of these approaches. The overriding concern is not technology, but rather the types of questions asked and the methodologies for using them. Voting machines used with question sets based on a constructivist model of learning can improve classroom dynamics, as indicated both by frequent animated student discussions and student surveys. Voting machines also help students and lecturers to understand in real time whether a concept has been assimilated or additional effort is required. The purpose of this paper is to report interesting but sometimes preliminary results in a timely manner with the hope that the information will be useful to researchers and instructors interested in using voting machines.

II. QUESTION METHODOLOGY

In previous research, we have studied the context dependences of student learning.[12–14] Our results showed that by using carefully designed question sets, the effects of specific contextual features on students' learning can be measured and evaluated.[13] We have extended this research and have identified a promising method of question design for use with voting machines.[15–18]

Students are presented with a three-question sequence in which all three questions focus on the same concept, but have different features. The questions appear similar to experts, but appear different to beginning students who often are attracted to surface features of the context.[19] Voting summaries are shown to the class after each question, followed by a discussion with students. The first question is a simple warm-up that builds confidence. Because most students answer the first question correctly, the discussion typically is brief.

The second question is more difficult, and significant fractions of students usually select different answers. The spread of selected answers in the ensuing voting summary exhibits an impasse, and students realize that they do not yet fully grasp the concept. The correct answer is not revealed at this point. Rather, students are asked to volunteer why they selected each of the answers, and real viewpoints are expressed. It is important to take another ''straw'' vote after the discussion before revealing the correct answer. This vote can be done by voice or by having students reanswer the same voting machine question.

The final question is used to check whether students have assimilated the concept. It also must be difficult and have surface features different from the previous two. Usually, most students answer correctly and discussion is brief. In a few cases students will continue to select incorrect answers, indicating that additional work is needed. The instructor should then extend class discussion and take another vote on the third question.

III. RESEARCH CONTEXT AND VOTING MACHINE USAGE

Voting machines were used in the winter 2003 and winter 2004 quarters of a three-quarter calculus-based introductory physics course for first year engineering honors students at The Ohio State University. The emphasis was on electricity and magnetism. Approximately 230 students were divided into three lecture sections, only one of which used voting machines. Lecture sections using voting machines were handled differently for the two quarters. In winter 2003, 65 students were formed into the same 17 groups for laboratory, recitation, and lectures. These groups had assigned seating during lectures, and each group was given a single handheld unit.[18] In winter 2004, 62 students were formed into 17 groups for laboratory and recitation activities, but chose their own seating during lectures. Each student was furnished his/her own handheld unit and voted as an individual.

In winter 2003 all groups voted, though some group members occasionally were absent. Handhelds were gathered and returned for each lecture. In winter 2004, handhelds were given to all students at the beginning of the quarter. All but three were returned at the end of the quarter, but several had dead batteries. Students frequently forgot to bring their units to class, or stopped using them when they malfunctioned. Over the quarter, the number of students voting dropped from 90% to approximately 60% of those attending lectures. This problem was resolved by changing the distribution system.

In the ensuing spring and fall quarters of the same sequence, mail-slot holders were placed along the walls in the lecture hall for each handheld. Students picked up and returned the units before and after each lecture, and the units were periodically checked by lab demonstration personnel. More than 90% of students attending lectures voted without an appreciable decrease in this percentage throughout both quarters.

IV. EXAMPLES OF THREE-QUESTION SEQUENCES

The following examples of three-question voting machine methodology originally were presented as PowerPoint slides, but were reformatted for publication. The typical time to complete a three-question sequence decreased from 8 min to 5–6 min as students and the lecturer gained experience.

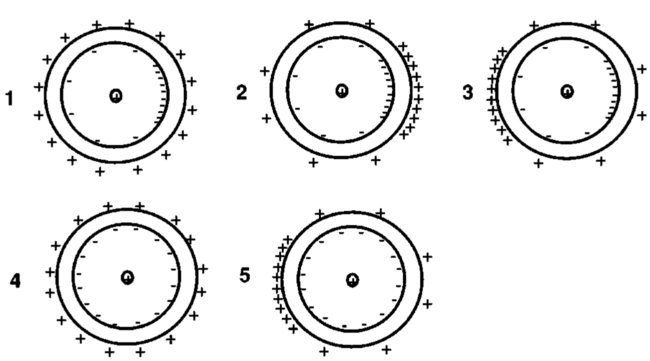


Fig. 1. Electrostatics, question 1: A positive charge is kept (fixed) at the center inside a fixed spherical neutral conducting shell. Which of the following represents the charge distribution on the inner and outer walls of the shell?

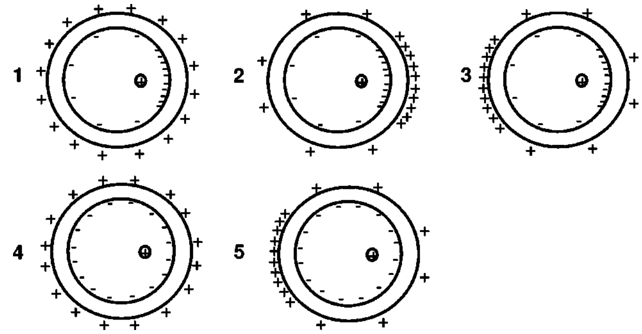


Fig. 2. Electrostatics, question 2: A positive charge is kept fixed off-center inside a fixed spherical neutral conducting shell. Which of the following represents the charge distribution on the inner and outer walls of the shell?

The first question was voted on by groups in winter 2003, and illustrated the concept that the zero electrostatic field inside a metal isolates inside from outside charges.

> *Electrostatics, question 1 (Fig. 1).* "A positive charge is kept (fixed) at the center inside a fixed spherical neutral conducting shell. Which of the following represents the charge distribution on the inner and outer walls of the shell?" All groups selected 4, which is the correct answer.

> *Electrostatics, question 2 (Fig. 2).* "A positive charge is kept fixed off-center inside a fixed spherical neutral conducting shell. Which of the following represent the charge distribution on the inner and outer walls of the shell?" The selections were varied; eight groups (47%) selected 1, which is the correct answer. However, six groups (35%) selected 2, and three groups (18%) selected 3. After a brief but animated discussion in which the correct answer was not revealed, a straw voice vote was taken. All groups selected the correct answer, which was then revealed.

> *Electrostatics, question 3 (Fig. 3).* "A positive charge Q is kept fixed at the center of a spherical neutral conducting shell. A negative charge $-Q$ is brought near the outside of the sphere. Which of the following represents the charge distributions?" This question is a reversed version of question 2. Fifteen groups (88%) selected 4, which is the correct answer.

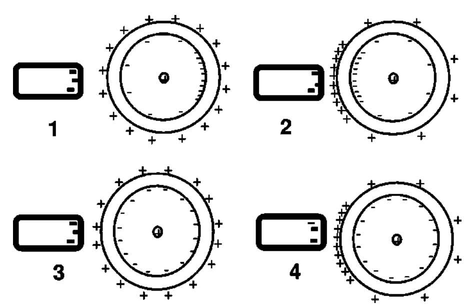
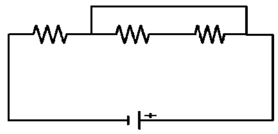
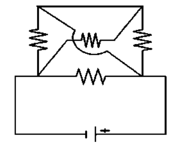


Fig. 3. Electrostatics, question 3: A positive charge Q is kept fixed at the center of a spherical neutral conducting shell. A negative charge $-$Q is brought near the outside of the sphere. Which of the following represents the charge distributions?



A. V/R **B.** V/(2R) **C.** V/(3R)
D. 2V/R **E.** 3V/R

Fig. 4. Circuits, question 1: In the following figure all resistors have the same value R and the voltage of the battery is V. Find the total current flow through the battery. *One way to do this is to trace each possible path from one side of the battery back to the other side*.



A. V/R **B.** V/(2R) **C.** V/(3R)
D. 2V/R **E.** 3V/R

Fig. 6. Circuits, question 3: Consider the circuit given below. Again, each resistor has the same value R and the battery's voltage is V. Find the total current flow through the battery. *The loop in the diagonal wire means that it loops over the other wire and is connected only on its ends*.

Students in the two classes frequently were confused if they could not immediately redraw an electrical circuit so that its elements were either in series or parallel. Tracing wires to see how elements were placed into circuits was not a popular strategy at first. The next set of questions was voted on by individual students in winter 2004.

Circuits, question 1 (Fig. 4). "In the following figure all resistors have the same value R and the voltage of the battery is V. Find the total current flow through the battery. *One way to do this is to trace each possible path from one side of the battery back to the other side*." In this example, the bare wire shorts out two of the resistors, so the correct answer is V/R. Eighty-one-percent of the votes were correct, and students seemed satisfied after a brief discussion.

Circuits, question 2 (Fig. 5). "Now, you add one wire to the same circuit, as shown. Though there is only one additional wire, there are more paths going from one side of the battery to the other. Find the total current flow through the battery at this time." In this case, all three resistors are in parallel, and the correct answer is 3V/R. Only 40% of students selected this answer. After voting, the correct answer was not immediately revealed, resulting in a barrage of student questions. The lecturer then traced the wires, under the direction of the students, to determine how each particular resistor was connected in the circuit.[20] After a series of questions, a voice vote was taken. Almost 90% of students selected the correct answer, which was then revealed.

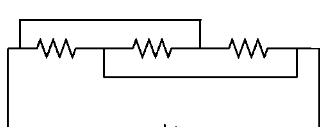
Circuits, question 3 (Fig. 6). "Consider the circuit given below. Again, each resistor has the same value R and the battery's voltage is V. Find the total current flow through the battery. *The loop in the diagonal wire means that it loops over the other wire and is connected only on its ends*." At first this problem seems different than the first two. However, the resistor on the right-hand side is shorted out as occurred in the first question, and the other three resistors are in parallel as in the second question. The correct answer is again 3V/R. This time, 86% of the students voted for the correct answer, which was then revealed. However, a few students that answered the first question failed to answer question three in the 2 min allotted, and still may have had difficulty tracing wires. Some additional discussion was required.

The third example illustrates Ampere's Law, $\oint \vec{B}\cdot\vec{dl} = \mu_0 I$, which holds for any loop shape and geometry of current passing through the loop. However, the lack of dependence on shape and geometry is not always emphasized. This concept was presented for voting in the following series of questions.

Ampere's Law, question 1 (Fig. 7). "An Amperian loop is drawn around two current carrying wires as shown below. What is the value of $\oint \vec{B}\cdot\vec{ds}$ around the loop?" Ninty three percent of students selected C, which is the correct answer. Students seemed satisfied after a short discussion.

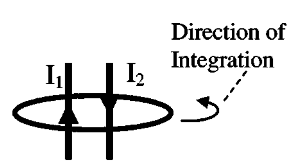
Ampere's Law, question 2 (Fig. 8). "An irregularly-shaped Amperian loop is drawn around a wire carrying a current I. The wire is inclined at an angle θ with respect to a normal to the plane of the loop. What is the value of $\oint \vec{B}\cdot\vec{ds}$ integrated around the loop?" The effect of the wire's angle on the integral had not been discussed, and the wire was clearly off-center in the loop. Only 14% of students selected the correct answer, which is A. Several minutes of discussion followed, with students asking the questions and doing most of the talking. Following the discussion, over 80% of the students selected A, which was then revealed as the correct answer.

Ampere's law, question 3 (Fig. 9). "An Amperian loop is drawn around wires carrying current I_1 and



A. V/R **B.** V/(2R) **C.** V/(3R)
D. 2V/R **E.** 3V/R

Fig. 5. Circuits, question 2: Now, you add one wire to the same circuit, as shown. Though there is only one additional wire, there are more paths going from one side of the battery to the other. Find the total current flow through the battery at this time.



A. $\mu_0 I_1$ **B.** $\mu_0 I_2$ **C.** $\mu_0 (I_1 - I_2)$
D. Zero **E.** $\mu_0 (I_1 + I_2)$

Fig. 7. Ampere's law, question 1: An Amperian loop is drawn around two current carrying wires as shown below. What is the value of $\oint \vec{B}\cdot\vec{ds}$ around the loop?

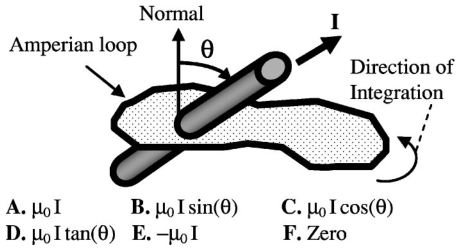


Fig. 8. Ampere's law, question 2: An irregularly shaped Amperian loop is drawn around a wire carrying a current I. The wire is inclined at an angle θ with respect to a normal to the plane of the loop. What is the value of $\oint \vec{B}\cdot\vec{ds}$ integrated around the loop?

> I_2. The loop is irregular and in places folded over, as shown by the arrows. The wires are inclined at angles θ_1 and θ_2 with respect to a normal to the plane of the loop. What is the value of $\oint \vec{B}\cdot\vec{ds}$ integrated around the loop?'' This time 70% of the students voted for F, the correct answer, and 18% for E, which was almost correct, but did not take into account that the path of the loop around current 1 was reversed. Sometimes, as in this case, question 3 reveals that additional work is needed. The lecturer then must be prepared to adapt lecture material to the needs of the students. In this case, a brief subsequent discussion concentrated mostly on applying the right-hand rule to the path to determine the sign of the contribution.

V. RESULTS OF STUDENT SURVEYS

In end-of-quarter surveys, students were asked to rate statements from 2 (strongly agree) to -2, (strongly disagree). For example, in winter 2003 the mean was 1.59 for the statement ''having the same groups in lecture, recitation and lab has helped my group become a better team.'' However, the mean was only 0.84 for the statement ''I like using the voting machine.'' There were several possible contributing factors. The initial voting machine hardware had difficulties, and less assertive students initially might have been penalized by voting in groups.

Approximately 8% of students in a mid-course survey stated that when they could not answer the questions, they simply deferred to others in their group. In response, the lecturer then encouraged discussion on all questions, independent of the percentage of correct group responses. During the quarter, 15% of students also stated that they disliked the assigned seating required for group voting. Despite these negative statements, an end-of-quarter survey revealed that almost half of the students felt that discussing questions within their group was the most positive aspect of using voting machines.

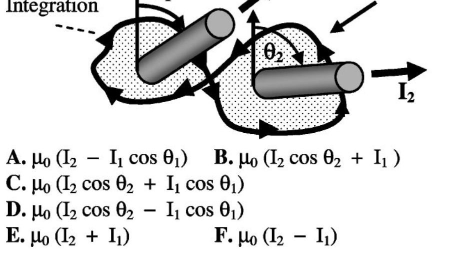


Fig. 9. Ampere's law, question 3: An Amperian loop is drawn around wires carrying current I_1 and I_2. The loop is irregular and in places folded over, as shown by the arrows. The wires are inclined at angles θ_1 and θ_2 with respect to a normal to the plane of the loop. What is the value of $\oint \vec{B}\cdot\vec{ds}$ integrated around the loop?

In winter 2004, the voting machine hardware was improved. Students voted as individuals and were permitted to choose their own seating. The mean for ''I like using the voting machine'' rose to 1.30 out of 2. Students enjoy using the voting machine. Typically, several students from the other 2004 lecture sections participated, and lecturers in sections not using the voting machine received repeated requests to do so from their students. In the end-of-quarter survey, only 5% of the responses were negative. Most students had very positive comments: ''The voting machine was awesome. We get to think about a question as soon as we talk about it. I wish we could do more.'' ''I thought the voting machine was a great idea because it gave the professor valuable feedback as to when the students were confused. I think this kind of system should be implemented in other types of classes as well.'' ''It's cool, an interactive way of increasing our physics understanding.''

VI. RESULTS OF STUDENT VOTING RESPONSES

Understanding, as indicated by the number of correct answers for the simple first question, degraded for the more complex second question. After discussion, a higher fraction of correct answers is observed for the equally complex third question. This pattern was typical not only for the three sets of questions shown, but for many other question sets used in the course. We suspect that a pattern in which the second question provides an impasse may represent a more effective learning pathway for the lectures, because it incorporates many of the features recommended by well-supported constructivist approaches.[11,21]

The second set of questions on Ampere's law exhibited a possible misconception. A closer look at this question showed that 48% and 33% of students selected answers B or C, respectively. In both of these answers, the angle of the current played an explicit role, resulting in multiple distracters for the same misconception. Students believed that the answer had to include angles. The number of correct answers for the third question was only 70%, somewhat lower than expected because 18% of students did not take the path into account. The number of incorrect answers indicated that more discussion was required regarding the sign of the contribution to the line integral around the loop versus the direction of the current through the loop.

To further study the possible implications of student voting results, additional tools are needed. For example, we could use concentration analysis to study whether students' low scores on the second questions imply that they have misconceptions or randomly selected incorrect ideas.[22] Misconceptions may be indicated when certain types of incorrect answers are highly favored. Correlation analysis of students' voting results and their performances also may reveal interesting relations.

After obtaining considerable anecdotal evidence, a first step was taken toward a more systematic evaluation study. The Ampere's law question was presented in all three lecture sections. One used the three-question voting machine sequence, while the other two used a transparency of question 3 and spent considerably more time lecturing about the correct answer. Question 3 was then placed on the second midterm a week after the lectures. In the non-voting-machine sections, 28 out of 160 students answered incorrectly (17.5%). In the voting machine section, 4 out of 62 (6.5%) answered incorrectly. Although not unquestionably statistically significant, the higher score for the voting machine section is promising and has motivated a more comprehensive ongoing study.

VII. SUMMARY AND IMPLICATIONS

As has been seen by others,[3] the use of voting machines in lectures can help to create a dialogue between individual students and between students and lecturers. As evidenced by end-of-quarter surveys, almost all students enjoyed using this technology.

We have experimented with several ways of distributing and using the voting machines. When students sat in groups and voted as a group in lectures, end-of quarter surveys indicated that they very much liked discussing questions with their group. However, in a midcourse survey, a few students stated that their group was dominated by a group expert, and several students expressed displeasure with having assigned seats in lectures.

When voting machines were given to individual students for an entire quarter there were fewer complaints, but the percentage of students voting in lectures decreased to approximately 60% of those attending lectures by the end of the quarter. Voting machine modules were then distributed for each class in the following two quarters, and the percentage of students voting remained well above 90%.

Using three-question sequences appear to help students assimilate concepts in a short period of time, though the long-term effects are yet to be studied. There is one promising indication that students using voting machines and three-question sets tend to perform better on a concept-oriented question than lecture sections not using the devices. A complete study is being formulated to fully test this latter possibility. Voting machines have now been used in classrooms for a decade. It is time to ascertain whether they can be used to enhance learning as well as increase interactivity.

ACKNOWLEDGMENTS

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[1]Examples include the Personal Response System manufactured by GTCO CalComp, ⟨http://www.gtcocalcomp.com/interwriteprs.htm⟩. The voting system used at The Ohio State University, which has two-way communication capability, was designed by Lei Bao and its construction was subcontracted. It is not yet commercially available.

[2]Voting systems are discussed at ⟨http://celt.ust.hk/ideas/prs/exp_share.htm⟩.

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