Using a dual safeguard web-based interactive teaching approach in an introductory physics class

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We modified the Just-in-Time Teaching approach and developed a dual safeguard web-based interactive (DGWI) teaching system for an introductory physics course. The system consists of four instructional components that improve student learning by including warm-up assignments and online homework. Student and instructor activities involve activities both in the classroom and on a designated web site. An experimental study with control groups evaluated the effectiveness of the DGWI teaching method. The results indicate that the DGWI method is an effective way to improve students' understanding of physics concepts, develop students' problem-solving abilities through instructor-student interactions, and identify students' misconceptions through a safeguard framework based on questions that satisfy teaching requirements and cover all of the course material. The empirical study and a follow-up survey found that the DGWI method increased student-teacher interaction and improved student learning outcomes.

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I. INTRODUCTION

In physics classes, students exhibit improved conceptual understanding and problem-solving abilities when they participate in interactive learning environments [1]. These environments include the Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) project [2,3], Physics by Inquiry [4], the Comprehensive Unified Physics Learning Environment (CUPLE) Physics Studio [5], Peer instruction [6,7], and virtual reality simulation environments [8], among others. Typically, these inquiry-based learning environment courses require changes in classroom arrangements or the purchase of electronic classroom response systems.

Because educators and researchers seek methods to promote interactive learning that do not significantly modify traditional course arrangements, web-based preparatory warm-up exercises and online homework have been developed.

Educators and researchers have focused on the extent to which electronic homework improves student achievement, although opinion varies on its effects. Some research reports that online homework is more beneficial than written homework [9–11]. For the most part, the research on web-based homework has found that it provides student

results more quickly, more accurately measures learning outcomes, and costs less than traditional pen-and-paper homework [12–14]. Web-based homework systems include WebAssign [15], CAPA [16], OWL [17], or Homework Service, all of which automate the process of collecting and grading student homework.

Some research has found that using a web-based system to collect and grade homework online does not significantly affect student performance [18,19]. Studies have also reported, however, that although the web-based homework alternative to the traditional pen-and-paper-based approach does not provide significantly greater benefits to students, it works as well as standard methods of collecting and grading homework. This finding supports the view that technology itself does not improve or impair student learning.

Because web-based tools can provide critical formative assessments [20–22], educators and researchers have focused on identifying useful strategies for using web-based homework to enhance student learning.

Warm-up exercises have become an important feature of teaching and learning practices [23]. In the Just-in-Time Teaching (JiTT) pedagogical approach, warm-ups are used as the basis for each classroom session to enhance learning [24,25]. Warm-up exercises are brief conceptual exercises that are due a few hours before lecture in which students read assigned materials, answer several questions, and submit their answers online. Because the JiTT warm-up exercises reveal students' prior knowledge and misconceptions, instructors can modify the lecture based on warm-up results to reduce students' misconceptions. Many researchers and instructors in the U.S. have reported the effectiveness of JiTT, not only in physics but also in other subjects

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such as math, chemistry, and psychology [26,27]. However, we encountered difficulties when we introduced the JiTT approach to universities in China. An international research project investigating over 5000 students in the U.S. and China found that Chinese students exhibited a high level of performance on tests of physical concepts due to “numerous and rigorous courses in middle school and high school” [28]. Middle school and high school students in China who choose science or engineering majors and plan to go to a university enroll in approximately 5 years of physics courses that include 2 years of courses in middle school and 3 years in high school. The physics curriculum incorporates six content themes, which include force and motion, thermodynamics, electricity and magnetism, waves, optics, and nuclear physics. All students receive identical curricula in physics and must perform well on the same national college admission examination. Because of Chinese students’ strong background in physics, it was difficult to identify misconceptions in physics classes, and the common conceptual warm-up questions often failed to evaluate their prior knowledge in introductory physics courses. Furthermore, in a typical JiTT class with large enrollment, the teacher is able to identify common difficulties without grading all of the warm-up questions. Usually teachers only need to read a few student responses to the warm-up questions before class to obtain a general idea of student misconceptions. In contrast, Chinese students’ high level of performance on preliminary tests makes it difficult for teachers to identify students’ misconceptions by grading a few warm-up questions in a free-response format. Consequently, teachers interested in applying the JiTT method in class have been forced to spend considerable time grading questions and designing new questions that were not provided by physics education research products, which could hinder the adoption of the JiTT approach.

Therefore, we modified the JiTT to improve introductory physics courses for high-performing students. In this paper, we discuss how we combined warm-up exercises with online homework that included many questions to serve as a dual safeguard framework. We also present a study that investigated the effectiveness of the dual safeguard web-based interactive (DGWI) teaching approach in improving student outcomes in an introductory physics course.

II. RESEARCH DESIGN

In our research, we developed a DGWI teaching system based on the JiTT approach that combined warm-up assignments with online homework in an introductory physics course.

A. Design of the DGWI teaching approach

In 1998, Hake reported the results of a study of test results for 6000 students of mechanics, which found that

the average normalized gain for the interactive-engagement teaching method ($g = 0.48$) was higher than the gain for traditional teaching methods ($g = 0.23$), indicating that interactive engagement improved student learning [1]. Various interactive engagement programs have been used in introductory physics courses, such as Studio Physics [29], Peer Instruction [30], and the New Studio method [31]. Research has found that this type of teaching intervention improves students’ academic performance and satisfaction with learning outcomes.

To provide an interactive-engagement teaching environment based on the JiTT approach, we developed a dual safeguard learning feedback loop by combining warm-up assignments with online homework in an introductory physics course. We used the warm-up assignments to obtain information about students’ prior knowledge, misconceptions, and confusion based on relevant exercises. Students’ responses to the warm-up assignments were used to provide the instructor with information to modify the upcoming lecture to provide a more instructive and engaging course. Similarly, the goal of the online homework was to assess teaching effectiveness by comparing students’ homework responses to students’ responses to the warm-up questions. Furthermore, the postclass homework was used to identify course content that continued to confuse students and required more explanation in discussion sessions.

In the first interactive feedback loop, students revealed their misconceptions through the warm-up exercises, and the instructor focused on those misconceptions and attempted to correct them. In the second feedback loop, the instructor and teaching assistants focused on resolving the remaining misconceptions exhibited in students’ online homework through in-class discussions. The DGWI teaching method was designed to focus on all aspects of the introductory physics course by combining warm-up assignments, classroom teaching, online homework, and discussion sessions.

B. Procedures involved in the DGWI approach

The DGWI approach requirements for both instructors and students throughout the entire teaching process included four instructional components. The teaching activities of the instructor and students involved activities both in the classroom and on a designated web site [32]. The entire teaching process consisted of four components (see Table I).

For each instructional component presented in Table I, the students’ and instructors’ activities involved activities in the classroom or on the designated web site.

Preclass preparation.—Before each lecture, students in the experimental class were required to prepare assigned content and complete the warm-up exercises, which consisted of multiple-choice and fill-in-the-blank questions. The warm-up questions were adapted from traditional homework

TABLE I. DGWI teaching process.

Instructional components	Student activities	Instructor activities
Preclass preparation —First safeguard	Prepare the assigned material, perform the warm-up exercises, post results online, and identify whether the results need to be explained.	Review students' responses and prepare the classroom lesson.
In-class lesson	The instructor organizes classroom teaching to include course material needed to construct the student knowledge base and correct key student misconceptions, as well as the content requested by most students.	
Online homework —Second safeguard	Repeat the warm-up exercises and repost the results online.	Identify the main points for discussion.
Discussion session	The instructor and the TAs lead discussion and collaborative learning sessions in response to student homework.	

assignments related to the lecture topic. The instructor adapted the questions to the online format; for example, some of the questions were converted from calculation problems to multiple-choice and fill-in-the-blank questions. Each question included two additional response options (E and F). Response option E, which stated “this question is too easy for me,” was designed for students who felt that the problem was too easy and could easily be responded to at first glance, and option F, which stated “this question is too difficult for me,” was designed for students who felt that they could not correctly respond to the question even after in-depth reflection. These two response options were provided to reduce student responses based on guess work.

For each question, students were asked to identify whether the question should be explained during the upcoming lecture, and the instructor organized and modified the classroom lecture based on student responses.

Students were required to respond to the questions on paper as usual. The only difference compared to traditional pen-and-paper homework was that they had to post the final results online on the designated web site. Because the questions covered almost the entire lecture content, student responses sufficiently revealed their prior knowledge, misconceptions, and difficulties. During the period between the submission deadline and the lecture, the instructor organized and adjusted the classroom lesson based on the responses to the warm-up assignments that were automatically provided by the computer.

Classroom lesson.—In contrast to traditional classroom teaching, the instructor constructed the classroom lesson based on students' responses to the warm-up assignment. This procedure allowed the instructor to save time and focus on three key elements: the core knowledge that students would use to construct their knowledge base, the trigger point the instructor established for warm-up assignments (e.g., because the experimental trigger point was 70%, the system identified warm-up questions in which fewer than 70% of the students responded correctly to the question), and the content requested when most students

identified a question as being too difficult and requiring further explanation. In the classroom, the instructor primarily focused on lecture rather than discussion.

Online homework.—Students were required to repeat the warm-up exercises as homework. They worked out the problems on paper and posted the final results on the designated web site as they had done for the warm-up exercises. The student homework was also graded by computer and the instructor and the teaching assistant used the results to design the discussion session.

Discussion session.—In general, a discussion session was required after two classroom lectures. The instructor organized the material for the discussion session based on the results of students' online homework and students' responses in class. This key component enabled the instructor to identify material that continued to confuse students after the lecture so that it could be addressed during the discussion session.

For this component, a teaching assistant was trained by the instructor to assist during the discussion session. Each discussion session included approximately 30 students who participated in collaborative learning and discussion. Completing the online homework before the discussion session was the foundation for in-class collaborative learning.

The design of the warm-up exercises and classroom teaching, online homework, and discussion sessions was used to develop the dual safeguard interactive teaching system. Initially, the warm-up exercises identified students' misconceptions and difficulties, and the instructor used the classroom lesson to reduce students' learning difficulties and enable them to construct their knowledge base. This process formed the first teaching safeguard. Then, the online homework identified what students had learned, and the instructor and teaching assistant resolved any remaining confusion during the discussion sessions. The second process formed the second teaching safeguard.

In web-based homework prior to the development of the DGWI approach, students had to read the online materials,

respond to questions, and write out the calculation procedures as well as the results on the computer, which was time consuming. In contrast, in our research, students were required to complete the warm-up exercises and homework on paper as usual but only posted the answers online rather than including the calculation procedures. The purpose was not only to maintain student study habits but also to ensure that students did not spend too much additional time on assignments [31]. Posting answers online was relatively easy and took only a few minutes. In addition, the instructor was able to quickly access and identify students' misconceptions and difficulties because all of the questions were multiple-choice or fill-in-the-blank items, and the computer automatically collected and graded student homework.

C. Data collection

Data for the experimental study were obtained from eight 90-minute lectures in experimental and control thermodynamics classes. The topics covered in the thermodynamics classes included molecular kinetic theory as well as the first and second laws of thermodynamics.

First-year university students majoring in computer science, automation, engineering science, and mathematics were recruited as study participants. These students scored in the top 1% on China's college entrance exam, which is taken by approximately 9 million students each year. The students were taking the required introductory physics class and had studied basic physics for 5 years before entering university. Students were randomly assigned to the experimental or control groups. Students in both groups were presented with the same educational content covered in the same number of class periods. In contrast to the control classes in which students received traditional instruction, students in the experimental class were exposed to the DGWI teaching approach. One control class was taught by another experienced instructor, while the experimental class and the second control class were taught by one of us who has used the DGWI approach for several years [33].

The teaching procedures for the experimental and control classes are presented in Fig. 1.

Pretest.—Prior to taking the class, students in both classes completed a pretest based on the Thermal Conductivity Instrument (TCI) [34] that included 32 questions as well as questions in other areas of physics and questions on scientific reasoning. For the TCI test, several questions (Q1, Q2, Q12, Q13, and Q23) were removed from the test because students exhibited sufficient comprehension of these topics.

In the class lesson component, traditional methods were used to present the course material to students in the control classes. For the control classes, the instructor controlled the class and assisted students in filling in “knowledge gaps” during class. The homework questions for control class 1 were primarily quantitative questions with content and

FIG. 1. A schematic representation of the experimental study design.

difficulty levels that were similar to the experimental class homework. Control class 2 was assigned the same homework as the experimental class, which primarily consisted of multiple-choice and fill-in-the-blank questions.

The discussion session was taught by teaching assistants with the same number of teaching hours, and the class size (approximately 30 students) was similar in both the experimental and control groups. The goal of the discussion sessions in the introductory physics course was to enable students to understand the course material, improve students' problem-solving abilities, and resolve students' difficulties. The control class participated in traditional discussion sessions, while discussion sessions in the experimental class adopted the DGWI teaching approach.

Posttest.—After completing the 8 thermodynamics lectures, students were asked to complete a posttest that was identical to the pretest; the posttest thus included TCI questions, questions on other areas of physics, and several scientific reasoning questions.

The TCI is an instrument used to assess undergraduate engineering students' understanding of fundamental thermodynamics concepts. The TCI instrument was developed by physics education researchers in the U.S., and the questions used were different from the homework questions used in class. To ensure that study data were reliable, the experimental and control group instructors were not familiar with the questions on the TCI instrument, and the TCI pre- and posttests were administered by a different instructor.

III. DATA ANALYSIS

In the present study, we investigated the extent to which the dual safeguard web-based interactive system improved students' academic performance.

Based on the results of the pre- and posttests, an additional 8 TCI test questions (Q3–Q5, Q9–Q11, Q14, Q18, Q20) that exhibited average scores above 85% in both the pre- and posttests were eliminated from the analysis to reduce possible “ceiling effects.” Moreover, because the

TABLE II. Control and experimental group g values.

Group	N	Pretest mean (SE)	Posttest mean (SE)	g (SE)
Experimental	72	0.61 (0.02)	0.74 (0.02)	33.4% (0.05)
Control 1	123	0.64 (0.01)	0.70 (0.01)	16.8% (0.05)
Control 2	144	0.60 (0.01)	0.65 (0.01)	14.7% (0.04)

base concept in one question (Q19) was not defined in the class textbook, scores for this question were also removed from the analysis. Consequently, the analysis included data from only 17 TCI questions.

A. Normalized gain (g)

To assess the effectiveness of the DGWI teaching approach, we required a comparable measure associated with the instructional methods studied. In a detailed study of FCI results that investigated 62 introductory physics courses with over 6000 high school, college, and university students, Hake [1] introduced the normalized gain (g value):

$$g = \frac{\text{absolute gain}}{\text{maximum possible gain}} = \frac{s_{\text{post}} - s_{\text{pre}}}{100\% - s_{\text{pre}}}.$$

The absolute gain is equal to the difference between the pretest mean score (s_{pre}) and the posttest mean score s_{post}

of the class, and the maximum possible gain is equal to the difference between the maximum possible test score (assumed to be 100) and the pretest mean.

The g value remains roughly the same for classes with a similar instructional approach regardless of the various pretest means and is optimal for comparing course effectiveness over diverse groups exhibiting a wide range of initial performance levels. Hake's study found that $g = 0.23 \pm 0.04$ s.d. for traditional courses and $g = 0.48 \pm 0.14$ s.d. for interactive engagement courses [1].

Tables II and III presents the TCI test results for the experimental and control groups. The data indicate that the g value for the experimental class was twice the g value of the control classes, which is consistent with Hake's findings for interactive teaching methods. In the experimental groups, the interaction was increased between an instructor and students via the DGWI approach.

TABLE III. The average pretest score and g value.

	Experimental class		Control class 1		Control class 2	
	Pretest mean	g	Pretest mean	g	Pretest mean	g
T06	88.9%	12.5%	67.5%	45.0%	77.8%	0
T07	2.8%	5.7%	3.3%	6.7%	59.1%	55.7%
T08	40.3%	20.9%	52.0%	-27.1%	43.6%	-8.3%
T15	77.8%	56.3%	71.5%	42.9%	63.1%	52.7%
T16	84.7%	-54.5%	77.2%	0.0%	77.8%	-206.1%
T17	50.0%	19.4%	60.9%	-14.6%	50.3%	-97.3%
T21	72.2%	5.0%	82.9%	9.5%	16.1%	-12.0%
T22	48.6%	32.4%	60.9%	18.7%	58.4%	43.5%
T24	80.6%	71.4%	91.9%	-50.0%	91.3%	23.1%
T25	65.3%	36.0%	71.5%	31.4%	75.2%	43.2%
T26	80.6%	50.0%	95.1%	-50.0%	81.9%	70.4%
T27	61.1%	78.6%	78.9%	34.6%	81.2%	75.0%
T28	75.0%	72.2%	81.3%	26.1%	71.1%	44.2%
T29	63.9%	50.0%	68.3%	35.9%	66.4%	26.0%
T30	50.0%	80.6%	47.9%	67.2%	40.3%	80.9%
T31	45.8%	48.7%	44.7%	32.3%	59.1%	52.5%
T32	43.1%	4.9%	40.6%	-1.4%	40.3%	21.4%

TABLE IV. Two-tailed p values for the t -tests of mean differences.

	Experiment-control 1	Experiment-control 2	Control 1-control 2	Experiment	Control 1	Control 2
Pretest mean	0.046	0.77	0.046			
Pretest-posttest mean				0.002	0.0001	0.001
g values	0.003	0.003	0.964			

TABLE V. Mean scores and standard deviations for class tests and t -test p values.

Question no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Experiment (mean $\pm$ SE)	(88 $\pm$ 4)%	(99 $\pm$ 1)%	(89 $\pm$ 3)%	(74 $\pm$ 5)%	(75 $\pm$ 5)%	(80 $\pm$ 2)%	(58 $\pm$ 5)%	(90 $\pm$ 3)%	(91 $\pm$ 3)%	(92 $\pm$ 3)%	(86 $\pm$ 3)%	(92 $\pm$ 2)%	(74 $\pm$ 4)%	(80 $\pm$ 3)%	(83 $\pm$ 2)%
Control 2 (mean $\pm$ SE)	(91 $\pm$ 2)%	(99 $\pm$ 1)%	(83 $\pm$ 3)%	(63 $\pm$ 4)%	(56 $\pm$ 4)%	(90 $\pm$ 4)%	(60 $\pm$ 3)%	(90 $\pm$ 2)%	(92 $\pm$ 2)%	(93 $\pm$ 4)%	(86 $\pm$ 2)%	(89 $\pm$ 3)%	(86 $\pm$ 2)%	(66 $\pm$ 3)%	(82 $\pm$ 2)%
p value (two-tailed)	0.385	0.692	0.194	0.089	0.003	0.027	0.726	0.753	0.710	0.623	0.577	0.381	0.005	0.001	0.427
t -test															

FIG. 2. Students' self-reporting on the extent to which they benefited from the DGWI approach.

B. Results of t -tests

We used t -tests to investigate the difference between the experimental and control groups. The significance level was set at 0.05 for every factor. The two-tailed p values are presented in Table IV.

The data in Table IV indicate that pretest scores for the experimental class and control class 2 did not exhibit a statistically significant difference (p value = 0.77). The pretest scores for the experimental class, however, were significantly different from the control class 1 scores (p value = 0.046 < 0.05). From Table II, we know the mean of the pretest was slightly lower in the experimental class than in control class 1. One possible cause of this phenomenon is that in recent years China undertook reforms of its college entrance examination system. Although students must learn the same curriculum to participate in a unified college entrance examination, the actual tests administered in different provinces are slightly different. In particular, the thermal test is compulsory or optional in different provinces. This difference leads to differences in pretest scores. The pretest mean for control class 2 was also significantly different from the value for control class 1 (p value = 0.046 < 0.05).

After learning the course material, all three classes exhibited significant improvement on the posttest compared to the pretest. For the g values, the experimental class was significantly different from the control class, but there was no significant difference between the control classes.

IV. DISCUSSION

A. Effectiveness of DGWI teaching approach

To avoid test effects, we chose the TCI instrument for the pre- and posttest measures. The instructors and students were not familiar with the TCI, and instructors did not administer the pretests or posttests.

The experimental group exhibited a higher g value than the control groups (see Table II), indicating that the DGWI

teaching approach was more effective in improving students' conceptual understanding than traditional lecture-based instruction.

For the experimental class and control class 2, students in the different classes exhibited similar levels of prior knowledge, which was confirmed by the results of the statistical analysis; moreover, the course content, syllabus, number of lecture hours, and the instructor were identical. The only difference between the classes was that the experimental class used the DGWI approach while control class 2 followed traditional teaching methods. The analysis found that the g value exhibited by the experimental class was twice the g value found for control class 2.

Compared to the students in the experimental class, students in control class 1 exhibited more comprehensive prior knowledge. Although the two classes had different instructors, these two classes followed the same syllabus and required the same number of lecture hours, and the homework source and content in the two classes were also identical. Table II indicates that the experimental class exhibited a g value that was twice the g value found in control class 1.

Care must be taken in interpreting these results. Control class 2 and the experimental class were taught by the same instructor using different teaching methods. The instructors of the experimental class and control class 1 were both professors with considerable teaching experience. Although the homework for control class 1 and the experimental class was taken from the same source and exhibited the same level of difficulty, the format of the homework in the two classes was different. In contrast, the homework for control class 2 and the experimental class was identical. Consequently, the instructor and homework factors were controlled in the experiment. This assumption was supported by the similar g values exhibited by control classes 1 and 2 (see Table II).

To confirm the effectiveness of the DGWI teaching approach, we compared students' final exam test results for the experimental class and control class 2, which were taught by the same instructor. Both classes took the same exam and the exam questions were identical. The exam contained multiple-choice questions, fill-in-the-blank questions, and calculation problems. The results are summarized in Table V.

In Table V, questions 1–9 are multiple-choice questions, questions 10–13 are fill-in-the-blank questions, and question 14 is a calculation problem. The proportion of students who answered the questions correctly is slightly different between the two groups, but there is not a statistically significant difference (p value = 0.427). After excluding certain questions to prevent ceiling effects (the mean scores in the experimental group and control group 2 were more than 85%), responses to seven questions (questions 3, 4, 5, 6, 7, 13, and 14) were analyzed. For the experimental group, the total mean and standard errors of those questions

are $(76 \pm 4)\%$, and for the control group 2, they are $(72 \pm 3)\%$.

The proportion of students who answered the questions correctly was higher in the experimental group than in control class 2, and this difference was statistically significant (t -test p values are $0.03 < 0.05$). In particular, test scores for questions 4, 5, and 14 were higher in the experimental group than in control class 2. The experimental class scored lower than control class 2 on question 13. The differences in scores for questions 5, 6, 13, and 14 were statistically significant. The analysis found that the experimental class had higher scores on the class test compared to the control group.

The experimental class also responded to a survey regarding the DGWI approach, and survey results provided further evidence for its effectiveness. Most students reported that the DGWI approach helped them learn physics (see Fig. 2). Of the students surveyed, 62% reported that the DGWI approach was of significant benefit to them in learning physics, while 25% reported that the DGWI approach was beneficial; 10% reported that they experienced little benefit from the DGWI approach, and 3% reported that they did not benefit from the approach.

Therefore, the improvement in teaching effectiveness seems to be primarily due to the DGWI approach.

B. DGWI increased effective interaction in teaching

In our research, we developed a dual safeguard web-based interactive teaching approach for introductory physics classes. In the DGWI teaching approach, there were two feedback loops to ensure effective instructor-student interaction. Prior to class, warm-up exercises were designed as the first safeguard to identify students' misconceptions and difficulties. Based on student responses to the warm-up exercises, the instructor organized and modified the classroom lesson to correct students' misconceptions and develop students' conceptual understanding and knowledge base. This was the first feedback loop. After the lesson, students repeated the warm-up exercises as homework to assess the effectiveness of the lesson. The second safeguard procedure was the discussion session in which the instructor and the teaching assistant clarified students' remaining confusion regarding physics concepts and provided training to improve students' problem-solving abilities. The web-based procedures enabled instructors to quickly review students' responses to the warm-up and homework assignments to identify key points for in-class discussion. This was the second feedback loop.

In the two feedback loops, the effectiveness of student-instructor interaction was reflected in students' responses to the online questions and how the instructor organized the teaching sessions. Below, we provide an example of the DGWI teaching process. The warm-up and homework questions used are presented in the Appendix.

TABLE VI. Student responses to the online warm-up exercises and homework.

Question or answer		A	B	C	D	E	F	Sampleno.	G ^a
1 C	Preclass warm-up exercises	61%	1%	37%	0%	0%	0%	72	6 (8%)
	Homework	38%	0%	61%	0%	0%	0%	72	5 (7%)
2 B	Preclass warm-up exercises	6%	90%	1%	1%	0%	0%	72	5 (7%)
	Homework	8%	88%	1%	1%	0%	0%	72	4 (5%)
3 A	Preclass warm-up exercises	88%	3%	3%	4%	0%	0%	72	5 (7%)
	Homework	93%	1%	1%	3%	0%	0%	72	5 (7%)
4 A	Preclass warm-up exercises	91%	3%	3%	1%	0%	0%	72	5 (7%)
	Homework	91%	4%	1%	1%	0%	0%	72	5 (7%)
5	Preclass warm-up exercises	59%	58%	56%				72	12 (17%)
	Homework	62%	62%	61%				72	6 (8%)

^aG represents the number (percentage) of students requesting additional explanation.

Table VI presents students' responses to the online warm-up exercises and homework for one lesson. Questions 1, 2, 3, and 4 were multiple-choice questions. The responses A, B, C, and D were statements answering the question, while responses E and F were the statements "this question is too easy or difficult for me," respectively. The percentage in each column represents the proportion of students selecting a particular response. Question 5 was a fill-in-the-blank question that required three responses; for this question, columns A, B, and C represent the average level of accuracy for the first, second, and third response, respectively.

Students' responses revealed their misconceptions regarding the course material. Because over 70% of students (the trigger point established by the instructor) answered questions 2, 3, and 4 correctly, the content related to these questions was not emphasized in class. Because less than 70% of the students answered warm-up questions 1 and 5 correctly, the instructor focused on the related content in the lecture. For example, because students' responses to question 1 indicated difficulty in differentiating between the steady and equilibrium states, the instructor spent more time in class describing and illustrating these concepts. The instructor did not explicitly provide the correct answer to question 1 in the lecture, but presented concrete examples that illustrated the characteristics of equilibrium and stability states to enable students to identify the difference between the two phenomena independently and construct their own knowledge systems.

After the first student-instructor interaction in class, the proportion of students who responded correctly to question 1 increased from 37% to 61%. The proportion of students who responded correctly to question 5, however, only increased from 56% to 61%. Although the increase in the proportion of students who responded correctly to question 5 was modest, the proportion of students who requested further explanation of this question decreased from 17% to 8%. Because less than 70% of the students correctly

responded to questions 1 and 5 after the lecture, these questions were also addressed in the discussion session. Table VI reveals that approximately 7% of the students requested further explanations of these questions both prior to the lecture (for the warm-up questions) and after the lecture (for the homework questions). Although these students may have been able to answer the questions correctly, they still experienced confusion regarding certain concepts. Thus, the instructor and teaching assistants focused on assisting these students through individual discussions during the discussion session.

Table VI also indicates that the proportion of correct responses to questions 2, 3, and 4 was similar for the warm-up and homework sessions. The lecture exerted a limited influence on student performance for these questions, which may be due to a ceiling effect. Although question 5 did not exhibit a ceiling effect, the proportion of correct responses to the warm-up and homework questions was also similar. Student performance on the warm-up and homework exercises revealed that the lecture did not fully resolve students' misconceptions and difficulties. Consequently, the discussion session was critical in enabling the instructor to improve students' understanding of the material and problem-solving abilities.

Table VI indicates that the proportion of students with correct responses was less than 70% for 40% of the warm-up questions. After the lecture, the proportion of students with correct responses was less than 70% for 20% of the homework questions. Similar situations also occurred for other course lectures. The DGWI approach improved instructors' abilities to identify the misconceptions and difficulties students encountered in learning physics. In the classroom, instructors could facilitate students' development of an accurate knowledge base and focus on students' difficulties. The instructor could use the online system to monitor students' responses and provide students with concrete and effective guidance in class. The DGWI approach thus improved teaching effectiveness by increasing effective student-teacher interaction.

Following the DGWI approach, the instructor could organize the lecture based on the prior knowledge identified by the warm-up exercises. Afterwards, the instructor could use the homework assignment to monitor the effectiveness of the lecture and respond to students' requests for additional instruction. Finally, the instructor was able to use the discussion session to assist students in constructing their knowledge bases and improve their learning efficiency.

C. Using DGWI to identify student misconceptions or difficulties

The questions used in the DGWI approach were based on students' targeted level of understanding for the introductory physics course. For the thermodynamics course, there were 69 questions at different levels of difficulty, which covered all of the course content.

In general, it was difficult for students to identify their misconceptions and the difficulties they encountered in learning physics. The DGWI method established a system of dual safeguards that covered all course content so that students' misconceptions could be identified. For example, 17% of the students asked the instructor to further explain question 5 after the warm-up session, and 8% of the students continued to request further explanation for this question after the lecture (see Table VI).

Table VI also indicates that approximately 7% of the students requested additional explanation of content related to the warm-up and homework questions, which suggests that a few students experienced difficulty in learning the related content. Although they may have been able to respond to the questions correctly, they still needed the instructor's assistance to resolve misconceptions.

Students were required to review course content and respond to the warm-up questions prior to class. If students viewed a question as too easy or too difficult, they could choose the corresponding response so that they did not waste time on questions they could not answer. If students felt that they needed further explanation of the topics related to a particular question, they could also select the corresponding response so that the instructor could modify the lecture based on student feedback; however, instructors did not explicitly answer the warm-up questions during the lecture. Because students were not provided with the answers to the warm-up questions, they were able to respond to identical questions on the homework assignment after the lecture based on their interpretation of the course content. By using the DGWI approach, the instructor was able to identify the content that students had already mastered and the concepts that students continued to have difficulty with. The students were able to exhibit their misconceptions and invest more effort on the related topics.

Compared with the JiTT approach, the DGWI approach employs a different measure to identify students' prior knowledge. JiTT warm-up questions are typically

free-response questions designed to probe students' difficulties that are based on research regarding common student misconceptions prior to a lecture. Because the questions must be of high quality to be effective, question designers must exhibit sufficient understanding of students and considerable teaching experience; in addition, too many warm-up questions cannot be used for a given lecture. The DGWI approach is an instrument that targets students' learning outcomes based on the course content and teaching goals. The DGWI questions use a multiple-choice and fill-in-blank format to provide instructors with efficient feedback regarding the difficulties students encounter in learning course content. The DGWI warm-up questions cover the entire course content. In addition, the DGWI approach, which asks students to identify questions that require further explanation, assesses students' learning difficulties. For example, Table VI indicates that 7% of the students requested further explanation for homework question 5, which suggests that students experienced difficulty and harbored misconceptions with respect to the related content.

In DGWI, both the lecture and the discussion session addressed students' misconceptions and the difficulties students encounter in learning course content. The lecture was the initial point at which the instructor could contribute to students' knowledge, while the discussion session supplemented the lecture and provided a second point at which the students could consolidate their knowledge. A set of questions covering all of the course content provided a system of dual safeguards (warm-up or homework and lecture or discussion) that efficiently provided feedback through the course web site. Thus, both instructors and students were able to effectively communicate regarding students' misconceptions and learning difficulties. The experimental study provided evidence for the effectiveness of the DGWI approach. As Table III indicates, the experimental class receiving the DGWI teaching approach exhibited only a single negative g value while the two control classes exhibited four negative g values. Because the dual safeguard system reduced students' misconceptions, the experimental group exhibited fewer negative g values. In contrast, because the instructors and students in the control groups did not experience the DGWI safeguards, students did not learn as much and the control classes exhibited more negative g values.

D. Analysis of the student attitude survey

At the end of the quarter, students in the experimental group completed a five-item survey regarding the DGWI teaching approach. The survey employed a five-point Likert scale ranging from 2 (completely agree) to -2 (completely disagree). The results for the five survey questions are presented in Table VII.

Table VII indicates that 50% of the students liked the new teaching approach and that only 8.33% disliked the

TABLE VII. Student survey results. (The numbers represent the percentage of students who chose a particular response.)

Statements	2	1	0	-1	-2
I like the new teaching approach.	9.7%	40.3%	41.7%	7.0%	1.4%
I like using the website [32].	11.1%	30.6%	32.0%	23.6%	3.1%
I like to repeat the same questions.	5.6%	55.6%	25.0%	11.1%	2.8%
I agree that some questions were “too difficult or easy for me.”	45.8%	22.2%	26.4%	2.8%	2.8%
How much did you benefit from DGWI teaching?	8.1%	53.0%	26.5%	9.2%	3.0%

approach. With respect to using the web site, over 70% of the students expressed a positive or neutral attitude. With respect to responding to identical questions on the homework, more than 60% of the students liked repeating the same questions and thought that the new approach was beneficial. The students were not required to devote too much extra time to completing the homework on the web site. When students thought a question was too easy, they were able to indicate that “the question was too easy for me,” and when they felt the questions were too difficult, they were able to indicate that “the question was too difficult for me”; therefore, 68.1% of the students agreed that it was appropriate to add response options that identified a question as “too difficult or easy.”

In the experimental group, 69.4% of students had average pretest scores of less than 70%. These students, whose learning improved and who exhibited relatively higher g values, appreciated the new teaching approach; however, some of the students whose average scores on the pretest exceeded 70% disliked the new approach. In general, students expressed positive views regarding the DGWI teaching approach.

V. CONCLUSION

To improve the interaction between teachers and students who exhibit an extensive preliminary knowledge of physics, we modified the JiTT approach and developed a dual safeguard web-based interactive teaching approach for an introductory physics course. The results of this research indicated that the DGWI approach improved students’ learning and understanding of physics. The experimental class that used the approach exhibited a normalized gain that was twice the gain exhibited by the control classes that were taught using traditional methods. This result was consistent with Hake’s claim that the g value is closely related to the instructional approach and that interactive teaching doubles the g value compared to traditional teaching methods.

The DGWI method is based on a double-guard framework of warm-up exercises and homework that includes questions that cover all course material and teaching requirements. The instructor is able to obtain feedback regarding students’ learning outcomes and the gap between students’ current knowledge and the desired level of

knowledge. The dual safeguard network enables instructors and students to identify misconceptions so that instructors can use lectures and discussion sessions to develop students’ problem-solving ability and construct new knowledge. Through the DGWI method, instructors are able to use pretest feedback that reflects students’ prior knowledge and misconceptions to modify the focus of instruction and to use posttest results that reveal remaining student misconceptions after the lecture to modify the content of the discussion sessions.

The DGWI approach uses the Internet to improve the interaction between the instructor and the students by providing extensive information on students’ current level of knowledge. In a traditional classroom, it is difficult for the instructor to perform educational assessments and to quantitatively estimate the extent to which students understand each lesson. The DGWI approach overcomes this difficulty by performing pretests and posttests consisting of online warm-up assignments and homework. The online system maintains records of student learning that can be used for further educational research.

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APPENDIX

Question 1

Which one of the following statements correctly describes the equilibrium state of a thermodynamic system (i.e., the state at which the macroscopic properties p , V , and T do not change with time)?

A. The state in which the pressure and temperature are uniform within the system.

B. The stable state that the system reaches after a long time without exchanging macroscopic energy and matter with the environment.

C. The state in which every molecule in the system is at equilibrium.

D. The question is too easy so I do not wish to answer it.

E. The question is too difficult so I do not wish to answer it.

Question 2

A certain amount of ideal gas expands following the rule that $pV^2 = \text{constant}$. How will the temperature of the ideal gas change after the expansion? The temperature:

A. Increases.

B. Decreases.

C. Does not change.

D. Either increases or decreases.

E. The question is too easy so I do not wish to answer it.

F. The question is too difficult so I do not wish to answer it.

Question 3

A certain amount of ideal gas expands following the rule that $pV^{1/2} = \text{constant}$. How will the temperature of the ideal gas change after the expansion? The temperature:

A. Increases.

B. Decreases.

C. Does not change.

D. Either increases or decreases.

E. The question is too easy so I do not wish to answer it.

F. The question is too difficult so I do not wish to answer it.

Question 4

A container is equally divided into two parts by a wall. The left side contains CO_2 and the right side contains H_2 . The gases on both sides have the same mass and the same temperature. If there is no friction between the dividing wall and the container, in which direction will the wall move?

A. It will move to the left.

B. It will move to the right.

C. It will not move.

D. I cannot determine whether the wall moves.

E. The question is too easy so I do not wish to answer it.

F. The question is too difficult so I do not wish to answer it.

Question 5

A certain ideal gas has volume $V(\text{m}^3)$, pressure $p(10^5 \text{ Pa})$ and temperature $T(\text{K})$. The mass of each gas molecule is $m \times 1.66 \times 10^{-27} \text{ kg}$. When the values of V , p , T , m are assigned as A (10, 1.5, 300, 2), B (0.3, 2.0, 400, 32), and C (2.7, 1.25, 250, 4), respectively, what is the number density n (3 significant digits, in the unit of 10^{25} m^{-3}) that corresponds to each set of values?

A. _____

B. _____

C. _____

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- [1] R. Hake, Interactive-engagement vs. traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses, *Am. J. Phys.* **66**, 64 (1998).
  - [2] R. J. Beichner, Student-centered activities for large-enrollment university physics (SCALE-UP), <ftp://ftp.ncsu.edu/pub/ncsu/beichner/RB/SigmaXi.pdf>.
  - [3] R. Beichner, The SCALE-UP project: A student-centered, active learning environment for undergraduate programs, <http://publish.illinois.edu/disruptivespaces/files/2014/07/SCALE-UP-Paper1.pdf>.
  - [4] L. C. McDermott and P. S. Shaffer, The Physics Education Group at the University of Washington, *Physics by Inquiry* (John Wiley and Sons, New York, 1996), Vols. I and II.
  - [5] J. M. Wilson, The CUPLE physics studio, *Phys. Teach.* **32**, 518 (1994).
  - [6] C. H. Crouch and E. Mazura, Peer Instruction: Ten years of experience and results, *Am. J. Phys.* **69**, 970 (2001).
  - [7] I. D. Beatty, W. J. Gerace, W. J. Leonard, and R. J. Dufresne, Designing effective questions for classroom response system teaching, *Am. J. Phys.* **74**, 31 (2006).
  - [8] S. Zhou, J. Han, N. Pelz, X. J. Wang, L. Y. Peng, H. Xiao, and L. Bao, Inquiry style interactive virtual experiments: A case on circular motion, *Eur. J. Phys.* **32**, 1597 (2011).
  - [9] M. Thoennessen and M. Harrison, Computer-assisted assignments in a large physics class, *Comput. Educ.* **27**, 141 (1996).
  - [10] C. A. Ogilve, "Effectiveness of different course components in driving gains in conceptual understanding," Department of Physics at MIT, internal report [<http://publish.illinois.edu/disruptivespaces/files/2014/07/SCALE-UP-Paper1.pdf>] (2000).
  - [11] N. Demirci, University students' perception of web-based homework in a general physics course, *Eurasia J. Math. Sci. Technol. Educ.* **3**, 29 (2007).
  - [12] N. Demirci, Developing web-oriented homework system to assess students' introductory physics course performance and compare to paper-based peer homework, *Turk. Online J. Dist. Educ.* **7**, 105 (2006).
  - [13] N. Demirci, The effect of web-based homework on university students' physics achievements, *Turk. Online J. Educ. Technol.* **9**, 156 (2010).
  - [14] W. Amanda, Online homework vs. traditional homework: Statistics anxiety and self-efficacy in an educational statistics course, *Technol. Innovat. Stat. Educ.* **6**, 1 (2012).
  - [15] WebAssign, <http://www.webassign.net>.
  - [16] CAPA, <https://loncapa.msu.edu/>.

- [17] University of Massachusetts, OWL—Online Web Learning, <http://www.cesd.umass.edu/CESD/OWL/index.html>.
- [18] S. Bonham, R. Beichner, and D. Deardorff, Online homework: Does it make a difference?, *Phys. Teach.* **39**, 293 (2001).
- [19] S. W. Bonham, D. L. Deardorff, and R. J. Beichner, Comparison of student performance using web and paper-based home work in college-level physics, *J. Res. Sci. Teach.* **40**, 1050 (2003).
- [20] W. Fakcharoenphol, E. Potter, and T. Stelzer, What students learn when studying physics practice exam problems, *Phys. Rev. ST Phys. Educ. Res.* **7**, 010107 (2011).
- [21] K. H. Wang, T. H. Wang, W. L. Wang, and S. C. Huang, Learning styles and formative assessment strategy: Enhancing student achievement in web-based learning, *J. Comput. Assist. Learn.* **22**, 207 (2006).
- [22] T. Buchanan, The efficacy of a World-Wide Web mediated formative assessment, *J. Comput. Assist. Learn.* **16**, 193 (2000).
- [23] G. Wang, in *Proceedings of the 2nd International Multi-Conference on Engineering and Technological Innovation (IMETI'2009)*, Orlando, Florida, pp. 219–223, <http://www.iis.org/cds2008/cd2009sci/imeti2009/paperspdf/f665aa.pdf>.
- [24] K. A. Marrs, R. E. Blake, and A. D. Gavrin, Web-based warm-up exercises in Just-in-Time Teaching—Determining students' prior knowledge and misconceptions in biology, chemistry and physics, *J. Coll. Sci. Teach.* **33**, 42 (2003).
- [25] A. Gavrin, J. X. Watt, K. Marrs, and R. E. Blake, Just-in-Time Teaching (JiTT): Sing the web to enhance classroom learning, *Computers in Education Journal / Computers in Education Division of ASEE* **14**, 51 (2004).
- [26] A. Marrs Kathleen and N. Gregor, Just-in-Time Teaching in biology: Creating an active learner, *Cell Biol. Educ.* **3**, 049 (2004).
- [27] W. Luo, Just-in-Time-Teaching (JiTT) improves students' performance in classes—Adaptation of JiTT in four geography courses, *J. Geosci. Educ.* **56**, 166 (2008).
- [28] L. Bao *et al.* Learning and scientific reasoning, *Science* **323**, 586 (2009).
- [29] J. M. Cummings, R. Thornton, and D. Kuhl, Evaluating innovation in Studio Physics, *Am. J. Phys.* **67**, S38 (1999).
- [30] N. Lasry, E. Mazur, and J. Watkins, Peer Instruction: From Harvard to the two-year college, *Am. J. Phys.* **76**, 1066 (2008).
- [31] C. M. Sorensen, A. D. Churukian, S. Maleki, and D. A. Zollman, The new studio format for instruction of introductory physics *Am. J. Phys.* **74**, 1077 (2006).
- [32] www.zjjiao.com (in Chinese).
- [33] Li Lieming, Speak on the base of data—Quantitative, and semi-quantitative teaching research linked closely with daily teaching, *Phys. Eng. Suppl.* **9** (2009); G. Zhou, S. Zhong, J. Feng *et al.* A network assistant exercise discussion class mode and its quantitative assessment, *Phys. Eng.* **23**, 55 (2013) (in Chinese).
- [34] K. C. Midkiff, T. A. Litzinger, and D. L. Evans, Development of engineering thermodynamics concept inventory instruments, *Proc. Front. Educ. Conf.* **2**, F2A (2001).