Additional Evidence of Far Transfer of Scientific Reasoning Skills Acquired in a CLASP Reformed Physics Course

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Abstract. The introductory physics course taken by biological science majors at UC Davis, Physics 7, was radically reformed 16 years ago in order to explicitly emphasize the development of scientific reasoning skills in all elements of the course. We have previously seen evidence of increased performance on the biological and physical science portions of the MCAT exam, in a rigorous systemic physiology course, and higher graduating GPAs for students who took Physics 7 rather than a traditionally taught introductory physics course. We report here on the increased performance by a group of biological-science majors in a general chemistry course who took the first quarter of Physics 7 prior to beginning the chemistry course sequence compared to a similar group who began taking physics after completing the first two quarters of general chemistry.

Keywords: Transfer of Learning, Scientific Reasoning Skills, Active Learning, CLASP
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INTRODUCTION

We have previously seen evidence of increased performance by students who take Physics 7 instead of a traditionally taught introductory physics course on *both* the biology and physical science portions of the MCAT exam [1], in a subsequently-taken junior/senior level biology course [1,2], and an increase in graduating GPAs of biological science majors [1]. In this paper we report on the increased performance in the general chemistry course of a group, labeled Group 2, of biological science majors who took the first quarter of the reformed course, Physics 7A, in their first college term before beginning the general chemistry sequence. A different group, Group 1, very similar to Group 2 except that they took Physics 7A in the spring quarter of the freshman year after beginning the chemistry sequence in their first quarter, serves as the comparison or control group. The data reported here are much more robust and allow for a cleaner comparison than did the earlier data.

When we first began to observe evidence indicating that at least some students who took Physics 7A were exhibiting increased performance in subsequent courses and on exams, it was not clear that there were no other factors involved, because the increases showed up in a course (one quarter systemic physiology course) and on an exam (the *biological sciences* portion of the MCAT) that had little if any direct content overlap with Physics 7. This is also the case, for the most part, with the results reported here on increased performance in the one-year introductory chemistry course. Therefore, to the extent that far transfer is occurring, it is definitely not transfer of content knowledge per se that is responsible for the future increased performance, but rather a transfer of something less tangible. We used the term scientific reasoning skills in the title more as a placeholder for whatever it is that is transferring, rather than intending to imply that we know with any definitiveness what it is that is transferring. There are, however, some rather unique features of the Physics 7 course that provide strong clues as to what the students are acquiring that positively affects their learning in subsequent courses.

In this very short paper, we will not discuss prior work by a large number of researches on transfer and why it has been so difficult to observe, although it must be occurring to some extent, if students' knowledge and understanding advances as they progress through the educational system. We return to this point briefly in the Discussion Section.

THE UC DAVIS REFORMED PHYSICS 7 COURSE–CLASP

Physics 7 differs from other introductory physics courses in multiple ways. The originators of the course were immersed in the K-12 science educational reform movement as it developed in the 1980's and early 90's through various projects involving both teachers and students. From these direct experiences, especially with adult learners—the K-8 teachers—there was absolutely no doubt that learning environments based on constructivist learning principles coupled with the conviction of the tremendous advantages of cooperative group learning environments were the key to creating and implementing effective learning environments at the college level. To the greatest extent possible, Physics 7 was designed and implemented to be true to these principles. Except for a small number of economic, bureaucratic, and logistical constraints (at that time, 1200 students enrolled per year), everything was on the table. This included how the course was structured in terms of learning environments; content and content sequencing; learning goals; and how student success in achieving those goals was to be assessed. Over the past 16 years there has been a gradual evolution and refinement of the course. We have adopted the phrase Collaborative Learning through Active Sense-making in Physics (CLASP) to refer to the approach taken in Physics 7. This is much more fully described in a recently submitted paper [1].

Essential features relevant to this paper are summarized in Table 1:

TABLE 1. Salient Features of CLASP.

Instructional Setting	280 minutes per week working in small groups in discussion/lab; 80 minutes per week in lecture
Content	Organized around approximately 30 general models, instead of topics
Content Sequencing	Course begins with models based on conservation of energy, particles, and thermodynamics
Primary goal	Making sense of a wide variety of phenomena in terms of generally applicable models; learning and *practicing Model-Based-Reasoning*
Student Assessment	Weekly quizzes in lecture typically using a model(s) to construct an explanation of a previously unseen phenomenon (both qualitative and quantitative)
Student Materials	Developed in house and sold by Hayden McNeil
Student Population	Essentially all biological science majors are required to take this "calculus-based" introductory one-year physics course. Over 1700 students enroll each year.

THE EXPERIMENT

In collaboration with faculty from the departments of mathematics and chemistry we conducted an experiment to explore the pedagogical effects of creating a cohort of 48 entering freshman students who would be exposed to several math and science courses simultaneously with each course emphasizing sense making to a much greater degree than is typical in introductory math and science courses [3]. As is typical in such collaborative efforts involving more than one department and various administrators, unforeseen circumstances prevented carrying out the experiment exactly as proposed. However, the actual implementation created a situation that made the analysis reported here possible: namely, the circumstance that one group of students, Group 1, took two quarters of chemistry prior to taking physics and another group of students, Group 2, took one quarter of physics prior to taking chemistry.

Details of the Two Groups' Course Trajectories

Both Groups 1 and 2 consisted of 48 students who were recruited during freshman summer advising: Group 1 in summer of 2007 and Group 2 in summer of 2008. Both groups took a one-year calculus course created especially for this project, which featured active learning in the lecture. In both groups, students were split into two lab and discussion sections in chemistry and into two discussion/lab groups in Physics 7 for at least the first two quarters of each course. By the third quarter a third to a half of the students in each group were not in "cohort sections" due to scheduling issues. Thus, students from both groups experienced their math and two-thirds of chemistry and physics in sections with their fellow group members. What is important for the analysis presented in this paper is the fact that both groups took the same calculus, chemistry, and physics courses in cohort sections.

The difference between the two groups is whether they took the first quarter of the physics course before or after they took the first two quarters of chemistry. Both groups began calculus in the fall of their freshman year. Group 1 students also began chemistry in the fall of their freshman year, but did not begin physics until the spring quarter of their freshman year. Group 2 students, who entered college one year later took the first quarter of physics along with calculus during their freshman fall quarter. They then switched from physics to chemistry in the winter quarter. They resumed and completed the physics course in the summer and/or sophomore year.

The intent of the original project was to make the chemistry labs and one-hour discussion sections more active learning than the very traditional way they were. This was partially achieved for Group 1, but due to the unexpected departure of a key individual leading this part of the project, the chemistry lab and discussion sections for Group 2 students were standard.

Results

Because there were more than two hundred students in each of the chemistry and physics classes, the performance of the students in the two groups can be compared to all 200+ students taking each class. The average of the course grades received by students in each group exceeded the average of all students in those classes. Figure 1 shows the amount each group's average course grade exceeded the average for the entire class in the three quarters of the chemistry class as well as in the first quarter of physics. The classes are spread temporally along the x-axis from fall of 2007 to fall of 2009. The error bars are the standard error of difference, SED. The difference is considered significant if it is greater than twice the SED. Details and statistics are shown in Table 2.

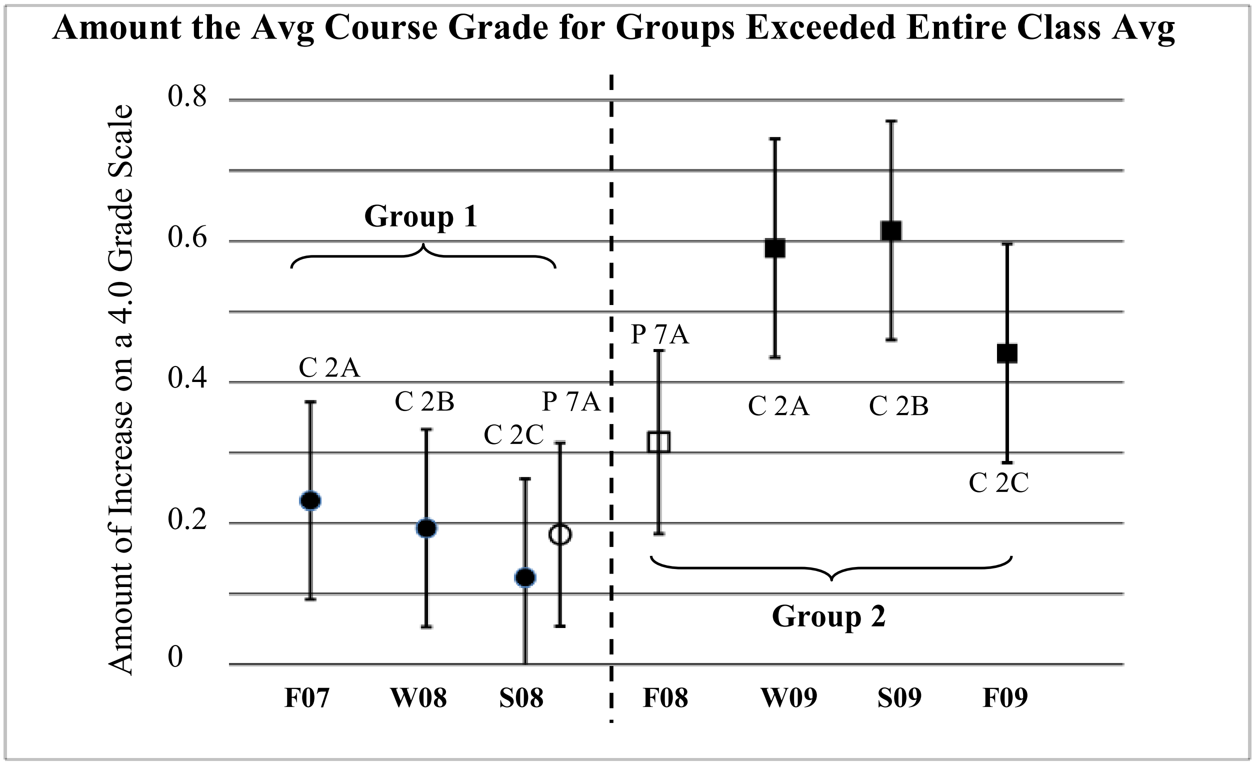

FIGURE 1 The data points show the amount the average course grade of students in Group 1 and Group 2 in the three quarters of their chemistry course and the first quarter of their physics course exceeded the average for the entire class. The error bars are the standard error of difference, SED. Solid circles are Group 1 chemistry grades and the open circle is the Group 1 physics grade. Solid squares are the Group 2 chemistry grades and the open square is the Group 2 physics grade. Group 1 students began chemistry in the fall quarter of their freshman year and took Physics 7A in the spring quarter simultaneously with Chemistry 2C. Group 2 students took Physics 7A in the fall of their freshman year prior to beginning chemistry in the winter quarter. Group 2 students continued with physics in either the summer or fall of 2009.

TABLE 2. Details and statistics for each chemistry and physics course.

Quarter	Total class grade distribution N, mean, (SD)	Group grade distribution N, mean, (SD)	Statistical Significance p	Standard Error of Difference SED	Increase in Avg Group Grade over entire class
Group 1					
F-07 CHE 2A	388 2.76 (0.80)	46 3.01 (0.76)	0.062	0.124	0.232
W-08 CHE 2B	350 2.50 (0.90)	45 2.69 (0.67)	0.16	0.138	0.193
S-08 CHE 2C	390 2.77 (0.89)	42 2.90 (0.73)	0.39	0.143	0.123
S-08 PHY 7A	324 3.31 (0.57)	19 3.49 (0.48)	0.17	0.133	0.184
Group 2					
F-08 PHY 7A	259 2.87 (0.78)	39 3.19 (0.67)	0.018	0.13	0.31
W-09 CHE 2A	297 2.73 (0.90)	36 3.32 (0.76)	0.0002	0.16	0.59
S-09 CHE 2B	295 2.68 (0.91)	35 3.26 (0.72)	0.0001	0.16	0.62
F-09 CHE 2C	311 2.61 (0.90)	23 3.04 (0.71)	0.027	0.19	0.43

DISCUSSION

Consider first the performance of the Group 1 students in chemistry. Although there were some active-learning enhancements made to the CHE 2A lab and discussion sections, performance in CHE 2A is indistinguishable from that in the other two quarters; it is likely the enhancements were too small to overcome the dominance of the lecture and type of exams. From examination of the SAT scores and high school GPAs, Group 1 is indistinguishable from the remainder of the students in the same lecture course. (The average high school GPAs were 3.87 and 3.88). The increased performance, about 0.2 grade point, which is not statistically significant, is probably due to the effect of being in multiple small class sections together. We note that Group 1's performance in physics is indistinguishable from that in chemistry.

The situation is different, however, for Group 2. There is a statistically significant increase in the performance of Group 2 in their physics class, which is consistent with a slight increase in high school GPA and SAT scores. Group 2's average high school GPA is 3.94 compared to the average GPA of the entire class of 3.86. SATs were similarly slightly higher. The striking difference, however, is the statistically significant increase in performance in the two chemistry quarters, which were completed during the students' freshman year after taking Physics 7A in the fall. The increased performance of Group 2 compared to the rest of the class is about 0.6 of a letter grade.

As we previously stated, the only known significant difference between Groups 1 and 2 is the sequencing of their first quarter physics class with respect to their chemistry sequence and, as mentioned above, their slightly better high school preparation. Their math classes were identical. The physics class, and in particular the discussion/lab sections, were identical. Students experienced the same cohort effects of being together in the same classes. The chemistry courses are very stable and similar from quarter to quarter. For both Groups, the TAs who taught the Group sections in chemistry and physics spoke frequently of the pleasure of teaching enthusiastic freshmen. Several of the TAs taught both Groups. All indications were that the two groups were similar in their responses to all three courses (math, chemistry, and physics.)

We looked for but could not find any factors (differences in instructor behavior, exams, etc.) that could explain the increased performance of Group 2 in chemistry compared to the Group 1 performance other than when the groups took physics in relation to chemistry. We are not claiming that a similar effect would not be seen if the first term of some other physics course were taken prior to chemistry. However, as pointed out in the earlier section on CLASP, there are several rather unique factors related to this particular course that collectively are likely responsible for the effect seen here. To our knowledge, a dramatic result such as this has not been previously reported when physics is taken prior to chemistry.

IMPLICATIONS

Bransford and Schwartz [4] discuss an alternative to more traditional approaches to transfer of learning and suggest a more fruitful approach: a focus on people's "preparation for future learning." Taking this perspective on transfer, perhaps what it is that students experience in Physics 7 (and probably don't experience in traditionally taught introductory math and science courses) is continued practice in learning how to learn with understanding. Perhaps by focusing on what it is in particular about a CLASP course—Physics 7— that prepares students to be better learners in chemistry and biology, we can make further progress in improving math and science education for our students. We strongly suspect that what students take with them from Physics 7A results from the continual emphasis on reasoning and sense-making, as opposed to "getting an answer," in all aspects of the course. That is, it isn't sufficient to modify just the discussion sections, or the labs, or the homework, or the student assessment, or what students spend class time doing. All elements need to emphasize reasoning and sense making.

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