JOURNAL OF CHEMICAL EDUCATION

Article

pubs.acs.org/jchemeduc

Demonstration Show That Promotes and Assesses Conceptual Understanding Using the Structure of Drama

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ABSTRACT: Demonstration shows are a widely used form of Informal Science Education. While there is evidence that the shows are highly enjoyable, little work has been done to investigate the cognitive impacts of these shows. This article describes the development and production of *The Boiling Point*, a show that uses the structure of a play to support investigation of a chemical concept. Evaluation of this show provides evidence that this alternative form of demonstration show is not only enjoyable, but also promotes positive attitudes toward science and increases the audience's understanding of the target concept, as demonstrated by recurring assessment of concept knowledge embedded within the show.

KEYWORDS: *General Public, Elementary/Middle School Science, Inquiry-Based/Discovery Learning, Demonstrations, Public Understanding/Outreach, Misconceptions/Discrepant Events, Interdisciplinary/Multidisciplinary, Analogies/Transfer, Kinetic-Molecular Theory, Phases/Phase Transitions/Diagrams*

Informal Science Education (ISE) plays a key role in science education by providing learning opportunities in a broad range of out-of-school environments.[1] It also embraces a diverse set of learning outcomes which are described in the Strands of Learning (Table 1), published by the National Research Council.[2] These include outcomes like excitement and interest (Strand 1), which are strongly linked with informal programming, as well as outcomes like increased understanding of concepts and processes (Strands 2 and 3) that are more typically associated with classroom learning.

Table 1. Strands of Informal Science Learning[a]

	Learners will...
1	Experience excitement, interest, and motivation to learn more
2	Understand and use concepts, explanations, arguments, models, and facts related to science
3	Manipulate, test, explore, predict, question, observe, and make sense of the natural and physical world
4	Reflect on science as a way of knowing
5	Participate in scientific activities
6	Think about themselves as science learners

[a]From the National Research Council.[2]

Demonstration shows are a popular form of ISE performed by many groups at universities, museums, and other venues across the country. Many examples of these shows have been reported in this journal.[3−11] The majority of these publications report Strand 1 outcomes of excitement, interest, and appreciation as their primary goals and credit the spectacular, exciting, and visceral nature of demonstrations in achieving them.[12] However, few if any presenters target or assess the understanding and application of concepts described in Strand 2. Others explicitly eschew conceptual learning as a goal, stating, for example, "No attempt is made to give thorough explanations—in fact, such rigor is deliberately avoided".[6] This focus on providing entertaining experiences may be due to the notion that ISE is a leisure activity and thus incompatible with learning. It may also be due to a concern that an overtly educational presentation, and the subsequent assessment of any cognitive impacts, may undermine the audience's enjoyment, thereby diminishing attendance.[2]

The Amazing Chemical Circus[13] was a demonstration show designed to achieve the cognitive goals described in Strand 2 of

Received: June 22, 2015
Revised: October 29, 2015

DOI: 10.1021/acs.jchemed.5b00490
J. Chem. Educ. XXXX, XXX, XXX−XXX

Table 2. Elements and Structure of a Stage Play and of *The Boiling Point*

	Beginning		Middle		End
Stage Play	Introduction to CHARACTER in STATUS QUO	DRAMATIC QUESTION makes the audience engage in content to find out what happens	REVELATIONS provide essential information	PHYSICALIZATION of METAPHOR aids understanding of concepts and ideas	DRAMATIC QUESTION answered
Boiling Point	Host CHARACTERS introduce topic, invite children into investigation	CONCEPT QUESTION presented with possible answers	DEMONSTRATIONS provide evidence	PHYSICAL DRAMATIZATION models particulate phenomenon	CONCEPT QUESTION answered
		VOTE 1 on Question		VOTE 2 on Question	

ISE. It was created by Fusion Science Theater, an interdisciplinary team of chemists, educators, and theater artists, who were inspired by the ability of plays to engage audiences in difficult issues and concepts. The team adapted elements of applied drama to promote learning of the concepts demonstrated. Interestingly, placing cognitive outcomes as the show's main priority did not detract from the audience's enjoyment of the show. Assessment of cognitive and affective gains using pre- and postshow questionnaires showed significant increases in understanding, engagement, and self-efficacy.[13]

The script of the *Circus* was made available to other outreach groups. There have been some reports of adoption and adaptation by other users,[14,15] but a wider implementation has not yet been achieved. There are two likely explanations for this: Show production required a team of two actors, three chemistry teachers, a technical crew, and a studio theater; and the show was loosely scripted, consisting of a combination of scripted lines and an outline of teaching points. Because of these features, the *Circus* required expertise and facilities not available to typical presenters, which was an obstacle to the widespread use of the show to promote learning in diverse ISE venues.

■ RESEARCH GOALS

The goals of the current research were to further develop and refine the methods piloted in the *Circus* to design a demonstration show that

(1) improves the audience's knowledge of a chemical concept (Strand 2);
(2) increases audience interest, enthusiasm, and enjoyment of learning science (Strand 1);
(3) is scripted and transportable, and can be performed by other informal science educators.

To achieve these ends, a new show, "*The Boiling Point*",[16] was created and performed, and its impacts were evaluated.

■ DESIGN OF THE BOILING POINT

Whether intended for use in classrooms or museums, the content and structure of an educational experience designed to teach science concepts should be based on a sound theoretical foundation. Therefore, show development was informed by the description and requirements for conceptual development posited by the conceptual change model.[17] According to this framework, learners must recognize the insufficiency of their naïve conceptions and then engage in active learning to construct explanations that are comprehensible, plausible, and fruitful.

Most demonstration shows feature numerous demonstrations pertaining to a wide variety of chemical concepts. However, given the challenging nature of conceptual shift, *The Boiling Point* focused on one conceptual goal: the application of kinetic molecular theory to the phase change of liquid water to gaseous water. This target concept was selected for a variety of reasons:

(1) it is plagued by robust misconceptions;[18,19]
(2) it figures prominently in Next Generation Science Standards;[20] for grades 2, 5, and Middle School;
(3) it can be represented by a particulate model;
(4) it can be illustrated via relatively safe and portable chemical demonstrations.

The Boiling Point used four dramatic elements piloted in the *Amazing Chemical Circus: revelations*, *dramatic question*, *physicalization of metaphor*, and *character* (see Row 1 of Table 2). It aligned these elements into a structure that resembles that of a simple story or play. A story begins with the introduction of the protagonist in a status quo context and then introduces an event that disrupts that equilibrium. This raises the dramatic question of the play in the form of: How will things turn out for the protagonist? The audience will watch, process, and ultimately make sense of the revelations that follow to find out the answer to that question. To help the audience make meaning or derive the lesson of the story, plays convey metaphors in concrete terms (sets, props, masks, or choreography). For example, the fiddler on the roof is a metaphor for the uncertain, unstable, yet tenacious existence of the characters in the play of the same name. These elements and structure were selected for use in *The Boiling Point* because of their ability to pique and focus attention, motivate engagement with evidence, and support the formation of abstract concepts, activities that are critical in construction of a new concept.

The adaptation and arrangement of the four elements in *The Boiling Point* is shown in Row 2 of Table 2. The dramatic question of the play is replaced by a concept question posed near the start of the show: "What happens to [the molecules of] water when it boils?" This question creates a desire to know the answer, and encourages the audience to attend to the rest of the show to figure it out. In the middle, demonstrations are offered without explanation to provide information needed to answer the question. Since modeling has been shown to enhance

DOI: 10.1021/acs.jchemed.5b00490
J. Chem. Educ. XXXX, XXX, XXX−XXX

learners' ability to visualize and explain phenomena on a particulate level,[21] *The Boiling Point* included physical dramatizations that invite volunteers to play the role of water molecules during vaporization. As in a play, the answer to the concept question is not revealed until the end of the show.

In order to evaluate the learning that the show intended to promote, a unique assessment tool was implemented. The concept question, "What happens to [the molecules of] water when it boils?" was posed near the beginning of the show and at the end, just before the answer was revealed. Each time, four options were offered as possible answer to the question. They were, (1) "They disappear", (2) "They break up", (3) "They spread out", and (4) "I don't know". Distractors (1) and (2) were derived from previously published misconceptions.[18,19] The audience was then asked to vote for the best answer by ballot. This Recurring Question structure allowed before-and-after assessment of the audience members' understanding of the concept.

The last element conserved from the Amazing Chemical Circus was that of Host Character. *The Boiling Point* featured a scientist and a comic silent assistant who invited the audience members to engage in show content and facilitated interactions like Q&A, voting, and physical dramatizations.

Box 1. SYNOPSIS OF THE BOILING POINT

The Boiling Point begins with a welcome by two host characters, a Scientist and her Silent Assistant (mime), who solicit observations of a pot of boiling water. The Silent Assistant raises the question, "What happens to [the molecules of] water when it boils?" The characters present flat foam models of molecules and atoms and use them to present three possible answers as hypotheses: they disappear, they spread out, or they break up. They also present a fourth option: "I don't know", and ask the audience to vote by ballot for the choice they think is best.

After the vote, the characters perform demonstrations to help the audience answer the question. An open tube of a mixture of gaseous hydrogen and oxygen is positioned near a lit candle and allowed to combust. The lit candle is then placed at the spout of a kettle of boiling water where the steam extinguishes the flame. A balloon is placed on the spout of the same tea kettle. The balloon inflates as the water continues to boil, but when the kettle is removed and placed into an ice bath, the balloon contracts and the ambient air pressure pushes it into the body of the kettle. No oral explanations are given for the phenomena.

When the Silent Assistant asks why the demonstrations have occurred as observed, the Scientist explains the need for the science practice of representing particles of matter with physical models. The earlier two-dimensional space-filling model of the introduction is supplemented by a "Dance of the Water Molecules", wherein children from the audience don cardboard hydrogen and oxygen signs to enact the molecular explanation for the balloon and teapot demonstration. Each audience member votes again for the best answer to the question, "What happens to [the molecules of] water when it boils?" After the voting is completed, the Scientist and Silent Assistant lead a discussion with audience members to select the option best supported by the demonstrations and models.

SHOW PRODUCTION

The Boiling Point was developed by the Fusion Science Theater team over the course of a year via a cyclic process of writing, performance, assessment, reflection, and revision for another performance. A team of two actors and the playwright transported and performed the show at local community centers, classrooms, museums, science festivals, and other public venues. The running time for the show was approximately 35 min. A video of a performance of *The Boiling Point* is available on the Fusion Science Theater Web site at www.FusionScienceTheater.org.

Transfer of The Boiling Point to Another Group

To determine whether this script was useful and usable by others, Students Participating In Chemical Education (SPICE), a group of undergraduate students at the University of Wisconsin—Madison, were provided with training and materials to perform the show. SPICE members were already trained in performance of traditional demonstration shows and routinely received requests from local schools and organizations for performances.

EVALUATION OF THE BOILING POINT

To evaluate the effectiveness of *The Boiling Point* in meeting Learning Goals for Strands 1 and 2 for ISE, five performances at two locales were selected. Three performances were at the University of Wisconsin—Madison "Science Expeditions," and two at the Madison Children's Museum. Approval from the appropriate Institutional Review Boards was obtained for all data collected. Because the target audience for the show was children between five and 11 years old, only ballots and questionnaires that indicated that the child was in that range were included in the analysis. Upon their arrival, children were given a prelesson and a postlesson ballot (see Figure 1), a postshow attitude questionnaire, and a pencil. The prelesson vote occurred prior to the demonstrations (see Row 2 of Table 2) and provided assessment of the audience's prior knowledge of the molecular nature of water's phase transition from liquid to gas. The postlesson vote, taken after the physical dramatization of the demonstrations, asked the same question and was a measure of concept attainment. Ballots were collected immediately after each vote.

--first vote—	--first vote--	--first vote-	--first vote-	Circle one:
1	2	3	4	Boy | Girl
DISAPPEAR	SPREAD OUT	BREAK UP	I DON'T KNOW	Age:
--first vote--	--first vote--	--first vote-	--first vote-	

Figure 1. Paper ballots, provided to child audience members, included multiple-choice answers to the concept question ("What happens to [the molecules of] water when it boils?") and demographic information.

After the show, children were asked to fill out the attitude questionnaire. For younger children, parents were asked to help administer the questionnaire by writing down the children's answers but not influencing their responses. The questionnaire contained a series of items to be rated and one open-ended question. The most central items are reported here. The items, "How much did you like the show?", "The show made science

DOI: 10.1021/acs.jchemed.5b00490
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seem fun", "The show made science easier to understand", and "The show made me want to learn more science" were answered by choosing among the following: "not at all (0)", "a little bit (1)", "pretty much (2)", and "very much! (3)". (The choices were also illustrated with a frowny face, one smiley face, two smiley faces, and three smiley faces, respectively.) Another question asked, "Would you like to come to more shows like this one?" and could be answered by choosing "NO", "MAYBE", or "YES". The open-ended question read, "Tell us what you thought of the show in your own words".

Strand 2: Understand and Use Concepts

Overall, the percentage of children voting for the correct option increased from 41% (N = 93) in the prelesson vote to 76% (N = 88) in the postlesson vote. A chi-square analysis comparing these proportions was highly significant ($X^2_{(N=181)} = 23.1$, $p < 0.001$, effect size, phi = 0.357). The consistency of the before–after improvement can be seen in Figure 2, which shows strong

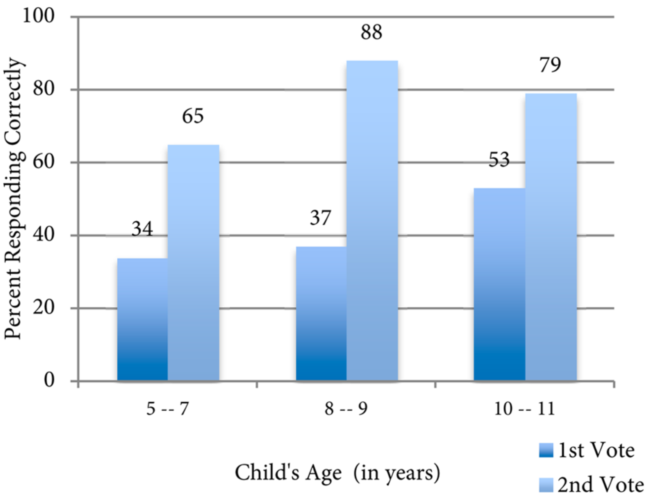

Figure 2. Percent of children answering concept question correctly on pre- and postlesson assessment of *The Boiling Point*.

and significant increases in concept understanding at each age level. (Age 5–7, $X^2_{(N=72)} = 6.7$, $p = 0.01$, effect size, phi = 0.305; age 8–9, $X^2_{(N=52)} = 14.2$, $p < 0.001$, effect size, phi = 0.523; age 10–11, $X^2_{(N=57)} = 4.2$, $p < 0.05$, effect size, phi =0.273).[22]

Strand 1: Interest and Motivation

As measures of interest and engagement, a majority of the children chose "very much!" in response to the questions regarding how much they liked the show (64%) and whether it made science seem fun (62%). As a measure of feelings of self-efficacy, 33% of the children said the show made science "very much!" easier to understand and another 37% responded "pretty much." As measures of future motivation, 51% answered "very much!" to the item about wanting to learn more science. Figure 3 shows the means of these ratings. Moreover, 60% said they would like to come to more shows and only 9% said they would not.

Out of 69 questionnaires that were turned in, 25 included written comments. Almost all of these comments (22) were positive, and many were enthusiastic: "It was a very funny show, and I hope you have more soon!" "The show is great and makes science fun, interesting", "I loved it!!", "I thought it was fun, exciting, and entertaining", "It's much better than science at school", "I liked it so much!", "Five stars".

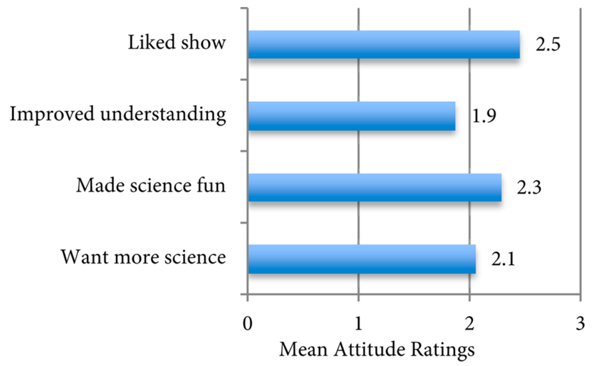

Figure 3. Mean attitudes toward *The Boiling Point* and toward science after the show. Possible responses ranged from 0 ("Not at all") to 3 ("Very much!").

Parent and Educator Attitudes

Educators and parents who attended these performances were asked to fill out a brief questionnaire (N = 59). Their responses were overwhelmingly positive: In ratings, 72% said the experience was "extremely valuable" for children and 78% they said would be interested in more shows like *The Boiling Point*. In open-ended responses, a parent said, "Interactive and fun and clear—This is how science should be!!"; a teacher said, "Showed the process of scientific thought in a way that kept the kids riveted and parents with a smile on their faces—Great audience involvement."

Transfer to Student Group

The Students Participating In Chemical Education (SPICE) group performed 11 shows at seven venues including public libraries, a children's museum, a school science fair, a church, a university, and a childcare center. Ballots were returned by 230 children between the ages of three and 12 years. The proportion of children answering the concept question correctly rose from 24% on the prelesson vote (N = 230) to 62% on the postlesson vote (N = 187), and this difference was highly significant ($X^2_{(N=417)} = 61.9$, $p < 0.001$, effect size, phi = 0.385).[23]

■ DISCUSSION

The before-vs-after differences in the audience members' responses to the concept question indicate that *The Boiling Point* show was successful at provoking a shift in their understanding of the vaporization of water at the molecular level. This success can be explained by reflecting on the impacts of four educational components of the show in light of the conceptual change model. They are *demonstrations, physical dramatization*, the *Recurring Question structure*, and *Host Character*.

It is hypothesized that demonstrations, in addition to drawing attention and generating excitement, produce cognitive dissonance[24] by acting as a discrepant event.[25] By selecting demonstrations that served as discrepant events for common misconceptions, it is likely that *The Boiling Point* increased the learners' dissatisfaction with their current, naïve conceptual understandings, priming them for the accommodation of a new concept.

Although studies about the cognitive impact of traditional demonstration shows are unavailable, research carried out in classrooms indicates that traditional demonstrations do not increase understanding of the concept demonstrated.[26] This

DOI: 10.1021/acs.jchemed.5b00490
J. Chem. Educ. XXXX, XXX, XXX−XXX

suggests that the cognitive dissonance generated by a surprising demonstration is not the only condition needed for conceptual change. According to the conceptual change model, the learner must also find the new concept intelligible and plausible.[17] This requirement was addressed in the second educational component, physical dramatization, which used particulate modeling to increase the plausibility and attain intelligibility of the target concept. Through the dramatization in *The Boiling Point,* audience members were able to view or actively participate in the particulate model, which related the increase of temperature to the increased motion of the molecules and the change from liquid to gas to the relative distance between the molecules. These particulate representations appear to have helped the audience make sense of the concept vaporization in a similar manner to the way physical metaphors help audience members conceive abstract concepts in a stage play.

The educational impact of these components was enhanced by the show's unique Recurring Question structure adapted from the dramatic structure of a play. Framed by the question, "What happens to [the molecules of] water when it boils?", demonstrations in *The Boiling Point* became not just events, but evidence for the plausibility (or lack thereof) of the particulate-based scenarios presented as possible answers. For example, the misconception presented in Option 3, "Water molecules break up", was contradicted when the steam exiting the teapot did not combust as the hydrogen/oxygen mixture had. Likewise, the correct answer, "Water molecules spread out", gained credence by the expansion of the balloon placed over the spout of the boiling pot. This option was also made more plausible by the physical dramatization used as a particulate model of the liquid to gas phase change.

The Recurring Question structure fostered engagement in other ways as well. Like the dramatic question of a play, the question "What happens to [the molecules of] water when it boils?" sparked interest by creating a desire to know the answer. This was heightened in the prelesson vote by asking the children to process the question and select the answer based on their previous knowledge. The second vote gave the children an opportunity to apply their new conceptual knowledge to answer the same question. This provided a fruitful context for the target concept, another condition of conceptual change. In other words, this arrangement allowed the audience to solve a problem that was not solvable by prior knowledge.[17] This Recurring Question structure also afforded a measure of the audience members' cognitive gains.

Finally, Host Characters engaged the audience by providing a point of human connection and identification. However, because the main question of the show was not about the fate of these characters, the Scientist and Silent Assistant were not the subjects or protagonists. Instead, the main question was a concept question that challenged the audience to understand the nature of vaporization. Therefore, in this setup, the protagonist was the learner in the audience, not a character onstage. This arrangement may have enhanced learning by inviting the audience member directly into the learning process.

Informal learning environments are dependent upon the learner's enjoyment of the experience to ensure continued attendance and engagement. Thus, ISE experiences must meet Strand 1 objectives, regardless of what other strands are targeted. The postshow questionnaires provided evidence that the audience enjoyed *The Boiling Point,* despite the conceptual focus of the show. This may be, in part, due to the spectacular nature of the demonstrations, but they are unlikely to be the main reason, as *The Boiling Point* presented only three demonstrations that occupied only 5−10 min of the entire show. The demonstrations of *The Boiling Point* were also objectively less spectacular than other popular chemistry demonstrations (e.g., Elephant's toothpaste,[27] Genie in a Bottle,[28] Whoosh Jug[29]). Therefore, there must be an additional cause for the high level of interest in *The Boiling Point*. It may be that the audience's enjoyment of *The Boiling Point* is akin to that experienced by the audience of a play as they work toward the answer to the dramatic question. It also may be that learning a new concept in an intriguing context is inherently satisfying. Regardless, data from *The Boiling Point* have provided evidence that a focus on conceptual learning and the inclusion of assessment in a demonstration show are not detrimental to the audience's enjoyment.

One limitation of this study was the abbreviated assessment of the audience members' conceptual knowledge. To avoid detracting from enjoyment of the show, the questionnaires were as brief as possible, limiting the audience to selecting one response from the choices provided. Such simplified assessment cannot capture the complexity of a learner's conceptual ecology, or fully explore the scope of any shifts. Additionally, this evaluation cannot distinguish between the effects of various components of the show. One particular component may be responsible for the differences in the pre- and postlesson answers, or it may be any combination of these components. Future work will explore these issues.

■ CONCLUSIONS AND IMPLICATIONS

The success of *The Boiling Point* is groundbreaking on a number of fronts. First, it demonstrates that it is possible to realize goals of increasing excitement and interest (Strand 1) and conceptual understanding (Strand 2) in a single show. Furthermore, it advances a design where engagement is driven by the audience's desire to learn the concept, rather than the traditional strategy of piquing interest through spectacle alone. The Recurring Question structure developed in *The Boiling Point* is a striking example of how arts-based methods can be adapted and implemented in ISE shows and activities to support and assess science learning. Finally, *The Boiling Point* was relatively easy to transport and produce. It was successfully performed by an ISE group beyond the authors of the script. Because of these characteristics, the development of *The Boiling Point* and the Recurring Question demonstration method has the potential to revolutionize the use of demonstration shows in informal science education settings.

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Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We acknowledge the National Science Foundation AISL for the generous grant (DRL #0732142) that funded this work, and Madison Area Technical College as the Sponsoring Project Officer. We would like to thank the students of SPICE, who displayed fortitude, determination, and great creativity in incorporating *The Boiling Point* into their repertoire: Won Hong, Allison Maytag, Jack Richeson, Katie Reichl, Sarah Schmid, and Patrick Shipway. We also thank the following

DOI: 10.1021/acs.jchemed.5b00490
J. Chem. Educ. XXXX, XXX, XXX−XXX

people for their invaluable feedback on the script of *The Boiling Point*: Peter Hewson, Professor Emeritus of University of Wisconsin—Madison, Rachel Lancor of Edgewood College, Madison, Wisconsin, Rebecca Oaks, and two anonymous reviewers. We are also grateful to Stephen Rose for his invaluable contribution to the physical design of the show.

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(22) There are a variety of possible reasons why there were fewer postlesson than prelesson ballots. For example, some ballots may have been lost in the chaos of the informal situation. But to answer the possible interpretation that a child did not turn in a second ballot because he or she did not know the answer, the analysis was recomputed, considering all nonvotes as wrong answers (N = 93 for each vote). This analysis still revealed a strong and significant before−after change in concept knowledge ($X^2_{(N=186)} = 18.4$, $p < 0.001$, effect size, phi = 0.315).

(23) The conservative analysis, counting missing second ballots as wrong answers, still yielded a strongly significant difference ($X^2_{(N=460)} = 34.6$, $p < 0.001$, effect size, phi = 0.274).

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DOI: 10.1021/acs.jchemed.5b00490
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