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ABSTRACT

This research investigated the teaching of concrete chemical concepts and procedures to beginning chemistry students. Data were collected for this study from students enrolled in a university-level course for nonscience majors (n=171). In the topic studied, chemical bonding, four different teaching strategies were investigated: remediation of basic concepts, bridging explanations, worked examples, and student-initiated discussions of concepts. Statistical analyses were used to compare each teaching strategy against the exam score on chemical bonding. Results of these comparisons indicated that none of the strategies were superior ($p>.05$); however, each had notable strengths and weaknesses. The students in the remedial group had the worst attendance, but scored the highest of all treatment groups on the bonding exam. Students in the worked examples treatment group had the best attendance, but derived the least benefit as indicated by the smallest increase between pre- and posttests and the weakest performance on the bonding exam. (Author/PR)

Remediation, Bridging Explanations, Worked Examples and Discussion: Their Effectiveness as Teaching Strategies in a Freshman-Level Nonscience Major Chemistry Course

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Abstract

This research investigated the teaching of concrete chemical concepts and procedures to beginning chemistry students. Data were collected for this study from students enrolled in a university-level, introductory chemistry course for nonscience majors. In the topic studied, chemical bonding, four different teaching strategies were investigated: remediation of basic concepts, bridging explanations, worked examples, and student-initiated discussions of concepts. Statistical analyses ($p = .05$) were used to compare each teaching strategy against the exam score on chemical bonding. Results of these comparisons indicated that none of the strategies were superior; however, each had notable strengths and weaknesses. The students in the remedial group had the worst attendance, but scored the highest of all the treatment groups on the bonding exam. The bridging explanation treatment group showed the greatest improvement between the pre- and posttests as compared to the other groups, but performed the worst when pre-exam class averages were compared to the averages on the chemical bonding exam. Students in the worked examples treatment group had the best attendance, but derived the least benefit as indicated by the smallest increase between pre- and posttests and the weakest performance on the bonding exam. Students who participated in the discussion sections only performed slightly better on the posttest than they did on the pretest, but their score on the bonding exam showed the greatest success when compared to their pre-exam class averages.

Purpose of the Study

"...Learning is an active, constructive, and goal-oriented process that involves problem solving" (Shuell, 1990a, p. 532). Many different strategies and techniques have been investigated to accomplish successful problem solving by students enrolled in chemistry. Some of these instructional means include drawing concept maps, diagrams and extra figures; understanding analogies; using factor-label methods and proportional reasoning approaches; memorizing algorithms; working examples; etc. The aim of this research is to establish the effects of four specific teaching strategies on student achievement in an introductory chemistry course for nonscience majors. This paper reports the results of a comparison among the four strategies: remediation, worked examples, bridging explanations, and discussion.

Significance of the Study

Learning is a continuous process which depends upon prior knowledge and results in an increased understanding of the subject in question. Novices usually have difficulty solving problems due to their lack of prior knowledge in a specific content area, not because they simply lack the ability to solve problems. However, prior knowledge can be detrimental in some cases when new input conflicts with existing connections (Shuell, 1990b). Students can be motivated by solving problems, but motivation is diminished when they fail to experience success (Woods, 1990). The more teachers understand how learning occurs, the more effective they will be in enhancing problem-solving performance.

Chemical education researchers have reported that formal operational skills are needed for success in many beginning chemistry courses because problems usually involve proportional and logical-deductive reasoning abilities (Atwater & Alick, 1990; Mulopo & Fowler, 1987; Niaz & Lawson, 1985; Pitt, 1983; Powers, 1984). Chemistry is a subject which combines knowledge in areas of conceptual and computational understanding. The question remains: What is the best mode of presenting problem-solving strategies to the students? This study addresses this question, and seeks to evaluate each of the four strategies as to their strengths and weaknesses.

Design

The design of the study is quasi-experimental (Borg & Gall, 1989). This study is exploratory and is desig: ed to investigate the effects of the various strategies applied in an actual classroom setting where student groups were self-selected. Even though only partial control was possible, there was an attempt to identify some of the casual factors for success in a large-group (171 students) lecture setting by assigning students to smaller experimental groups. Each experimental group received the standard three hours of large-group lecture per week, and was also provided an extra hour of instruction for the experimental period (four weeks).

Students were given a choice of four time slots and asked to select the one which best fit their schedules. After the students had completed the sign-up, then the treatments were randomly assigned to a particular time slot. To increase participation, 40 points of extra-credit was offered to the volunteers who completed all four weeks of the supplemental sessions. The four treatments investigated were: (1) remediation, (2) worked examples, (3) bridging explanations, and (4) discussion. Each of these groups was further divided into two subgroups. The first subgroup of students of each treatment group were presented rationales as to why certain concepts were valid; the other subgroups investigated why other concepts were invalid (see Table 1).

Treatment Groups

The remedial group was presented didactic information as a formal lecture, and the students were requested to take notes. Each of two subgroups was presented information regarding the same topics, e.g., formation of ions, valence electrons, oxidation numbers, electron configuration, ionic and covalent bond character, elemental properties, and introductory quantum mechanics. The difference in treatment between the two subgroups was the same for all treatments: subgroup A always received instruction as to why certain answers to multiple-choice chemistry problems were correct and subgroup B was always presented information as to why alternative choices to multiple-choice chemistry problems were incorrect. Immediately after each lecture a quiz was given to the students over the information presented in lecture. The quiz questions were selected from the American Chemical Society (ACS) exam that had been used as the pretest. These were paper and pencil quizzes directly reflected the information students had received in lecture; i.e., the quizzes were "taught to".

Students in the bridging explanation treatment group were asked to form self-generated "bridges" by describing in their own words how they knew (or what memory technique they used to determine) why particular questions in chemistry had certain answers (subgroup A) or why certain other choices were incorrect (subgroup B). The multiple-choice questions used for this treatment were also those that had been selected for the pre- and posttests. In both subgroups students responded to questions that appeared on the computer screen after they were given the correct answers by the experimenter. Subgroup A was asked explain why these choices were correct, and subgroup B was asked to explain why all the other choices were incorrect. Their written reflections were collected and analyzed as to the kinds of "bridges" the students were able to form, e.g., an analogy, a simple definition, a diagram, or a known trend of chemical characteristics.

Examples used for the worked examples treatment group were taken from the university's data bank of questions for this introductory-level chemistry course. (The students' homework and exam questions for the lecture part of the course were drawn from the same data bank.) For this treatment, 25 questions from the data bank were selected which were similar in nature to those that would appear on the bonding exam. During the hour that each subgroup was in class, the questions chosen for this treatment were worked by the instructor. In subgroup A only the correct choices were addressed, and in subgroup B all of the incorrect choices were discussed. Careful attention was paid to detail in the problems which required a mathematical component so that each question was always answered to the satisfaction of all the students present; i.e., the next question was never started until the current question was answered to the satisfaction of everyone present.

The discussion group was designed to resemble a typical help session. The students guided the direction of the discussion and the instructor was present only to keep the students on task, if necessary, and to provide minimal help when needed. Questions asked by students usually pertained to their homework or related to information presented in the large-group lecture. When a student asked a question, the instructor always attempted to get another student to answer the first student's question. Only when no student in the class could continue the topic of conversation did the instructor answer the question and/or correct the misconception.

Sample

The initial enrollment in the introductory chemistry course for nonscience majors at a large southwestern university was 181. By the time the study began (the eleventh class week of the spring semester 1992) 171 students remained. Students were asked to volunteer to participate in the study by signing their names under different time slots. The initial number of participants in the experiment was 125 (76 males and 49 females). At the end of the experimental period, 108 students remained (66 males and 42 females).

The profile of this particular lecture class at the time of the study depicts typical university students as follows: male:female (60.2% to 39.8%); class average in chemistry 76.6% (males 77.7% and females 74.7%); 66.2% of the students between 17 and 19 years of age; and 50.7% with a classification of freshman, 27.2% classified as sophomores, and the remaining 22% were juniors or seniors. The majority of the students (92.6%) were enrolled in a total of four or five courses, and 80.1% of the students stated that their degree plan required successful completion of a science course. Almost 43% of the students claimed to be liberal arts majors, and 14% were majoring in a business field. Only 11% of the students had graduated from a high school outside the state of Texas, and 94.1% of these schools were regarded as public and coeducational, with less than 1% claiming to have attended a high school for males only. Over 60% of the students were not employed at the time of the study, but 6.6% claimed to work 40 hours or more each week . Only 8.8% of all the students surveyed acknowledged that their job required knowledge of chemistry.

More than three-fourths of the students had completed three or more years of science. In mathematics, 52.2% of the students indicated that they had completed four years and 13.2% claimed to have completed five or more years. Sixty-nine percent of the students had passed at least one year of high school chemistry, and 17.6% had completed two or more years. Approximately 16% of the students indicated that they had previously taken a college chemistry course. The average SAT scores were 526 verbal and 588 mathematical. (The mean SAT for all entering freshman in the fall of 1991 was 1104.)

Instrumentation

The same pre- and posttest was given to all participants in the treatment groups. This test was developed by selecting items from the 1988 American Chemical Society (ACS) exam that were appropriate for high school students. This examination tested students' general knowledge of basic chemical concepts and their specific knowledge of chemical bonding (ionic and covalent). The test consisted of 25 multiple-choice questions on these topics, and was administered via an IBM computer system capable of randomly ordering the questions at individual PC terminals. At the end of the study students completed an instructor-prepared exam on chemical bonding in their large-group lecture class. Because all students (regardless of treatment group) were given the same lecture exam at the end of the study, this exam (on bonding) was considered to be the dependent variable. The number of students who actually completed all parts of the experiment was 113.

Results

Remedial

Students in this treatment group not only completed the ACS exam as the pre- and posttest, but also saw the same questions on their weekly quizzes. In light of this repetition, one would suspect that this group would have had the highest posttest average, but this was not the case. Students in this treatment group had the second highest average (73.2%) on the posttest (see Table 2). Also, the attendance in this treatment group showed the largest decrease over the four week period as compared to the other groups. But, interestingly enough, this group had the highest average of all treatment groups on the bonding exam (71.1%), the dependent variable.

Bridging Explanations

The data listed in Table 3 suggests that the use of student-generated bridging explanations had a more positive impact when used to address why certain responses to standardized questions are correct than why the alternative responses are incorrect (36.8% increase from pre- to posttest as compared to a 23.8% increase). Students in this group (who also had answered the same ACS exam questions three times) showed the greatest improvement between the pre- and posttest as compared to all test groups, an increase of 29.0%. As helpful as this treatment appears to be for evaluating the same test after a period of four weeks (the time between the pre- and posttest), the same positive effect was not seen if one compares the students' class average before the bonding exam with their average on that exam. This group, on the average, experienced the largest decline (10.6%) from their current (pre-bonding exam) average.

One of the interesting results in Table 4 is that 44.6% of the students knew that a certain answer was correct because they had prior knowledge of a particular definition (column heading, "Def"). Other information that proved to be interesting is that more students were able to tell why a particular answer was correct (69.5%) than were able to tell why particular responses were incorrect (59.2%). Sixty-one responses as to why answers were correct failed to give a plausible explanation, and of these 61 half (50.8%) were unable to even guess at the correct reason (column head, "No Clue"). This same trend continued with the students who were asked to explain why item choices on the ACS exam were incorrect. In this case almost half (41.3%) failed to cite any reason for responses being wrong ("No Clue"). No student responded in terms of a concrete analogy (e.g., electrons pair only when they spin in opposite directions like shoes placed in a shoe box) even though these had been used in the large-group lecture.

Worked Examples

The results from the worked examples group (see Table 5) show that the entire group had one of the smallest increases (13.5%) between the pre- and posttests, and had one of the largest drops from their prior class average to their average on the bonding exam (9.3%). However, only one student from this treatment failed to complete all four weeks of the study (i.e., this treatment had the best attendance of all the groups).

Discussion

As can be seen in Table 6, the discussion group had the smallest increase between the pre- and posttests (10.6%). On the other hand, they showed the smallest drop of all treatment groups when their pre-bonding exam class average was compared to their average on the bonding exam (only -3.1%). Students in this group were allowed to ask questions about information on bonding that they did not understand or wanted to explore further (and were encouraged to aid one another). Perhaps, when individual misunderstandings are addressed and time is provided to assimilate this information, the benefits are more long term.

Additional Results

In almost all cases subgroup A scored higher on the posttest than subgroup B. The only exception to this observation was the mean posttest score of subgroup B in the worked examples group. This implies that the more examples worked, the more effective is the treatment, because the student receives instruction on many different misconceptions as related to a single problem. However, as successful as students from subgroups A were on the posttest, they performed poorer on the bonding exam in <u>all</u> cases (see Tables 2, 3, 5 and 6). One should pay close attention to Tables 2, 3, 5 and 6. In all cases the mean score on the bonding exam was higher for members of subgroup A as compared to subgroup B, but this is somewhat misleading. What is important is the relationship (i.e., the change (Δ) from the pre-exam class average to the average on the bonding exam). In all cases the change between the two scores always showed a greater decrease for subgroup A than B. This observation is directly related to how students "see" multiple-choice exams. Practice in learning to eliminate wrong choices appears to have consistently increased student success.

As is usually reported by other authors, males performed better than females (see Tables 7 and 8) in this chemistry course. Males registered a greater increase between the pre- and posttests (18.8 % as compared to 14.4%), and a smaller decrease between their current class average and their average on the bonding exam (-7.3% versus -7.8%). Ten males (13.1%) and six females (12.2%) dropped out of the four week study.

Non-participants (Lecture Only)

Students who did not participate in the study (the lecture only group), recorded on average a lower performance on the bonding exam as compared to their class average prior to the exam. This decline (13.4%) exceeded that registered by any of the study's treatment groups or subgroups (see Table 9). Implications which can be drawn from these results are that smaller groups may improve the understanding of the basic concepts in chemistry, regardless of instructional strategy, and as students increase their time on task their performance improves. Neither of these interpretations is surprising.

Conclusion

It appears from the above study that different teaching strategies have different benefits and drawbacks, and one approach is not necessarily better than any other. F-tests were calculated on virtually every aspect of this study; e.g., treatment group differences on the bonding-exam scores, treatment group differences on pre- and posttest scores; treatment group differences (right and wrong subgroups) on posttest scores; and gender differences on pre- and posttest scores. The only statistical test which indicated a difference (.05 level of significance) was the simple regression between the treatment groups and the posttest scores. This simply indicates that any of the small-group instructional techniques used improved content knowledge in the broad area of chemical bonding. Students in the bridging explanations treatment group, however, recorded differences that approached significance ($p = .0762$), and males tended to benefit more from participating in the treatment groups than females ($p = .0817$).

The treatment regarding bridging explanations appear to be beneficial when addressing a narrow range of information, but review of basic (remedial) concepts may have the broadest application of all of the methods studied. Student-directed discussion may have the most immediate benefit for student test performance. Even the traditional lecture without follow-up has its advantages. The non-participant group (lecture only) was also compared statistically to the treatment groups. Results of these tests revealed no statistical significant differences on the bonding exam scores. Lecture only is a very efficient (and cost effective) means for instructing large groups of students, and does not appear to adversely impact their learning.

It is a mystery as to why the bonding exam average declined so much (-9.3%) from the prior class average in the worked examples group. With good attendance and questions similar to those that were used in both the large-group lecture's homework assignments and exams, one would expect to see improved exam averages. This observation might be explained from a consideration of the treatment. Students only spent one hour per week reviewing the bonding information (as all of the other groups had done), but this treatment may require more individual study. Since students were not permitted to keep and study the worked examples at their leisure (e.g., at home or other place), they may not have gained full benefit from this treatment. More study regarding the effects of worked examples is needed.

The teaching of problem solving in chemistry is a broad and diverse topic. Much student success seems to stem from understanding the vocabulary of chemistry. Implications of this statement might find use in a child's early science education. Starting chemical education in the primary grades by simply familiarizing students with the definitions and vocabulary (by concrete experiences, rote memorization, or frequent teacher and student usage) might have far reaching benefits for their future education. It seems as though it would be more advantageous for instruction in chemistry to be directed more at helping the student organize, understand and integrate the new information through the teaching of concepts and procedures and less at trying to teach abstract thinking and general problem-solving skills.

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Tables

Table 1

Distribution of Treatment Groups and Subgroups

	Monday	Tuesday	Wednesday	Friday
Remediation		Subgroup A* Subgroup B**		
Worked Examples			Subgroup A Subgroup B	
Bridging Explanations				Subgroup A Subgroup B
Discussion	Subgroup A Subgroup B			

*Instructed as to why certain answers are valid/right.
**Instructed as to why certain answers are invalid/wrong.

Table 2

Remedial

	Right	Δ	Wrong	Δ	Combo	Δ
Subjects	17	-4	17	-3	34	-7
Pretest	55.8		51.1		53.4	
Posttest	76.6	20.8	70.0	18.9	73.2	19.8
Quiz	70.6		71.5		71.1	
Evaluation	1.9		1.9		1.9	
Class Average	84.3		71.9		78.1	
Bonding Exam	74.7	-9.6	67.1	-4.8	71.1	-7.0

Table 3

Bridging Explanations

	Right	Δ	Wrong	Δ	Combo	Δ
Subjects	10	-2	15	-3	25	-5
Pretest	47.2		49.9		48.8	
Posttest	84.0	36.8	73.7	23.8	77.8	29.0
Evaluation	2.1		2.2		2.2	
Class Average	80.5		76.3		78.0	
Bonding Exam	69.2	-11.3	66.2	-10.1	67.4	-10.6

Table 4

Qualitative Information

	Right Answers						Wrong Answers			
Item	Resp	Cor	Def	Pict	Trnd	No Clue	Resp	Cor	Incor	No Clue
1	8	8	7	0	1	0	12	10	2	2
2	8	8	5	0	3	0	12	11	1	0
3	8	7	7	0	0	1	11	11	0	0
4	8	2	0	1	1	5	11	8	3	2
5	8	4	4	0	0	4	12	3	9	5
6	8	2	0	0	2	3	12	1	11	7
7	8	8	8	0	0	0	14	8	6	4
8	8	8	8	0	0	0	13	8	5	0
9	8	8	0	5	3	0	12	10	2	1
10	8	6	0	0	6	2	11	5	6	2
11	8	7	0	0	7	0	12	8	4	1
12	8	7	0	7	0	0	12	8	4	1
13	8	4	1	0	3	3	13	11	2	2
14	8	7	7	0	0	0	13	11	2	0
15	8	7	0	0	7	0	12	6	6	3
16	8	5	0	5	0	3	13	5	8	4
17	8	7	0	0	7	1	12	10	2	0
18	8	6	0	5	1	1	13	5	8	2
19	8	5	4	1	0	1	13	9	4	1
20	8	4	0	2	2	2	13	7	6	1
21	8	3	0	3	0	0	12	6	6	3
22	8	0	0	0	0	3	13	5	8	3
23	8	6	6	0	0	0	13	11	2	0
24	8	5	0	4	1	0	13	3	10	6
25	8	5	5	0	0	1	12	8	4	2
Totals	200	139	62	33	44	31	309	183	126	52
%		69.5	44.6	23.7	31.6	50.8		59.2	40.8	41.3

(Abbreviations: Resp=number of responses; Cor=number correct; Def=definition known; Pict=picture drawn; Trnd=periodic trend noted; Incor=number incorrect)

Table 5

Worked Examples

	Right	Δ	Wrong	Δ	Combo	Δ
Subjects	19	-1	17	0	36	-1
Pretest	50.7		44.0		47.6	
Posttest	64.0	13.3	58.1	14.1	61.1	13.5
Evaluation	1.8		2.0		1.9	
Class Average	83.7		67.0		76.0	
Bonding Exam	71.6	-12.1	61.2	-6.2	66.7	-9.3

Table 6

Discussion

	Right	Δ	Wrong	Δ	Combo	Δ
Subjects	17	-2	13	-1	30	-3
Pretest	54.8		50.2		52.8	
Posttest	66.4	11.6	59.2	9.5	63.4	10.6
Evaluation	2.2		2.1		2.2	
Class Average	77.8		61.9		70.9	
Bonding Exam	70.6	-7.2	63.5	-1.6	67.8	-3.1

Table 7

Gender Data

	Males			Females		
	Score	Δ	Number	Score	Δ	Number
Pretest	50.9		76	50.3		49
Posttest	69.7	18.8	66	64.7	14.4	43
Evaluation	2.1		66	1.9		42
Class Average	76.6		76	74.5		49
Bonding Exam	69.3	-7.3	73	66.7	-7.8	48

Table 8

Combined Gender Data

	Score	Δ	Number
Pretest	50.7		125
Posttest	67.7	17.0	109
Evaluation	2.0		108
Class Average	75.7		125
Bonding Exam	68.3	-7.4	121

Table 9

Lecture Only

	Score	Δ	Number
Class Average	78.5		51
Bonding Exam	65.1	-13.4	50