Enhancing conceptual change using argumentative essays

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We show the utility of following up collaborative group work with written exercises. In a previous paper we discussed promoting conceptual change using collaborative group exercises in a manner based on the notion of conceptual conflict developed by Hewson and Hewson in which representatives of differing viewpoints debate their outlook. In this paper, we describe an enhancement of this method based on Feyerabend's principle of counterinduction—the process by which one theory or idea is used to affect change in its rival. Students were required to follow up the conceptual conflict exercises with a written critique. Evaluations were done using the same enhanced version of the force concept inventory as administered to the students in the previous study.
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I. THE ORIGINAL EXPERIMENT

In our original experiment,[1] each intervention began with a collaborative group exercise in a manner based on the notion of conceptual conflict developed by Hewson and Hewson.[2] Students were asked to take on a particular role within each group of three to four students.[3] The students remained in the same group for all the exercises, but could change roles of reporter, scribe, time keeper, or critic in each activity. The only training students received was a warm-up exercise in which students had to come to a joint decision on who were the three greatest scientists of all time. Unlike the regular treatment sessions, all groups were asked to report on their findings.

For each exercise, students were presented with a demonstration or qualitative problem and were asked to discuss it for a fixed time. The time limits were set so that none of the groups had to wait for other groups to complete the task. Two groups were selected because they had developed different concepts to explain a particular physical phenomenon. A conceptual conflict was set up by having these two groups report to the class. The spokespersons of each group then debated the issue and the rest of the students were invited to address questions to this panel of ''experts.'' To emphasize that there were two concepts in conflict, the opposing issues presented by the two groups were clearly stated and the class then voted on which concept best resolved the problem. This voting is essential because students who have compartmentalized concepts often misinterpret statements in view of their eclectic viewpoint. Then the professor resolved the conflict by explaining with the aid of experiments from Ref. 4 how the replacement concept explained the demonstration or qualitative problem in accord with experimental findings, while the personal (alternative) scientific conception failed to do so. For example, in the first collaborative group exercise, students examine the motion of a dropped object with an object thrown horizontally. During the exercise students realize that various students in the class hold different viewpoints. At the end of the in-class collaborative group exercise, students are shown a video on the simultaneous motion of a dropped ball and a thrown ball from the same initial height and a video on the ''monkey gun'' experiment.

II. MORE IS NEEDED

In our previous work we showed the value of having students debate alternative views: it helps, but not as much as one would like.[1] In this new experiment, after completing the collaborative group conceptual conflict exercise, students were required to write a critique as homework due one to two weeks later. In writing the critiques, students had to clearly elucidate the contrasts between two perceptions of physics principles. Students had to give convincing arguments for both an alternative explanation and an explanation derived from the Newtonian framework. They also had to clearly state which viewpoint was ''correct'' in the sense that it agreed with experiment. The three critique exercises were in total worth 5% of their course marks, and there was an essay question on the midterm and on the final on one of the concepts covered by the critiques. The remaining exam items were standard end-of-chapter problems.

In the experiments described in Ref. 1, four basic concepts were discussed for which many students enter the class with alternative conceptions. For two of these concepts, the final post-test scores in the prior experiment were sufficiently low (roughly 60% for the treated group versus 40% for the control group) so that there was room for further improvement. Sternberg notes that ''In most discourse communities ... great emphasis is given to such factors as deference to authority, unreflective intuition, social dexterity and timely action.''[5] Nelson[6] points out that ''Left alone, [students] often simply create a collage of opinions.'' The critique was introduced to have students critically examine alternative possibilities and to try to resolve the ''collage of opinions'' coherently. For

Table I. Promoting conceptual change using only collaborative group exercises: Comparison of the overall gains pre- to post-test 1998 with 1999.

Test Group	Mean Difference	Standard Deviation
Pre-test 1998 versus Post-test 1998	3.24	4.95
Pre-test 1999 versus Post-test 1999	6.95	3.81

Table II. Promoting conceptual change using only collaborative group exercises followed by a written critique: Comparison of the experiments winter 1998 and winter 1999.

Question(s)	Test	Mean Score (Standard Deviation) Group A (33 students)	Group B (19 students)	Statistical significance (t test)	Concept
Baseline (FC1-1,5,12,16,22)	pre-test	8.8(4.0)	9.8(4.2)	p=0.38	
	post-test	11.4(4.6)	14.1(4.8)	p=0.051	
Set I (1,5,16,22,31,32)	pre-test	2.6(1.4)	2.1(1.0)	p=0.12	
	post-test	3.6(1.7)	4.8(1.3)	p=0.012	
Set II (5,16,22,31,32)	post-test	2.9(1.5)	4.0(1.2)	p=0.032	
Concept 1 (16, 31)	post-test	1.36(0.74)	1.84(0.38)	p=0.012	Bullet compared to dropped penny
Concept 2 (5,22,32)	post-test	1.49(1.1)	2.11(0.94)	p=0.043	Forces on a ball thrown in the air

example, in the third exercise consisting of the examination of the forces acting on a thrown baseball just after it leaves your hand and when it reaches the top of its motion, students enunciated a variety of personal (alternative) scientific conceptions including ''force dependent on velocity'' and the ''force of the hand balancing the force of gravity at the top of the motion.'' Some also introduce an ''*ma*'' or a ''momentum force.'' The rationale behind the critique is Feyerabend's[7] principle of counterinduction. The idea is that the evaluation of a theoretical framework does not occur until there is an alternative.

In view of Nelson's remarks,[6] it is certainly possible that many students were simply confused by the collaborative group exercises. The requirement of doing a critique is an attempt to enhance the development of students' critical thinking skills[8] so that they will carefully examine the alternatives presented to them in the conceptual conflict exercises. Doing the critique should greatly increase the likelihood that they will examine their personal (alternative) scientific conceptions. Our in-class collaborative group exercises are designed to produce the conceptual ecology[9] for students to question their alternative personal scientific conceptions. The critiques are designed to cause the students to engage in a kind of critical discussion to decide which natural interpretations can be kept and which must be replaced.

III. ANALYSIS OF STUDENT LEARNING GAINS

For our analysis, we establish a baseline consisting of all Force concept inventory[10] (FCI) questions except 1, 5, 12, 16, and 22. The questions in the baseline do not relate to the concepts under study. The analysis was then done on two concepts considered in the previous analysis.[1]

First concept: the motion of a bullet compared to a dropped penny. Personal (alternative) scientific conception; a fast moving bullet moves in a straight line in the air because of its great speed. The relevant questions for this concept are question 16 of the FCI and question 31 labeled as concept 1.

Second concept: the forces on a ball thrown in the air. Various personal (alternative) scientific conceptions; ''force dependent on velocity,'' ''force of the hand balancing the force of gravity at the top of the motion,'' an ''ma'' or a ''momentum force'' is in equilibrium with gravity at the highest point in its motion. The relevant questions for this concept are questions 5 and 22 of the FCI and question 32 labeled as concept 2.

The relevant questions for these two concepts as a whole are questions 5, 16, and 22 of the FCI and additional questions 31 and 32 labeled as set II. (Set I is all of these questions plus additional question 1 of the FCI.)

The analysis was done on only those students who took both the pre- and post-test and who were present for all three conceptual conflict exercises for the winter 1998 and winter 1999 experiments and additionally only those students who wrote all three critiques for the winter 1999 experiment. These requirements severely restricted the size of the sample.

In comparing the 1998 and 1999 experiments, we first tested the students for normality using both the Anderson–Darling[11] and Kolmogorov–Smirnov[12] tests. The results show no evidence of normality being violated. The Bartlett[13] and Levene[14] tests of homogeneity of variance were also applied where appropriate. The results showed no evidence of the homogeneity of variance being violated.

The overall FCI gains for each of the 33 students meeting our criteria in winter 1998 and for each of the 19 students meeting our criteria in winter 1999 were then compared using *t* tests. Some of the details are shown in Table I. It was found that $p<0.0005$ in all cases. Thus the addition of the critique produced a statistically significant improvement in winter 1999 compared with the use of collaborative groups alone in winter 1998.

Table II contains a detailed comparison of the results for winter 1998 and winter 1999. Note that in every case the winter 1999 group scored higher than the winter 1998 group. In addition to the statistically significant gains in the two tested concepts for the winter 1999 group over the winter 1998 group, there is a strong indication that the winter 1999 students also scored better in the baseline consisting of questions that do not relate to the concepts under study.

Recall that the purpose of the critiques is to enhance the development of students' critical thinking skills so that they will carefully examine the alternatives presented to them in the conceptual conflict exercises. Such a spillover might indicate that by doing the critiques, students actually increase their critical thinking skills and such an improvement leads students to reevaluate their entire conceptual framework.

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