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Activity

Using Prequestioning as a Hands-On Activity to Support Undergraduate Student Learning

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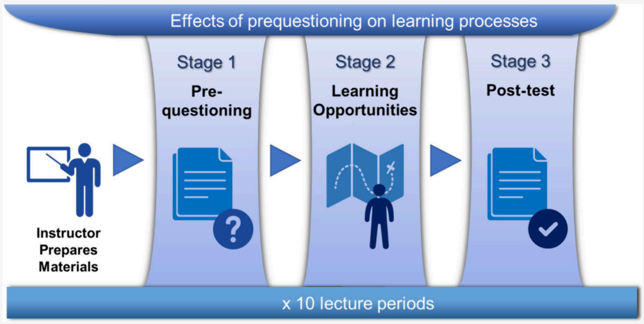

ABSTRACT: *Prequestioning* is a learning strategy that involves taking practice tests on to-be-learned information, followed by studying the correct answers. Despite promising results in laboratory studies, it has rarely been examined in authentic educational settings. In this activity, we implemented prequestioning as an interactive, hands-on activity in a small undergraduate environmental chemistry course. Across 10 lecture sessions, the instructor administered four *prequestions* targeting concepts to be covered in the upcoming lecture. Students attempted to guess the answers to each question before the lecturer presented the correct answers. On assessments occurring during the next lecture session, there was evidence of a *prequestioning effect*, that is, better performance on questions targeting prequestioned concepts versus non-prequestioned concepts, in most cases. The observed benefit of prequestioning highlights the potential utility of this strategy as a useful and affordable activity for enhancing learning in undergraduate chemistry and other similar courses.

KEYWORDS: *Pretesting, Prequestioning, Learning Strategies, Memory, Environmental Chemistry, Retrieval Practice*

■ BACKGROUND

In the learning sciences, there is considerable evidence that engaging in practice testing *after* instruction, or *retrieval practice*, can enhance long-term memory and other learning outcomes.[1−4] Recently, researchers have begun investigating whether practice testing *before* instruction—a strategy known as *prequestioning*—might also aid learning in non-lab-based courses.[5,6] Prequestioning entails students attempting to answer questions targeting material they have not yet studied, followed by opportunities to learn the correct answers.

Prequestioning vs Prelab Activities

Typically, prequestioning involves students attempting one or more *prequestions* in short answer, cued recall, or multiple-choice format, followed by correct-answer feedback (e.g., viewing the correct answers) via studying (e.g., a textbook chapter or video), direct instruction (e.g., a lecture), or both.[5] Importantly, prequestioning targets information that students do not yet know, and consequently their attempts to guess the answers are often incorrect.[7,8] Nevertheless, in prequestioning, because the opportunity to learn the correct answers usually occurs shortly after students have made their guesses, they are able to learn those answers while their memory of the questions remains fresh. On a later assessment, an advantage of prequestioning over no prior prequestioning (i.e., a control condition that simply studied correct information) is often observed. That benefit is known as the *prequestioning effect*.[5,7,8]

Prequestioning bears some resemblance to *prelab activities*, which are a common pedagogical strategy in physical science courses designed to prepare students for lab-based work.[9−12] According to Reid and Shah, prelab activities are short tasks lasting between 15 and 30 min and are done before the start of the laboratory session.[13] These activities often include reading lab manuals, completing worksheets on calculations, or viewing demonstrations.[12,14−16] Agustian and Seery summarized that prelab activities aim to achieve one or more of the following goals: (1) introducing students to chemical concepts, (2) familiarizing laboratory technique, and (3) addressing affective domains.[15] Hence, some prelab activities may appear to be similar to prequestioning, with both approaches potentially priming students for deeper learning during subsequent activities.[9,10,15] For instance, in prelab quizzes, students must take the assessment and achieve a certain minimum score to be allowed to participate in the laboratory session. Should they fail to obtain the requirement score, students can reattempt the quiz repeatedly until they satisfy the requirement.[15,17,18] However, prelab quizzes seek to help students understand experimental

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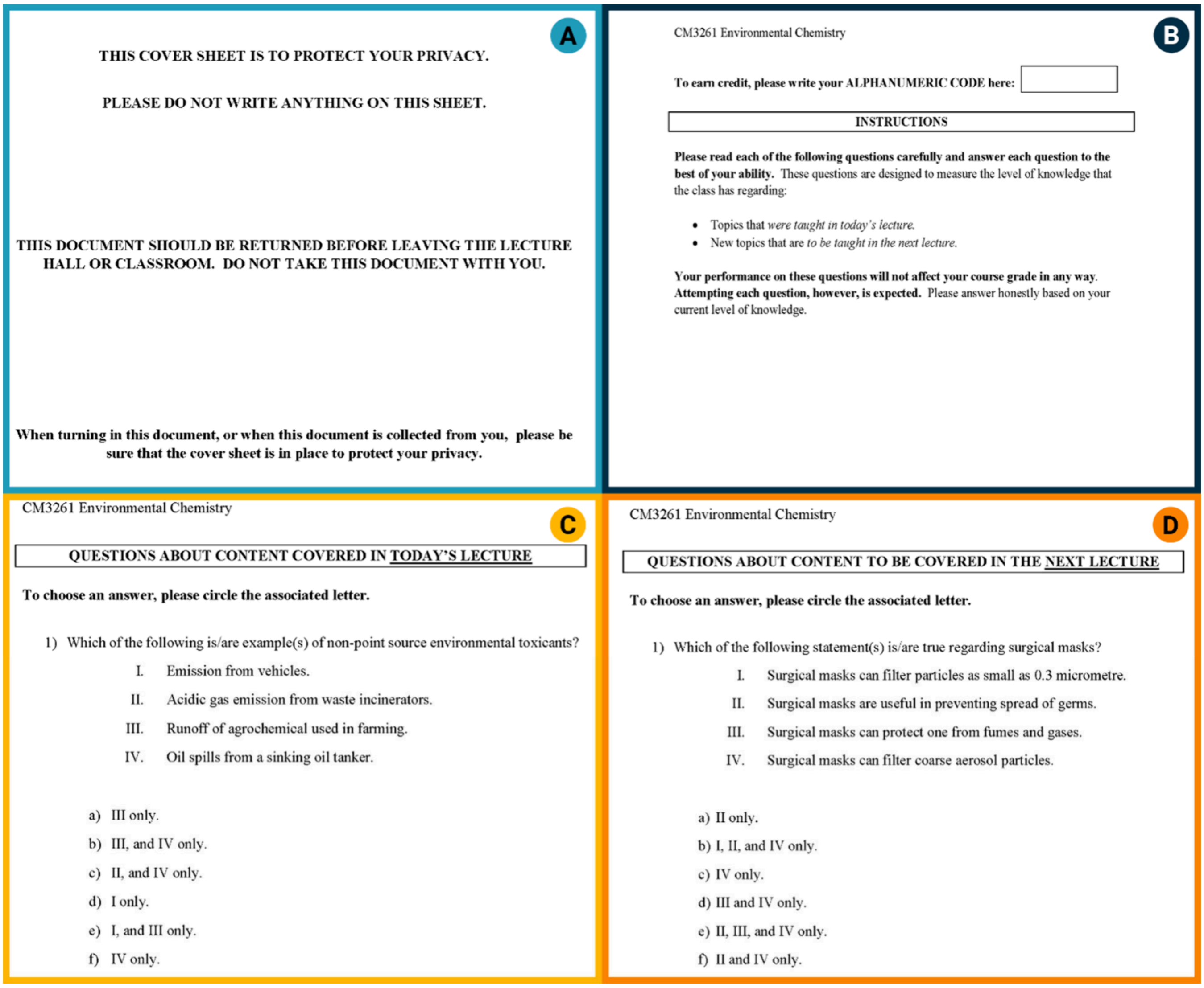

A

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CM3261 Environmental Chemistry

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INSTRUCTIONS

Please read each of the following questions carefully and answer each question to the best of your ability. These questions are designed to measure the level of knowledge that the class has regarding:

- Topics that *were taught in today's lecture.*
- New topics that are *to be taught in the next lecture.*

Your performance on these questions will not affect your course grade in any way. Attempting each question, however, is expected. Please answer honestly based on your current level of knowledge.

C

CM3261 Environmental Chemistry

QUESTIONS ABOUT CONTENT COVERED IN TODAY'S LECTURE

To choose an answer, please circle the associated letter.

1) Which of the following is/are example(s) of non-point source environmental toxicants?

I. Emission from vehicles.
II. Acidic gas emission from waste incinerators.
III. Runoff of agrochemical used in farming.
IV. Oil spills from a sinking oil tanker.

a) III only.
b) III, and IV only.
c) II, and IV only.
d) I only.
e) I, and III only.
f) IV only.

D

CM3261 Environmental Chemistry

QUESTIONS ABOUT CONTENT TO BE COVERED IN THE NEXT LECTURE

To choose an answer, please circle the associated letter.

1) Which of the following statement(s) is/are true regarding surgical masks?

I. Surgical masks can filter particles as small as 0.3 micrometre.
II. Surgical masks are useful in preventing spread of germs.
III. Surgical masks can protect one from fumes and gases.
IV. Surgical masks can filter coarse aerosol particles.

a) II only.
b) I, II, and IV only.
c) IV only.
d) III and IV only.
e) II, III, and IV only.
f) II and IV only.

Figure 1. Collage of snippets showing the sample structure of a typical worksheet (packet).

concepts while reducing cognitive load,[13] whereas prequestioning is intended to have students make often erroneous guesses about information that they are going to learn afterward, with no minimum score required to proceed further.[19]

Most research on prequestioning to date has been conducted in psychology laboratories (for a comprehensive accounting of such studies, the interested reader may consult ref 5 for a review article), and very few studies have explored prequestioning in authentic educational settings, especially in physical sciences courses. This activity, which is among the first to explore prequestioning in undergraduate chemistry,[20−22] was intended as a proof-of-concept for an activity that could be easily implemented in chemistry or similar courses.

■ SETTING AND PARTICIPANTS

We implemented a prequestioning activity in each of 10 lecture sessions of an undergraduate Environmental Chemistry course (CM3261) at the National University of Singapore. CM3261 is an elective chemistry course catered for undergraduate chemistry students in their third and fourth years of study.[20,23,24] It is a multidisciplinary course, integrating concepts such as systems thinking,[25,26] the planetary boundary framework, sustainability,[27−29] and UN SDGs[30−32] to illustrate the complex relationships between human activities and the environment and requires students to understand and memorize numerous terms and concepts, potentially imposing a high cognitive load.[33,34] During Semester 1, 2023−2024, when the activity occurred, CM3261 was taught using a flipped classroom approach, wherein students watch lecture videos made by the course lecturer prior to attending face-to-face sessions.[35,36]

The entire enrollment of the course, encompassing ten students, participated. The activity was conducted with ethics board approval (Reference ID: Psych-DERC 2023-July-01), all students provided informed consent before participation, and the activity was completed individually by each student.

■ MATERIALS

All materials were developed by the lecturer before each session. The materials included 11 worksheet packets (henceforth, *worksheets*) that were administered across 11 lecture sessions that were separated by at least 2 days (Note: prequestioning occurred in ten of those sessions for reasons described below.) Examples of the worksheets are shown in Figure 1.

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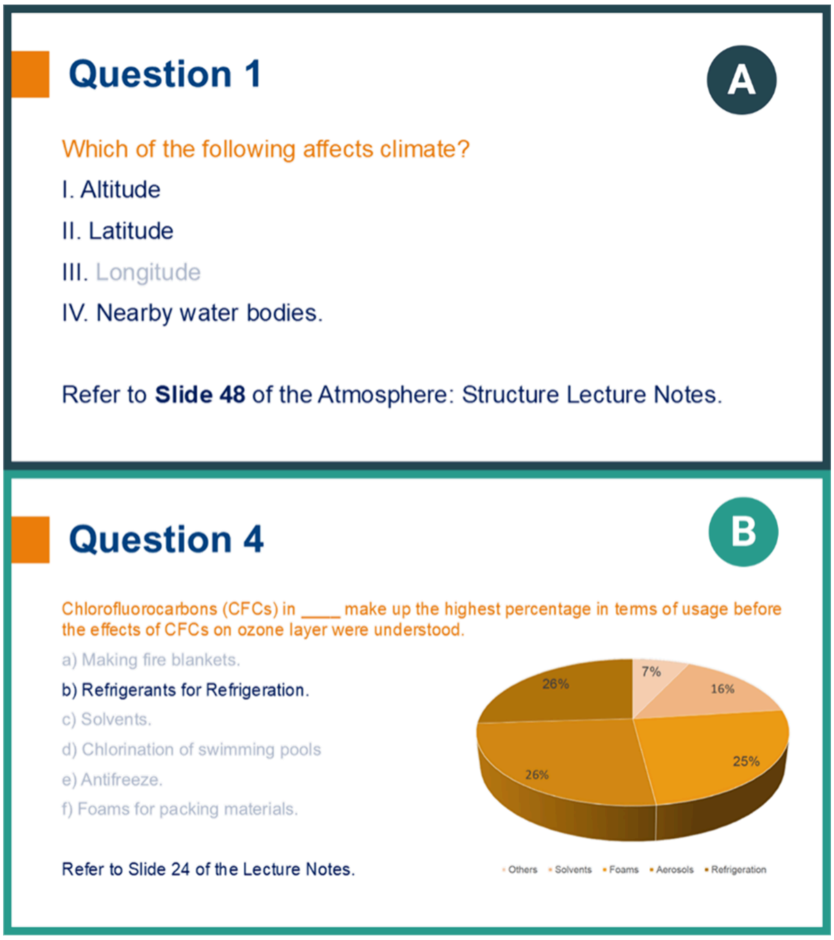

Figure 2. Sample PowerPoint slides that were shown to the students after completing the worksheets. (A) Postquestion on a topic taught during that class. (B) Sample slide showing a prequestion on a topic that will be taught in the next lecture session.

In addition, a set of PowerPoint slides used to provide correct answer feedback was developed for each session. Examples of the slides are shown in Figure 2.

The worksheets contained the following items in the following order:

- A cover page to ensure student privacy (Figure 1A).
- Instructions indicating that the worksheet would assess knowledge of current and upcoming content (Figure 1B).
- Eight multiple-choice questions (MCQs) as postquestions with six plausible options each. Typically, four postquestions were repeated from the previous worksheet, while four were new (Figure 1C). Question order and options for each question were shuffled from worksheet to worksheet.
- Four prequestions, also in MCQ format, previewing upcoming content (Figure 1D). Each prequestion covered a different concept that was to be introduced in the next lecture session.

The eight postquestions in lecture session 1 were all entirely new due to it being the very first lecture session; the final worksheet that was administered in session 11 consisted of only eight postquestions (there were no prequestions as that session was the final one in the course). An example prequestion, which reappeared in the next lecture session's worksheet as a postquestion, was: "*Which of the following affects climate? I) Altitude, II) Latitude, III) Longitude, IV) Nearby water bodies.*"

The prequestions functioned as the learning intervention—the activity intended to enhance learning—while the postquestions assessed the intervention's effectiveness. There were two types of postquestions: *tested* postquestions covered concepts included in the prequestions, whereas *untested* postquestions did not. The presence or absence of a prequestioning effect were determined by comparing the students' performance on the tested versus untested postquestions.

An exit survey was also developed for administration at the end of the course. The survey consisted of 14 multiple-choice questions. There were two questions each, one for prequestioning and one for retrieval practice (each featuring five standard Likert scale response options, such as a scale from "very helpful" to "very unhelpful"), addressing effects or effectiveness of the strategy for:

- Memory (e.g., "How do you believe that the questions ... affected your memory for the content covered by those questions?")
- Understanding (e.g., "How do you believe that the questions ... affected your understanding for the content covered by those questions?")
- Learning course content (e.g., "In terms of helping you learn information in the course, how effective were the questions ... ?")

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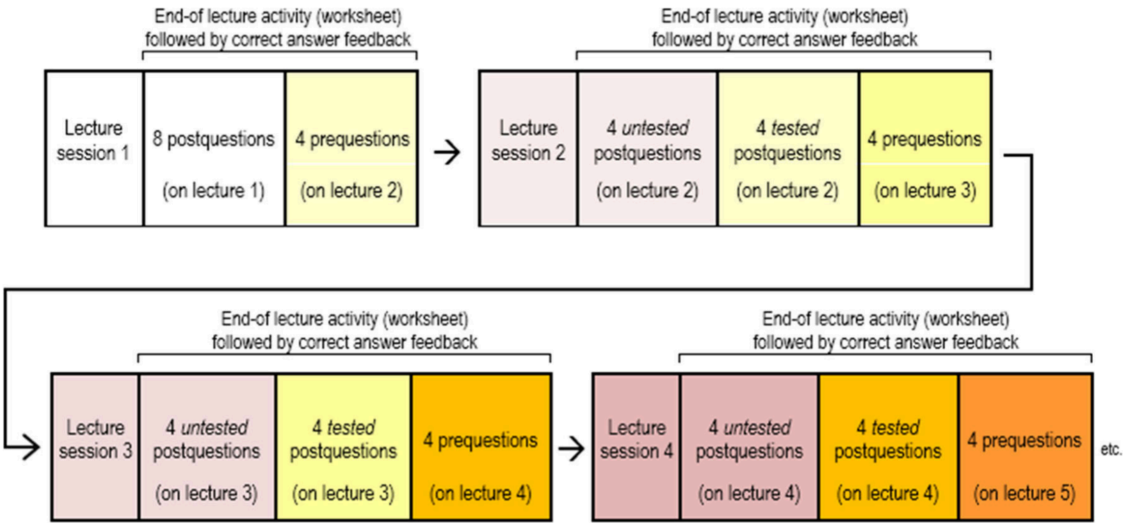

Figure 3. A schematic of the prequestioning activities and associated events during the first four lecture sessions. At the end of each lecture session, students attempted 8 postquestions that assessed knowledge of content that was covered in that day's lecture, as well as 4 prequestions covering content to be taught in the next lecture. The course lecturer then presented the correct answers. For lecture sessions 2−11, the 8 postquestions were comprised of 4 untested (i.e., never-before-seen) postquestions as well as 4 tested postquestions (which were identical to the prequestions administered previously), which were randomly intermixed. (Note: because there was no opportunity to administer prequestions in any prior lecture session, the first lecture session lacked tested postquestions.) See Figure S1 of the Supporting Information for an expanded activity timeline.

- Identifying topics to study (e.g., "Please rate the effectiveness of the questions ... in terms of identifying topics to study in the course.")
- Motivating to study (e.g., "Please rate the effectiveness of the questions ... in terms of motivating you to study in the course.")

In addition, there were two questions each, one for prequestioning and one for retrieval practice, asking about:

- Using questions to guide studying (e.g., "Did you use the questions ... to guide your study activities for this course?")
- Comfort level in answering questions (e.g., "How comfortable were you in answering the questions ... ?")

The full exit survey can be found in the Supporting Information.

PREPARATION

On the first day of class, the research team briefed students on the activity's purpose, informing them that worksheets would be administered at the end of 11 lecture sessions. These worksheets would measure their knowledge of previously and subsequently taught material and provide practice in answering test questions.

Participation in the activity was voluntary, with students receiving 5% of their overall course grade for completing the worksheets and survey questions regardless of their specific answers. Further, all participants were assigned an alphanumeric identifier at the start of the activity, which they used in lieu of their name on each worksheet. The key matching the identifier with each student's name was not known to the lecturer throughout the course, thereby ensuring that students could engage in the activity without fear of their responses being linked to their identities.

An alternative activity (essay assignments) was offered to students who chose not to participate, but none chose this option.

ACTIVITY

Unlike prior investigations of prequestioning in classrooms, some of which required class time both before and after lecture sessions (to administer prequestions and assess their effects on learning), prequestioning in this activity required class time only at the end of lecture sessions. It occurred as follows.

At the end of each of the 11 lecture sessions (each session lasting 2 h, inclusive of a 10 min break) in the course, students received a worksheet and were given 15 min to complete it (i.e., answering the eight postquestions and four prequestions, except for the first and last lecture sessions, which lacked postquestions and prequestions, respectively). They were reminded not to leave any questions blank and that it was appropriate to guess. The remaining 5 min of the class were used by the lecturer to display the correct answers to all the questions via PowerPoint slides at the front of the classroom. Students were required to hand in their worksheets before they left the classroom. (It should be emphasized that the postquestions were included for research purposes, that is, as a way to measure the effects of the prequestions (i.e., the *tested* postquestions were nearly identical to the prequestions used on the preceding lecture session's worksheet). The prequestions, being the learning intervention, were the most critical part of the activity.)

Figure 3 depicts the first four implementations of the prequestioning activity during the course. The full worksheet packets and the corresponding PowerPoint slide decks containing the answers can be found in the Supporting Information.

The exit survey was administered toward the end of the semester, immediately after the students have completed their final written examinations for the course. Students were given 10 min to complete the exit survey. To preserve their anonymity for the exit survey from their lecturer, students were instructed to write down their alphanumeric identifier that was given at the start of the prequestioning activity instead of their name.

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■ DATA SCORING AND ANALYSIS

All worksheets were marked by a research assistant using an answer key provided by the lecturer. The scores for each worksheet, which included performance for the four tested postquestions and performance for the four untested postquestions, were recorded electronically. The mean difference between the tested and untested postquestions was then calculated for each student for every topic (except for the postquestions on worksheet 1, as it entailed the first topic of the course and there were no prequestions administered beforehand; thus, it was not possible to measure the prequestioning effect for that topic).

■ RESULTS

To assess the effectiveness of prequestioning, we first compared postquestion performance for tested versus untested questions separately for each lecture session. This comparison determined whether prequestioning on a set of four concepts from the upcoming lecture session yielded better performance on postquestions administered during that session. As the data for each topic did not consistently meet the normality assumptions required for *t*-tests, we performed nonparametric Wilcoxon signed-rank tests for all comparisons. Results are listed in Table 1.

Table 1. Postquestion Performance By Lecture Topic Comparing Tested vs Untested Postquestions

topic number	topic taught during lecture	Wilcoxon signed-ranks test *p*-value	prequestioning effect, mean difference (SD)
1	lithosphere	0.054[a]	0.36 (0.28)
2	hydrosphere	0.42	0.071 (0.19)
3	waste management	0.066	0.25 (0.30)
4	environmental toxicology	0.040[a]	0.23 (0.28)
5	air pollution	0.11	0.18 (0.18)
6	structure	0.42	0.063 (0.18)
7	ozone layer	0.021[a]	0.38 (0.23)
8	food chain	0.036[a]	0.23 (0.25)
9	climate change	0.61	−0.056 (0.41)
10	sampling	0.17	0.19 (0.37)

[a]*Note*: $p < 0.05$; prequestion effect mean difference refers to participant-level mean performance (proportion correct) on tested postquestions minus performance on untested postquestions.

As shown in the table, despite the small class size, there was a statistically significant difference (i.e., $p < 0.05$) in favor of the tested condition, that is, evidence of a prequestioning effect, in four lecture sessions. Moreover, the numerical mean difference in performance between tested and untested postquestions favored the tested questions in nine of ten lecture sessions. We next performed a Wilcoxon signed-rank test on participant-level mean difference scores for tested versus untested postquestions across all lecture sessions. In that analysis, which addressed the overall impact of prequestioning across the course, there was also evidence of a prequestioning effect ($p < 0.0059$). That analysis is consistent with examination of the postquestion performance as depicted in Figure 4.

In that figure, there are indications of a prequestioning effect for all but one lecture session (Climate Change) and a strong prequestioning effect overall. The mean advantage of tested versus untested postquestions, that is, the magnitude of the prequestioning effect in terms of proportion correct, was $M = 0.19$, $SD = 0.09$. Together, these results suggest that students were better able to answer postquestions addressing concepts that had previously been prequestioned; in other words, the prequestioning activity enhanced learning.

To analyze the exit survey data, we performed Wilcoxon signed-rank tests that compared students' ratings for prequestioning versus retrieval practice. With respect to the effects of the two practice test types on memory and understanding as well as associated learning behaviors and outcomes, in all cases, there were no significant differences. With respect to students' comfort level with attempting prequestions versus postquestions, however, the ratings favored retrieval practice over prequestioning ($p < 0.0005$). That result suggests that students were more comfortable with answering postquestions than prequestions.

■ DISCUSSION

Overall, prequestioning appeared to confer substantial learning benefits and did not yield deleterious effects in an environmental chemistry course. Spending approximately 15 min of class time to engage in a prequestioning activity (if there was no need to assess the effectiveness of that activity with postquestions, the amount of time required would be even less) was beneficial for learning in most cases. Overall, the observed 0.19 proportion correct average prequestioning effect across lecture sessions translates to a gain of nearly two letter grades, according to conventional grading scales. We conclude that the apparent prequestioning benefits in this activity were meaningful in academic terms, which likely reflects among the first successful demonstrations of a prequestioning benefit in a physical sciences context.

Why Did Prequestioning Enhance Learning?

The observed effects can be explained through a three-stage theoretical framework proposed by Pan and Carpenter.[5] This framework comprises three stages that together describe the impact of prequestioning on learning outcomes:

- In stage 1, prequestioning triggers mental processes such as heightened curiosity.
- These processes influence stage 2, where correct answers are learned through feedback or instructional materials. Learning of these correct answers is more successful than if one processed the feedback without having engaged in prequestioning beforehand.
- Finally, stage 3 is when memory for prior learning is assessed, such as via a post-test. During this stage, the learning processes from the first two stages enhance performance compared to a control condition without prequestioning, resulting in a measurable prequestioning effect.

In the present activity, in the first stage, when students attempted to guess answers to the prequestions, they typically scored relatively poorly (with an average accuracy rate of $M = 0.39$, $SD = 0.11$ across all worksheets). This mediocre level of performance set the stage for productive learning processes during the second stage, where students had the opportunity to learn the correct answers (and were possibly quite eager and curious to do so, given the possible uncertainty around the accuracy of their guesses). These processes, in turn, influenced performance in the third stage, where students were better able to recall previously prequestioned (i.e., tested) information

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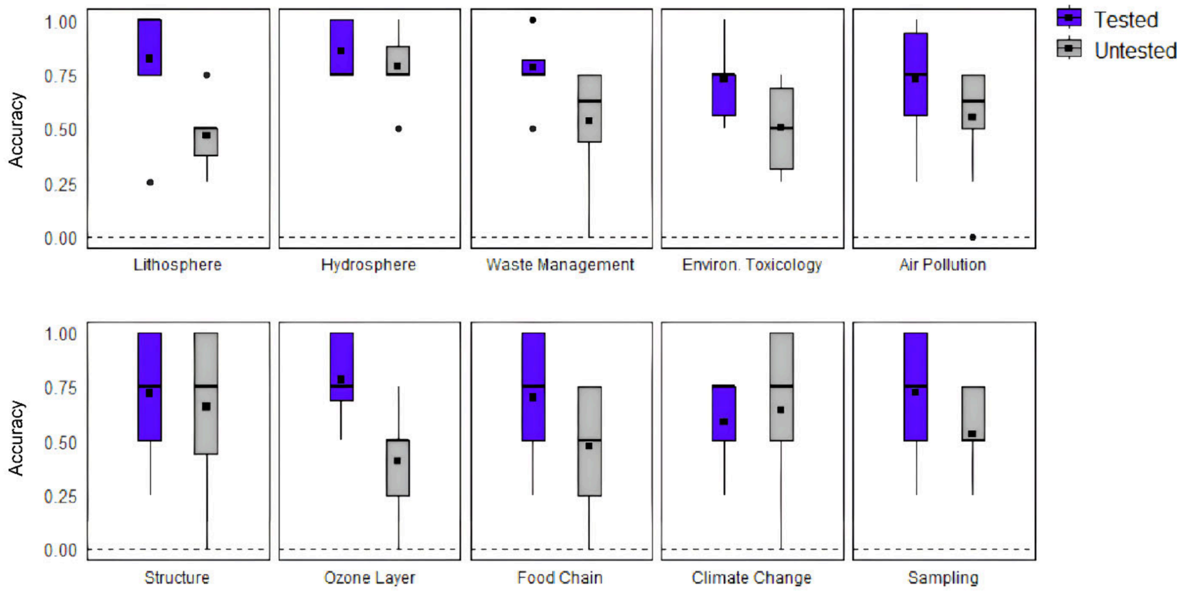

Figure 4. Comparison of students' accuracy between the tested and untested questions for each topic. Within each box, the dot represents the mean, the center line represents the median, and the upper and lower boundaries represent the interquartile range; whiskers extend to 1.5× the interquartile range, and outliers are plotted individually.

compared to nonprequestioned (i.e., untested) information on postquestions posed at the end of the next lecture.

Implications of Using Prequestioning in Chemistry

From our teaching experience, instructors are likely to benefit from using prequestioning on content-heavy courses such as analytical chemistry and laboratory. For instance, instructors could first conduct prequestioning on different parts and functions of various analytical equipment and then conduct the lecture before quizzing students again. Similarly, instructors can also ask case-based questions about operating analytical equipment to help students remember how to operate them.

Limitations and Caveats

A limitation regarding the evaluation of this activity is that prequestioning was not compared to a more competitive control condition, such as the study of learning objectives.[37] Without such a comparison—and given the fact that the prequestions and tested postquestions were very similar—it is impossible to rule out the possibility that the observed prequestioning effects stemmed from increased exposure to learning materials. Another limitation of this activity is the small sample size used ($N = 10$). As the sample size is small, the results obtained in this activity may not be generalizable to the population. Nonetheless, this activity establishes prequestioning as a beneficial activity that can enhance learning relative to business-as-usual instruction.

Another caveat is that prequestioning did not benefit all lecture topics equally. Two factors may explain this variation. First, for all topics except Climate Change, some participants achieved perfect scores on tested postquestions but rarely did so on untested ones, suggesting that while prequestioning enhanced learning, a ceiling effect may have attenuated the magnitude of the prequestioning effect. Second, for the topics Hydrosphere and Structure, a significant proportion of participants (∼30−40%) attained perfect scores on both tested and untested postquestions, suggesting that these topics were easier to learn, potentially masking any prequestioning effect.

Nonetheless, in all cases except Climate Change, the mean score for tested postquestions was higher than that for untested ones, highlighting the capacity of prequestioning to enhance learning. The unique patterns for Climate Change remain unexplained, although its heightened salience in media coverage may have affected how students approached that topic, which in turn affected the potential benefits of prequestioning for it.

Finally, in our worksheets, an estimated 1 in 4 questions involved bundled true/false format, where several true or false statements are MCQ options, which was chosen due to students' familiarity and prior experiences with that format. Although this format allowed for efficient data collection, the inherent structure of bundled true and false questions might have influenced response patterns in ways that do not fully reflect full understanding. Future studies should consider alternative question formats to further validate the effectiveness of the activity.

Practical Considerations

A practical challenge with the present prequestioning activities was that a substantial portion of students were uncomfortable with it. In fact, 40% reported feeling moderately or very uncomfortable answering prequestions. This discomfort may arise from a fear of making errors or incorrect guesses, and future implementations may need to implement measures to reduce it (such as discussing the value of making guesses as a way of uncovering what one does not already know).[38,39]

From the lecturer's perspective, the amount of preparatory work that was needed to implement the prequestioning activities was relatively modest. The lecturer had already engaged in a routine of preparing practice test questions for various courses; adapting such questions to serve as prequestions and/or postquestions was relatively simple. A standard worksheet design was developed and used throughout the course; beyond that, all that was required was to swap in the necessary questions for each lecture session and print out the worksheets prior to class. Future implementations of this activity could even use online quizzing platforms, such as Canvas.

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CONCLUSIONS

In an undergraduate chemistry course, a series of hands-on prequestioning activities (in the form of four multiple-choice prequestions presented at the end of lecture sessions, followed by brief correct answer feedback) enhanced performance on test questions administered two or more days later. Hence, devoting a few minutes per lecture session to engaging in prequestioning can be beneficial for student learning. Despite the limitations of sample size, this work provides valuable preliminary insights into prequestioning and highlights a promising activity for enhancing learning in chemistry and other physical science courses.

ASSOCIATED CONTENT

Data Availability Statement

Study data and materials (practice and criterial test questions) are archived on the Open Science Framework (OSF), accessible via https://osf.io/kgpvq/?view_only=778fb521c7b54f81b669313c2bcf2b57, and available from the authors upon request.

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.4c01405.

Activity notes for instructors, survey instrument, and exit survey (PDF) (DOCX)

Worksheets and PowerPoint slides (ZIP)

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Notes

The authors declare no competing financial interest.

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