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A Quantitative Analysis on Interactive Method Makes Teaching More Scientific

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Abstract: Some researches showed that, comparing the teaching experience and style of teacher, interactive teaching method, which could help teachers to collect and analyze feedback data regarding students' misconceptions or difficulties, was the key factor of improving the student learning outcomes. Interactive-engagement method makes teaching activities more scientific. In the study, we developed an interactive teaching approach with quantitative analysis 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 this teaching method. The results indicated that the method is an effective way to improve students' understanding of physics concepts, develop students' problem-solving abilities, and identify students' misconceptions.

Keywords: quantitative analysis, web-based teaching, interactive teaching, science, art

1. Teaching Scientifically

Is teaching an art or a science (Makedon, Alexander, 1990)? There has been a lot of debate about this issue. It is not a good solution to argue simply whether teaching is an art or science, or both, since it tells us nothing about how much of each teaching is, and exactly how the two are combined in teaching practice. Whether teaching is an art or science depends on which definition of teaching we adopt, or what we think the goals of teaching should be.

What are the goals of teaching? Most teachers would like to improve students' learning outcomes, especially the examination performance. 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 methods (g=0.48) were higher than the gain for traditional methods (g=0.23), indicating that interactive engagement improved student learning. In this study, comparing the teaching experience and style of teacher, interactive teaching method has become the key factor of affecting the learning outcomes in the following two aspects:

- Through interactive activities, the teacher is able to collect and analyze feedback data regarding students' misconceptions or difficulties, and discover the gap between their current knowledge and the desired level of knowledge, so as to adjust the lecture.
- The interaction of teacher and student motivates the initiative and enthusiasm of students in the teaching process.

In this case, teaching is more like a science than an art, and the interactive-engagement methods make teaching more scientific.

2. The Quantitative Analysis of Feedback Data from Teaching Activities

In fact, interactive approaches are not necessarily able to improve student outcomes. A case study using a clicker-like APP showed that the students' final average scores were not significantly different from previous ones.

In addition, we encountered difficulties when we introduced the Just-in-Time Teaching (JiTT) pedagogical approach to universities in China. In the JiTT approach, warm-ups are used as the basis for each classroom session to enhance learning (A. Gavrin and J. X. Watt et al, 2004). Many researchers and instructors in the U.S. have reported the effectiveness of JiTT, not only in physics but also in other subjects such as math, chemistry, and psychology (A. Marrs Kathleen and N. Gregor, 2004). However, 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" (L. Bao et al, 2009). 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. 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.

Obviously, whether to seek out students' misconceptions and difficulties and then modify the lecture accordingly is the key point to enhance the efficiency and effectiveness of teaching. In order to availably identify the problems in teaching, it is a good choice to quantify and analyze the feedback data. Then, with the help of Internet to collect and process learning data, the statistical results will provide scientific reference for the adjustment of teaching.

3. The Case Study in an Introductory Physics Class

In order to achieve effective teaching, we developed a dual feedback loop approach 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.

3.1. Building up Question Bank

The question bank is fundamental to designing and assigning the exercises, which is used to collect feedback data about students' learning. In order to be adapted to the online format, the bank is consisted of multiple-choice and fill-in-the-blank questions, all of which cover almost the entire lecture content, so as to sufficiently revealed students' prior knowledge, misconceptions, and difficulties. Meanwhile, according to the results of previous exercises, the questions will be modified to reflect the problems in the learning process. Now the question bank is the Third Edition.

In addition to the collection of objective learning data, we also gather some subjective attitude to learning content. For example, besides four options (A, B, C and D), 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. Moreover, for each question, students were asked to identify whether the question should be explained during the upcoming lecture.

3.2. Procedures Involved in This Approach

This teaching approach requires 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 (www.zjiao.com). The entire teaching process consisted of four components (see Table 1).

Table 1: The teaching process.

Instructional components	Student activities	Instructor activities
Preclass preparation	Prepare the assigned material, perform the warm-up exercises, post results online, and identify whether the results need to be explained.	Check students' responses and prepare classroom teaching
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	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.	

3.2.1. Preclass Preparation

Before each lecture, students in the experimental class were required to prepare assigned content and complete the warm-up exercises online, which consisted of the questions of the bank. The warm-up questions were adapted from traditional homework assignments related to the lecture topic.

Besides E and F options, students must choose whether the questions should be explained during the upcoming class session, and the instructor organized and modified the classroom lecture based on student responses.

3.2.2. 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.

3.2.3. Online Homework

Students were required to repeat the warm-up exercises as homework. They worked out the problems on paper and posted the 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.

3.2.4. 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 was the foundation for in-class collaborative learning.

3.3. Methods for Improving Data Validity

Besides the elaborative design of the warm-up exercises and homework, an important and practical problem, i.e. whether the students are sincere and careful or not, need to be solved to get a valid result. If the students don't care about the exercises and homework, any data related to their learning are meaningless. To ensure the authenticity of the data, the following measures are taken:

Integrate the exercise result as part of the final assessment. It is also pointed out that the grade of the exercise has nothing to do with students' score.

- To have psychological reinforcement, e.g. telling students that his final grade will surely improve if he has done a good job in these exercises.
- Print out the warm-up exercises and homework on paper for students.

4. 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. 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 designed 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 this approach for several years.

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

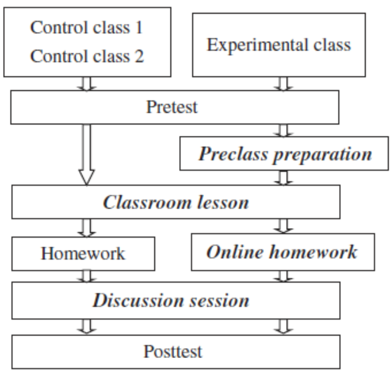

Figure1. A schematic representation of the experimental study design.

4.1. Pretest

Prior to taking the class, students in both classes completed a pretest based on the Thermal Conductivity Instrument (TCI) (K. C. Midkiff, T. A. Litzinger and D. L. Evans, 2001) 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 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 (about 30 students) was similar in both the experimental and control groups.

4.2. 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 pre- and posttests were administered by a different instructor.

5. Data Analysis

In the present study, we investigated the extent to which the dual 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 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.

5.1. Normalized Gain (g)

To assess the effectiveness of this 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 introduced the normalized gain (g value):

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

The absolute gain is equal to the difference between the pretest mean score (Spre) and the posttest mean score Spost 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.

Table 2 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 designed approach.

Table 2. The g values for the control and experimental groups.

Group	N	Pre-mean (SE)	Post-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)

5.2. *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 3.

Table 3. 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			

The data in Table 3 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 2, 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.

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.

To confirm the effectiveness of the designed teaching approach furtherly, we also 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 analysis found that the experimental class had higher scores on the class test compared to the control group.

6. Conclusion

In order to improve students’ learning outcomes, such as exam results, we developed an interactive teaching approach with quantitative analysis for an introductory physics course. This method is based on a dual interactive 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 process and the gap between students’ current knowledge and the desired level of knowledge. With the help of the method, instructors are able to identify students’ misconceptions so that they can use lectures and discussion sessions to develop students’ problem-solving ability and construct new knowledge. Moreover, the method uses the Internet to improve the interaction between the instructor and the students. 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.

References

A. Gavrin, J. X. Watt, K. Marrs, and R. E. Blake. (2004). Just-in-Time Teaching (JiTT): Sing the web to enhance classroom learning. *Computers in Education Journal / Computers in Education Division of ASEE, 14*, 51.

A. Marrs Kathleen and N. Gregor. (2004). Just-in-Time Teaching in biology: creating an active learner classroom using the Internet. *Cell Biology Education, 3*(1), 49-61.

C. M. Sorensen, A. D. Churukian, S. Maleki, and D. A. Zollman. (2006). The new studio format for instruction of introductory physics. *American Journal of Physics. 74*(12), 1077-1082.

K. C. Midkiff, T. A. Litzinger, and D. L. Evans. (2001). Development of engineering thermodynamics concept inventory instruments. *Impact on Engineering and Science Education. 2*, F2A.

L. Bao et al. (2009). Learning and scientific reasoning. *Science, 323,* 586.

Liang-Fang Shi and Jian-Jun Wang. (1996). The Debate of Teaching about Science or Art. *Curriculum, Teaching Material and Method.* 9, 57-59.

Makedon, Alexander. (1990). Is teaching a science or an art. *The Annual Conference of the Midwest Philosophy of Education Society (Chicago, IL, November 10, 1990).*

Richard R. Hake. (1998). Interactive-engagement vs. traditional methods: A six-thousand student survey of mechanics test data for introductory physics courses. *American Journal of Physics. 66*(1), 64-74.