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ABSTRACT

The study investigated the role of analogic instruction and reasoning level on the dependent measure of concept acquisition in an introductory college genetics course. The question of whether concept acquisition was facilitated through the use of instructional analogies was addressed. The control treatment consisted of expository instruction alone while the experimental treatment included instructional analogies. All students were given the same pretest measures of reasoning (the Classroom Test of Scientific Reasoning) and prior genetics knowledge. The effect of analogy-based instruction on immediate (weekly quiz) as well as delayed (end of semester) achievement was investigated. The role of analogic instruction on student attitude was also evaluated. Significant gains in student achievement were found with instructional analogy. The attitude survey indicated that a majority of students who received instructional analogies believed analogy-based instruction was beneficial. Instructional analogies, pretest of prior genetics knowledge, sample quiz items, and student attitud surveys are included. Contains 50 references. (Author/JRH)

EFFECT OF ANALOGIC INSTRUCTION AND REASONING LEVEL ON ACHIEVEMENT IN GENERAL GENETICS

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ABSTRACT

This study investigated the role of analogic instruction and reasoning level on the dependent measure of concept acquisition in an introductory college genetics course. The question of whether concept acquisition was facilitated through the use of instructional analogies was addressed. The control treatment consisted of expository instruction alone while the experimental treatment included instructional analogies. All students were given the same pretest measures of reasoning (the Classroom Test of Scientific Reasoning) and prior genetics knowledge. The effect of analogy-based instruction on immediate (weekly quiz), as well as delayed (end of semester) achievement was investigated. The role of analogic instruction on student attitude was also evaluated. Significant gains in student achievement were found with instructional analogy. The attitude survey indicated that a majority of students who received instructional analogies believed analogy-based instruction was beneficial. Instructional implications are presented.

INTRODUCTION

Genetics has been recognized as "one of the most difficult topics" for undergraduates (Mitchell & Lawson, 1988, p. 23). Evidence suggests this is because genetic concepts are highly theoretical in nature and cannot be directly experienced by the senses (Mitchell & Lawson, 1988; Lawson, 1992). Rather, theoretical concepts are imagined (hypothetical) entities constructed within the conceptual systems of the learner. Theoretical concepts derive their meanings from integration within hypothetico-deductive systems (Lawson, A. E., Abraham, M., & Renner, J., 1989) such as the postulates of modern genetics (Lawson, 1992; Moshman & Thompson, 1981). Accordingly, successful achievement of theoretical concepts requires students to be reasoning at the hypothetico-deductive level. Yet research indicates that a substantial percentage of college undergraduates have failed to acquire hypothetico-deductive reasoning ability (Thorton & Fuller, 1981; Ward & Herron, 1980; Gipson, Abraham & Renner, 1989; Killian, 1979; Walker, R., Mertens, T., & Hendrix, J., 1979; Lawson, 1982a; Cantu & Herron, 1978; Walker, Hendrix & Mertens, 1980).

Students who do not yet reason hypothetico-deductively remain excluded from full achievement of theoretical concepts. Given the diversity of reasoning ability and the hypothetico-deductive nature of genetics, clearly what is needed is instruction that makes theoretical concepts accessible to all learners (Gabel & Sherwood, 1980). To this end, investigators have demonstrated gains in student achievement with instructional analogy across a variety of concepts and instructional formats (for example Gabel & Sherwood, 1980; Newby & Stepich, 1991; Simons, 1984; Dupin & Joshua, 1989; Vosniadu & Ortony, 1983; Halpern, D., Hansen, C., & Riefer, D., 1990; Bean, Searles & Cowen, 1990; Gabel & Samuel, 1986; Catrambone & Holycak, 1985; Brown & Clement, 1989; Shapiro, 1985; Stavy, 1991; Clement, 1993; Wong, 1993; Brown, 1993; Harrison & Treagust, 1993).

Instructional analogy has been described by Newby and Stepich (Stepich & Newby, 1988) as "an explicit, nonliteral comparison between two objects, or sets of objects [in different content domains] that describes their structural, functional, and/or causal similarities" (Newby & Stepich, 1991, p. 4). In contrast to simple analogies often employed in college texts (e.g. the DNA double helix is like a ladder), an instructional analogy is characterized by multiple shared features (Stepich & Newby, 1988). The instructional analogy serves to link unobservable, theoretical concepts with familiar or observable phenomena (see Appendix A) ; (Stepich & Newby, 1988; Webb, 1985; Bean, Searles, Singer & Cowen, 1990; Nichter & Nichter, 1986; Flick, 1991; Zeitoun, 1983; Lawson & Lawson, 1993; Lawson, A. E., Baker, W. P., DiDonato, L., Verdi, M., & Johnson, M., 1993).

While a growing body of research supports the view that students benefit from the use of instructional analogy, counterexamples may be noted within the relevant literature. Spiro et al. (1988) have shown analogies may contribute to the development of entrenched misconceptions through oversimplification of complex new knowledge, a view shared by Webb (1985). Radford (1989) investigated the use of analogy for instruction of evolution and cellular respiration. He found both significant ($p<.001$ topic of evolution) and nonsignificant (topic of cellular respiration) posttest differences in the achievement of students receiving analogy-based and non-analogy instruction. Yet surprisingly, eighty-one percent of the students said analogies helped them understand the concepts (Radford, 1989). Gabel and Sherwood (1980) showed no statistically significant increase in chemistry achievement from use of an analogy-based curriculum.

With regard to genetics, Gilbert (1989) found no significant increase in achievement using an analogy-based text for a unit on heredity. Students in that study reported more negative attitudes toward the analogy lessons. Gilbert attributed the negative attitudes to the additional reading time required by the analogies (Gilbert, 1989). The current conflict in findings argues for a more definitive investigation of analogic instruction and reasoning level on student achievement.

RESEARCH QUESTION

What is the role of analogic instruction and reasoning level in concept acquisition? Two hypotheses relating to this research question were empirically tested:

Hypothesis 1. The use of analogies facilitates acquisition of new theoretical concepts because analogies link unobservable, theoretical concepts with familiar, observable phenomena.

This hypothesis led to the prediction that there would be a significant difference in concept acquisition scores in favor of students who received extended instructional analogies over control students who received no analogies.

Hypothesis 2. Because analogies facilitate the acquisition of new concepts through utilization of familiar and observable experiences, this acquisition is independent of the reasoning levels of the students. Accordingly, this hypothesis led to the prediction of no significant difference in concept acquisition between the two reasoning levels for students who received instructional analogies.

METHOD

Subjects

This study was conducted in recitation sections of General Genetics at a large suburban university. General genetics is an upper division course designed primarily for students majoring in the life sciences. Gender, college major, and class-standing were recorded for each student (see Table 1).

Materials

All students were pretested during their first recitation period by the researcher. The Classroom Test of Scientific Reasoning (Revised Pencil-Paper Edition) was used to measure reasoning level as described in Lawson (1978). This test consists of 12 items scored by the researcher according to the scale of Lawson (Lawson, 1978). Correct written responses and

Table 1

Demographic Description of Students

	Gender		CLASS STANDING						MAJOR		
	Female	Male	Fresh	Soph	Jun	Sen	Grad	Non	LS	NLS	NDCL
n	64	57	-	18	40	53	3	7	87	22	12
%	53%	47%	-	15%	33%	44%	3%	5%	72%	18%	10%

Key: Fresh = freshman; Soph = sophomore; Jun = junior; Sen = senior; Grad = graduate student. Non = none listed; LS = life science; NLS = non-life science; NDCL = none declared/not listed.

explanations were awarded 1 point for a possible 12 point total. Incorrect answers and explanations received a score of 0.

A researcher developed test was given to pretest student knowledge of genetic concepts. This was a pencil-paper test that used open-ended questions developed by the researcher to evaluate student conceptions regarding theoretical concepts frequently encountered in introductory college genetics. A copy of this test appears as Appendix B. A posttest quiz was administered at the end of the recitation session to assess students' achievement of each key concept (see Appendix C).

Instructional analogies were developed for key theoretical concepts (see Appendix A). Terms used with the key concepts were explicitly defined to control for the potential confounding effect of variation in definitions between samples. Definitions were taken from lecture material and the required text used in the course. A scripted handout was prepared as a guide for presentation of all analogies after Zeitoun (1983) and Radford (1989). Content validity was assessed during the development of analogies through an external evaluator's review and comparison with course specifications. The external evaluator was a cooperating science faculty member in genetics. The method of instructional analogy development was adapted from Newby and Stepich (1988), and Radford (1989).

Procedure

All students received three 50-minute lectures and one 50-minute recitation each week. The lecture format was expository. Lectures were supplemented by textbook readings and homework assignments. Students self-selected for recitation sections. The researcher instructed three recitation sections. Three recitation sections were instructed by a cooperating graduate teaching assistant.

The largest recitation section was selected as the control group. The two remaining sections taught by the researcher received analogical instruction. Students were not aware of their treatment condition or the experimental hypotheses of this study (a single blind experimental design).

During recitation, the instructor reviewed lecture topics and solved assigned problems. The control instruction consisted of traditional expository explanation alone while the experimental treatment included the instructional analogies developed as described (see Table 2 note for list of analogy topics). Time that was not spent on analogies during the control instruction was spent in non-analogic instructional examples. All students received identical homework, quizzes, and surveys. All students were given equal time to finish quizzes, and surveys.

RESULTS AND DISCUSSION

Quantitative Analysis

Hypothesis 1: Analogies facilitate acquisition of new theoretical concepts

The first hypothesis investigated was that the use of analogies facilitates acquisition by students of new theoretical concepts because analogies link unobservable, theoretical concepts with familiar, observable phenomena. This hypothesis led to the prediction that there would be a significant difference in concept acquisition scores in favor of students who received extended instructional analogies over control students who received no analogies. This prediction was first evaluated by the comparison of students' mean performance on the key theoretical concepts. The mean scores of students who received extended instructional analogies were higher than of students who did not receive analogies on 7 of 8 key concepts (see Table 2 and Figure 1).

Table 2

Analysis of Mean Performance on Key Concepts

Measure	n	M	SD	F	p
Concept 1					
Control	17	2.7	1.69		
Analogy	34	4.2	1.52	8.35	.006
Concept 2					
Control	19	2.8	1.80		
Analogy	32	3.4	1.21	2.10	.154
Concept 3					
Control	18	3.3	1.53		
Analogy	34	3.7	1.08	0.43	.514
Concept 4					
Control	16	5.4	0.87		
Analogy	34	5.4	0.91	0.24	.627
Concept 5					
Control	16	4.8	2.52		
Analogy	34	4.9	2.15	0.03	.861
Concept 6					
Control	15	4.7	0.84		
Analogy	33	4.8	0.59	0.31	.581
Concept 7					
Control	14	2.1	1.15		
Analogy	34	2.4	0.76	0.56	.460
Concept 8					
Control	13	4.2	1.14		
Analogy	32	4.7	0.58	3.20	.081

Note: concept 1 = chi-squared analysis; concept 2 = non-Mendelian inheritance; concept 3 = mitosis/meiosis; concept 4 = chromosomal aberrations; concept 5 = chromosome mapping; concept 6 = DNA replication; concept 7 = gene expression; concept 8 = lactose operon.

Statistical analysis

The Generalized Estimating Equation (GEE) was used to test the difference for statistical significance as described in Zeger, Kung-Yee, and Albert (1988). This method is particularly suited for the overall analysis of students' quiz scores because it

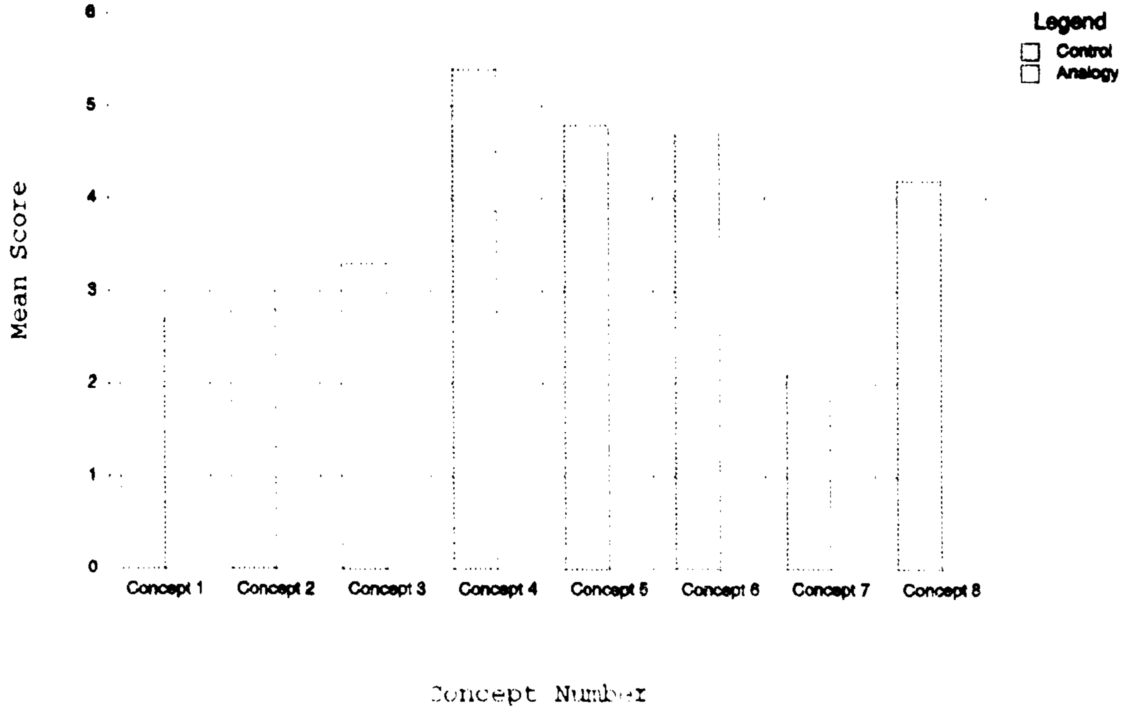

Figure 1. Distribution of concept means.

adjusts for the inherent correlation in a subject's scores on longitudinal, dependent measures and covariates (Zeger et al., 1988). The overall GEE was significant ($Z = 2.12$, $p = .034$) when adjusted for the covariates of score on the Classroom Test of Scientific Reasoning and the pretest of prior genetics knowledge.

Alternative hypotheses

These findings appear in keeping with other studies that indicate instructional analogies enhance the acquisition of theoretical concepts. However, a possible alternative hypothesis that mean differences resulted from preexisting group variables was also evaluated. Because reasoning level and prior knowledge have been hypothesized to be potential variables affecting student achievement (Mitchell & Lawson, 1988; Lawson and Weser, 1990; Novak, J. D. 1979), students' scores on the Classroom Test of Scientific Reasoning (Modified Pencil-Paper Edition) and the pretest of prior genetics knowledge were analyzed.

The mean score on the Classroom Test of Scientific Reasoning for students in the control group was 6.9 (n = 20, SD = 1.84) and 7.5 (n = 39, SD = 2.2) for the students who received analogic instruction. Mean differences among these groups were not statistically significant by ANOVA, $F(1, 61) = 1.312$, $p = .257$. The mean score for the pretest of prior genetics knowledge for students in the control group was 3.6 (n = 20; SD = 2.0) and 4.4 for the students who received analogic instruction (n = 39; SD = 2.5). Mean differences among these groups were not statistically significant by ANOVA, $F(1, 58) = 1.774$, $p = .188$. Thus, this alternative hypothesis seems unlikely. However, since this issue cannot be completely discounted in a situation in which subjects assigned themselves to the groups, pretest between-group differences on these two measures were used as covariates on all analyses.

Hypothesis 2: concept acquisition is independent reasoning level

The second hypothesis investigated was that because analogies facilitate the acquisition of new concepts through use of familiar and observable experiences, this acquisition is independent of the reasoning levels of the students. For this analysis, score totals on the Classroom Test of Scientific Reasoning were grouped as follows: 0 - 6 = empirico-inductive reasoning level, 7 - 12 = hypothetico-deductive reasoning level. This hypothesis led to the prediction of no significant difference in concept acquisition between the two reasoning levels for students who received instructional analogies.

This prediction was evaluated by the comparison of students' mean performance on the concepts taught using instructional analogies. Contrary to the predicted results, comparison of mean scores for the concepts with the GEE indicated a significant difference between the empirico-inductive and hypothetico-deductive reasoners who received instructional analogies when adjusted for the covariate of pretest score on the pretest of genetics knowledge. Further analysis of the means for each concept using ANCOVA revealed significant differences between the two reasoning levels for four concepts using the same covariate (see Table 3). As shown in Table 3, the remaining four concept means were not significant by ANCOVA. These results appear not to support the hypothesis.

Attitude Survey

Student attitudes were measured with a student attitude survey prepared for the study following Borg (Borg & Gall, 1989). Content validity and item clarity was established through external evaluator analysis prior to the initiation of

Table 3

Analysis of Mean Performance on Key Concepts by Reasoning Level for Students who Received Instructional Analogies

Measure	n	M	SD	F	p
Concept 1					
EI	10	3.2	1.34		
HD	24	4.7	1.41	5.64	.024
Concept 2					
EI	10	2.4	1.76		
HD	22	3.9	0.31	16.54	.000
Concept 3					
EI	10	3.4	1.13		
HD	24	3.8	1.07	0.58	.452
Concept 4					
EI	9	5.2	0.87		
HD	25	5.4	0.93	0.29	.593
Concept 5					
EI	10	3.4	2.39		
HD	24	5.5	1.75	4.45	.043
Concept 6					
EI	9	5.0	0.00		
HD	24	4.7	0.68	1.35	.255
Concept 7					
EI	10	2.0	0.78		
HD	24	2.6	0.70	2.09	.158
Concept 8					
EI	9	4.3	0.83		
HD	23	2.8	0.35	4.25	.048

Note: concept 1 = chi-squared analysis; concept 2 = non-Mendelian inheritance; concept 3 = mitosis/meiosis; concept 4 = chromosomal aberrations; concept 5 = chromosome mapping; concept 6 = DNA replication; concept 7 = gene expression; concept 8 = lactose operon. EI = empirical-inductive; HD = hypothetico-deductive.

instruction. The external evaluators (n=3) were faculty from Arizona State University and Grand Canyon University with experience in educational psychology. The resulting pencil-paper survey combined Likert and open ended questions to record demographic information and student attitudes (See Appendix D). Likert items used the following 1-5 scale: 1-STRONGLY DISAGREE 2-DISAGREE 3-NOT SURE 4-AGREE 5-STRONGLY AGREE.

The survey consisted of 15 Likert items. Of this total, 12 items were used for both the control and analogy treatment groups. The remaining 3 items were deliberately modified between groups. Three items regarding analogic instruction were used for students whc received analogic instruction. Appropriately, three items regarding control instruction were included for the control group.

The student attitude survey was distributed to all students during their last instructional period. The instructor provided a brief introduction in which students were assured of anonymity and the importance of their feedback to the course. Surveys were then collected by a student volunteer and held by a third party until submission of semester grades was completed.

A total was computed for Likert items used for both the control and analogy treatment groups. The lowest possible score was 12 (strongly disagree for all 12 common items). The median score was 36 (not sure for all 12 common items). The highest possible score was 60 (strongly agree for all 12 common items). An average item score was calculated if students circled two or more numbers in response to a question. The mean total score for students in the control group was 44.94 (n = 16) and 47.29 (n = 29) for students who received analogic instruction. Mean differences were not statistically significant by ANOVA,

$F(1, 45) = 2.15$, $p=.150$ for the total. Table 4 presents the mean responses to the three Likert attitude survey items regarding analogic instruction presented to students who received instructional analogies.

TABLE 4

Summary of Means for Analogy Items

Survey Question	Means
THE USE OF ANALOGIES IN RECITATION GREATLY HELPED ME REMEMBER CONCEPTS PRESENTED IN RECITATION	4.55
THE USE OF ANALOGIES IN RECITATION GREATLY HELPED ME UNDERSTAND THE CONCEPTS PRESENTED IN RECITATION	4.66
USING MORE ANALOGIES IN RECITATION WOULD HELP ME LEARN MATERIAL EVEN BETTER	4.17

Note: Likert items used the following 1-5 scale: 1-STRONGLY DISAGREE 2-DISAGREE 3-NOT SURE 4-AGREE 5-STRONGLY AGREE.

In addition, students' responses to open ended questions from the student attitude survey were categorized and presented according to the methods of Miles and Huberman (1984) and Seidman (1991). Frequency distributions and quotes that illustrate categories were then tabulated. A majority of students who received instructional analogies responded by indicating that they believed analogy-based instruction was beneficial. Eighty-eight percent (22 students) of students' responses were categorized as only positive, 2 students (8%) responded with both positive and negative comments, and 1 student (4%) responded with only negative comments. Representative student comments are given in Table 5.

Table 5

Representative Students Responses to Questions Regarding Analogic Instruction

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Which particular analogy/analogies helped most?

> "Any analogy he presented was helpful. They helped to clarify the more difficult concepts (Student 4)."
>
> "All were equal (Student 8)."
>
> "Don't remember all - (they where [sic] so many) but all helped to explain and also brought up important questions about processes (Student 1)."

Which helped the least?

> "None were particularly negative (Student 22)."
>
> "All helped (Student 12)."

CONCLUSIONS

The findings of this study suggest a trend that confirms prior studies. For example, the mean scores of students who received extended instructional analogies were higher than students who did not receive analogies for 7 of 8 concepts. The overall GEE was significant when adjusted for the covariates of score on the Classroom Test of Scientific Reasoning and the pretest of prior genetics knowledge.

However, the present study appears in contrast with the prediction of no significant difference in concept acquisition between empirico-inductive and hypothetico-deductive reasoners who received instructional analogies. Contrary to the predicted results, comparison of mean scores for the key concepts with the GEE indicated a significant difference between the the two reasoning levels for students who received instructional analogies. A significant difference was also found between these two groups for four of eight concept scores using ANCOVA.

IMPLICATIONS

This investigation holds several implications for future research on the instruction of theoretical course concepts. The current findings suggest further investigation of analogic instruction and reasoning level on student achievement. What is needed is a delineation of the role of instructional analogies and reasoning level to extend the existing literature on concept acquisition. Such an investigation would hold practical implications for the instruction of genetics and other theoretical course concepts.

The qualitative results presented here are of particular educational interest. The attitude surveys consistently indicated that a majority of students who received instructional analogies believed analogy-based instruction was beneficial. Such findings are in keeping with the findings of others, who report that students generally feel analogies help them understand better and learn more (for example Radford, 1989; Newby & Stepich, 1991; Halpern et al., 1990). This suggests analogies are an effective way of improving the instruction of theoretical course concepts that will fit into many teaching settings.

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APPENDIX A
Instructional Analogies

Instructional analogies incorporated existing sources whenever possible (Ayala & Kiger, 1980; Klug & Cummings, 1991a; Klug & Cummings, 1991b; Suzuki, Giffiths, Miller & Lewontin, 1989; Taylor, 1992a; Taylor, 1992b; Weaver & Hendrick, 1992). The rationale was to demonstrate the utility of analogic instruction with sources generally available to instructors.

Concept 2: Non-Mendelian Inheritance

Non-Mendelian genetics will be presented in terms of a car engine analogue. Students are readily familiar with the concept that particular car models are occasionally recalled by the manufacturer because they received defective parts. A particular model of car is described in terms of its manufacturer (such as General Motors). All cars of this model and year are described as receiving the same part (genotype) manufactured at one plant. As in penetrance, although all cars comprise the same genotype, only a proportion of the population expresses an engine malfunction (affected phenotype). Of these individual cars, a range is described in which some cars only "run rough" while other cars will not start at all (expressivity). Multiple factors (multiple genes) that affect engine function (phenotype) are then used as an analogy to epistasis. A pathway is described in which the presence of a battery, battery cables and spark plug is necessary for engine function. Whenever a step is blocked by the absence of a functional part (absence of a functional enzyme due to recessive allele), the engine stops. As in epistasis, the presence of a functional battery (indicated by the presence of a dominant B allele) may be covered up by a recessive allele for lack of battery cable (indicated by c) or lack of spark plug (indicated by s). Students realize that modified phenotypic expression may result from a particular combination of alleles present at different genes just as each "gene" in the engine-pathway affects the phenotype "run".

Concept 4: Chromosomal Aberrations

Changes in chromosome structure will be explained by computer analogy. The four possible changes are compared with functions of a word processing file (segment of a chromosome) on a floppy disk (chromosome). As with a chromosomal segment, the number of characters (genes) in the file depends on the file size (size of chromosomal segment). As with real chromosomal segments, the file can be copied (duplication) or deleted (deletion). For both duplication and deletion the number of genes (words in the file) affected depends on the size of the segment (file). Duplication creates a copy of the file which may be modified (altered during the course of evolution) to produce several different drafts of a document (members of gene families). With deletion, a file is lost, creating a deficiency on the disk for those genes. A file can also be moved (translocated) from one area of the disk to another by renaming it (translocation within a chromosome) or between two floppy disks (translocation between two nonhomologous chromosomes). Inversions and consequences of inverted sequences during gamete formation can be explained by analogy with incompatible file formats. A file created using the IBM cannot be read on the Macintosh. A similar chromosomal incompatibility is produced as a result of crossing over between inversions and its noninverted homologue. Fertilization involving these aberrant chromosomes do not produce viable offspring (fail to printout). As in real species, the inversion will be perpetuated by the maintenance of the two computer systems.

Concept 5: Chromosome Mapping

The technique of chromosome mapping will be explained using a car mileage analogy. Mileage along a highway will be compared to theoretical map units calculated through the percentage of offspring resulting from recombinant gametes. The distance between cities (loci) located along the same highway (linked genes) can be calculated from the frequency of tanks of gas used (recombinant products produced) by a car traveling from city to city. Given a car that uses 1 tank of gas for every 100 miles traveled on a trip in which 3 tanks of gas have been consumed, students calculate the distance between cities X and Y as 300 miles. Students then see that if 5 tanks are required for travel between city Y and city Z the distance is 500 miles. As in linkage maps, the end to end distance is used to order cities (loci) on our road map. If the distance from city X to city Z is 800 miles, the order must be X, Y, Z (complete linkage map). As with crossover frequency, the longer the distance between two cities, the more tanks of gas used (crossovers that can occur) between the cites (loci). Differences between theoretical maps (based on crossing over) and physical maps are discussed.

Concept 6: DNA Replication

Mechanisms of DNA replication will be explained using the analogy of a zipper made of velcro. The velcro is held together by hooks and loops (hydrogen bonds) formed between the two strands (DNA backbones). Individual bonds are weak enough to be reversibly broken and rejoined, but show strength when combined over the length of a zipper (DNA molecule). Stretches of velcro containing 3 hook/loops (GC base pairs) will hold to each other more tightly than those with only 2 hook/loops (AT base pairs), making them harder to separate (increasing T_m observed for GC rich regions). Replication will be explained by analogy between unwinding the DNA double helix and unzipping the zipper. Once unzipped (single strand DNA), a new section of velcro may be fastened to a complementary velcro strand (newly synthesized complementary DNA). Students will note that zipping starts a at the bottom-stop (RNA primer) and continues as the zipper-slider (DNA Pol III) proceeds along the strands. Zipping is completed at the top-stop (ligase seals the final DNA nick). The lecturer will note that actual DNA is a flexible helix and not rigid as the real zipper. Additional differences between a zipper and the DNA helix are noted.

Concept 8: Lactose Operon

Transcription in the Lac Operon will be compared with a train on a train track by exploiting the obvious visual similarity between schematic representations of the DNA double helix and tracks. RNA Polymerase like a train, starts at a particular point (the station/Promoter) and proceeds down the train track (DNA) to a final destination (transcription termination). The repressor molecule is like a boulder that normally lies on the train track just outside the station (the DNA sequence of the operator region). When the train hits the boulder it derails it (inhibits transcription of the structural genes). Lactose will be compared with a repair crew that removes (binds, making it incapable of interacting with the DNA) the boulder from the track. When lactose is present, the track is kept clear and the train can start at the station and proceed all the way down the track (transcribe the structural genes necessary for lactose metabolism).

Appendix B
Pretest of Prior Genetics Knowledge

Name ________________________________ Date____________

The following questions are about genetics topics often covered in other courses. Generate explanations based on previous courses or your own experiences. Your score depends on the ideas you give rather than right or wrong answers.

1. What do the following mean to you:
   a. gene

   b. transcription

   c. translation.

   d. mutation

2a. A couple has five girls. What do you think the probability is that their next child will be a girl?

b. Another couple is starting a family, what do you think the probability is that they will have three boys in a row?

3. Genetically, how would you explain what determines sex (male or female) in humans?

4. What do you think is meant by X-linked inheritance? Give an example of this pattern.

5. Give some ideas to explain how a geneticist might determine the location on a chromosome of a gene for blue eyes.

6. What are human chromosomes composed of? Speculate as to how such material(s) might be arranged to give the chromosome its structure.

7a. How are scientific hypotheses tested?

b. How do scientists determine whether actual results are close enough to predicted results to say an hypothesis has been supported?

8. In your own words state the purpose(s) of mitosis. Where and when does it occur?

9. What might be the purpose(s) of meiosis. Where and when does it occur?

10a. How would you define genetic engineering?

b. What do you think is meant by the term clone?

11. Give some ideas on the role of mutation in the process of evolution. How significant do you think mutation is in changing gene frequencies (the percentage of a gene in a population).

12. Many recessive conditions are deleterious or even fatal in human beings. Since this is the case, do you think recessive lethal genes can be eliminated from the population. Justify your answer.

APPENDIX C

Sample Quiz Items Used to Assess Achievement of the Key Concepts

Concept 1
A plant breeder made a cross yielding progeny that should segregate in a 3:1 Mendelian ratio. The observed results (n=100) consisted of 80 plants with red flowers and 20 plants with white flowers.

a) State the null hypothesis

b) Calculate a chi squared value by completing the Table

Class	o	e	d	d^2	d^2/e
Total	100	100			

c) In the space below, interpret the chi square value

Concept 2
Fur color for rabbits in this question is determined as follows:

B_C_ Black
bbC_ Cream
B_cc Albino
bbcc Albino

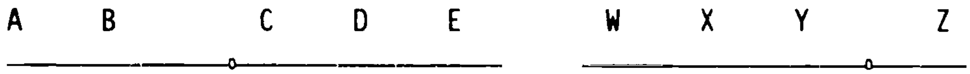
A heterozygous rabbit of genotype BbCc is crossed with an albino rabbit of the genotype BBcc. Give the genotypes and phenotypes for the F1 generation including frequencies for both genotypes and phenotypes.

Concept 3
a. Using one pair of homologs, draw the chromosomes at metaphase of a mitotic division. Using the same pair of chromosomes, draw metaphase I of meiosis. (Draw the chromosomes carefully, showing spindle fibers.)

b. How is interkinesis, the phase between the 1st and 2nd meiotic divisions, different than the interphase preceding meiosis?

Concept 4

Refer to the following 2 normal chromosomes to answer questions 1 through 3:



a. Define what is meant by the term deletion. Diagram an example derived from the normal chromosome(s) above.

b. Define what is meant by the term translocation. Show an example derived from the normal chromosome(s) above.

c. Define what is meant by the term inversion. Diagram an example derived from the normal chromosome(s) above.

Concept 8

a. Diagram and label a map of the lac operon:

b. For the following lac genotypes, predict whether the structural genes are transcribed (+) or not transcribed (-) in the absence and presence of lactose:

	No Lactose			Lactose			
	Z	Y	A	Z	Y	A	
$I^+ O^+ Z^+ Y^+ A^+$							
$I^- O^+ Z^+ Y^+ A^+$							
$I\ O^c Z^+ Y^+ A^+$							
$I^s O^+ Z^+ Y^+ A^+$							
$I\ O^+ Z^+ Y^+ A^+/F' I^+$							

APPENDIX D
STUDENT ATTITUDE SURVEY

COURSE NO.________SECTION_______TA'S NAME_________________________

YOUR ANONYMOUS RESPONSES TO THE FOLLOWING QUESTIONS WOULD BE ESPECIALLY HELPFUL IN IMPROVING THIS COURSE:

APPROXIMATE NUMBER OF COLLEGE CREDITS COMPLETED:
GENDER: M F
APPROXIMATE GPA:
NAMES OF COLLEGE SCIENCE COURSES COMPLETED:

CAREER GOALS:

DIRECTIONS: ANSWER AS HONESTLY AS POSSIBLE BY CIRCLING THE NUMBER THAT TELLS HOW YOU FEEL ABOUT EACH STATEMENT:

1-STRONGLY DISAGREE 2-DISAGREE 3-NOT SURE 4-AGREE 5-STRONGLY AGREE

<u>RECITATION:</u>	SD	D	NS	A	SA
1. THE TEACHING ASSISTANT (TA) PRESENTED RECITATION MATERIAL IN A CLEAR, UNDERSTANDABLE MANNER.	1	2	3	4	5
2. THE TA MADE CLEAR WHAT WAS EXPECTED OF ME.	1	2	3	4	5
3. QUIZZES IN RECITATION REFLECTED MATERIAL COVERED IN RECITATION VERY WELL.	1	2	3	4	5
4. FROM MY OBSERVATIONS THE <u>RECITATION</u> PART OF THIS COURSE COVERS MATERIAL AT AN APPROPRIATE PACE.	1	2	3	4	5
5. FROM MY OBSERVATIONS I AM CONFIDENT IN MY TA'S KNOWLEDGE OF THIS SUBJECT.	1	2	3	4	5
6. MY RECITATION GREATLY HELPED ME <u>REMEMBER</u> CONCEPTS PRESENTED.	1	2	3	4	5
7. MY RECITATION GREATLY HELPED ME <u>UNDERSTAND</u> CONCEPTS PRESENTED.	1	2	3	4	5
8. LONGER RECITATIONS WOULD HELP ME LEARN MATERIAL EVEN BETTER.	1	2	3	4	5
9. FROM MY OBSERVATIONS, I AM CONFIDENT IN MY TA'S MOTIVATION AS AN INSTRUCTOR.	1	2	3	4	5
10 MY TA CONVEYS ENTHUSIASM ABOUT THE COURSE.	1	2	3	4	5
11. IN SCIENCE, MEMORIZATION OF FACTS IS MORE IMPORTANT THAN LEARNING TO THINK CRITICALLY.	1	2	3	4	5
12. I WOULD VERY WILLINGLY TAKE ANOTHER GENETICS COURSE.	1	2	3	4	5
13. I FEEL I WOULD LIKE/ENJOY A CAREER IN GENETICS.	1	2	3	4	5
14. I WAS VERY MOTIVATED TO GET A GOOD GRADE	1	2	3	4	5
15. I WAS VERY MOTIVATED TO LEARN GENETICS	1	2	3	4	5
16. WHAT GRADE DO YOU THINK THE AVERAGE STUDENT IN <u>RECITATION</u> WILL RECEIVE.	A	B	C	D	E
17. WHAT GRADE DO YOU EXPECT TO RECEIVE FOR THIS COURSE.	A	B	C	D	E

(PLEASE COMPLETE BACK OF PAGE)

18. WHICH PARTICULAR RECITATION(S) HELPED MOST?

19. WHICH HELPED THE LEAST?

20. WHAT COULD YOUR TA REASONABLY DO TO IMPROVE THE LEARNING EXPERIENCE FOR YOU?

21. ABOUT HOW MANY HOURS PER WEEK DO YOU SPEND STUDYING?

22. HOW MANY HOURS FOR GENERAL GENETICS?

23. GIVE THE MOST IMPORTANT REASON(S) YOU HAD FOR TAKING THIS COURSE:

24. IF NEXT SEMESTER WE HAD TO LEAVE SOMETHING OUT IN TEACHING THIS COURSE, WHAT SHOULD IT BE?

STUDENT ATTITUDE SURVEY
EXPERIMENTAL

YOUR ANONYMOUS RESPONSES TO THE FOLLOWING QUESTIONS WOULD BE ESPECIALLY HELPFUL IN IMPROVING THIS COURSE:

COURSE NO.________SECTION________TA'S NAME____________________________

APPROXIMATE NUMBER OF COLLEGE CREDITS COMPLETED:
APPROXIMATE GPA:
NAMES OF COLLEGE SCIENCE COURSES COMPLETED:
CAREER GOALS:

DIRECTIONS: ANSWER AS HONESTLY AS POSSIBLE BY CIRCLING THE NUMBER THAT TELLS HOW YOU FEEL ABOUT EACH STATEMENT:

1-STRONGLY DISAGREE 2-DISAGREE 3-NOT SURE 4-AGREE 5-STRONGLY AGREE

<u>RECITATION:</u>	SD	D	NS	A	SA
1. THE TEACHING ASSISTANT (TA) PRESENTED RECITATION MATERIAL IN A CLEAR, UNDERSTANDABLE MANNER.	1	2	3	4	5
2. THE TA MADE CLEAR WHAT IS EXPECTED OF ME.	1	2	3	4	5
3. QUIZZES IN RECITATION REFLECTED MATERIAL COVERED IN RECITATION VERY WELL.	1	2	3	4	5
4. FROM MY OBSERVATIONS THE <u>RECITATION</u> PART OF THIS COURSE COVERS MATERIAL AT AN APPROPRIATE PACE.	1	2	3	4	5
5. FROM MY OBSERVATIONS I AM CONFIDENT IN MY TA'S KNOWLEDGE OF THIS SUBJECT.	1	2	3	4	5
6. THE USE OF ANALOGIES IN RECITATION GREATLY HELPED ME <u>REMEMBER</u> CONCEPTS PRESENTED IN RECITATION	1	2	3	4	5
7. THE USE OF ANALOGIES IN RECITATION GREATLY HELPED ME <u>UNDERSTAND</u> THE CONCEPTS PRESENTED IN RECITATION	1	2	3	4	5
8. USING MORE ANALOGIES IN RECITATION WOULD HELP ME LEARN MATERIAL EVEN BETTER	1	2	3	4	5
9. FROM MY OBSERVATIONS, I AM CONFIDENT IN MY TA'S MOTIVATION AS AN INSTRUCTOR.	1	2	3	4	5
10 MY TA CONVEYS ENTHUSIASM ABOUT THE COURSE.	1	2	3	4	5
11. IN SCIENCE, MEMORIZATION OF FACTS IS MORE IMPORTANT THAN LEARNING TO THINK CRITICALLY.	1	2	3	4	5
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14. I WAS VERY MOTIVATED TO GET A GOOD GRADE	1	2	3	4	5
15. I WAS VERY MOTIVATED TO LEARN GENETICS	1	2	3	4	5
16. WHAT GRADE DO YOU THINK THE AVERAGE STUDENT IN <u>RECITATION</u> WILL RECEIVE.	A	B	C	D	E
17. WHAT GRADE DO YOU EXPECT TO RECEIVE FOR THIS COURSE.	A	B	C	D	E

(PLEASE COMPLETE BACK OF PAGE)

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