Science History as a Means to Teach Nature of Science Concepts: Using the Development of Understanding Related to Mechanisms of Inheritance

Justin G. Lonsbury

and

James D. Ellis
University of Kansas

Introduction

Science Literacy and the Nature of Science

Only the irrational will dispute the need for science education. Today, science and technology pervade nearly all realms of human existence. Political battles are being fought over global warming, conservation, fossil fuels, and polluted drinking water. A rise in global terrorism has raised concerns about biological, chemical, and nuclear weapons. Pathogens are becoming immune to even the newest classes of antibiotics while cancer, heart disease, AIDS, and other medical ailments continue to kill millions. Furthermore, in our homes and at work, computer and telecommunication technology are assuming more wide-ranging and integral roles in our daily activities. Given these facts and the pervasiveness of science in all of our lives, meaningful science education should help students become science literate and increase the level of science literacy in the population.

While it is true that individuals are affected by science and the application of science-derived knowledge, DeBoer (2000) realistically asserts that "most citizens get by quite well at work and at home without thinking like scientists all of the time" (p. 594). This is clearly acceptable and no doubt helps people relate to one another in a socially pleasing way. However, science literacy helps individuals remain skeptical of the application of science-based knowledge, allowing each to be "better equipped to vote intelligently for measures freeing or controlling science-based technology and to debate it publicly or among friends" (Winchester, 1989, p. iii). The need for a science literate citizenry extends beyond the individual to include "benefits to national economies, science itself, science policymaking, and democratic practices, as well as to society as a whole" (Laugksch, 2000, p. 86). Without science literacy, humanity cannot accrue these benefits. As the American Association for the Advancement of Science [AAAS] (1990) states, "Without a science-literate population, the outlook for a better world is not promising" (p. xv).

The conception of science literacy that guided this study is that offered by the *National Science Education Standards* (National Research Council [NRC], 1996). Table I summarizes the *Standards'* view of science literacy.

Table 1
National Research Council's description of science literacy

A scientifically literate individual has the ability to:
1. Ask, find, or determine answers derived from curiosity about everyday experiences.
2. Describe, explain, and predict natural phenomena.
3. Read with understanding articles about science in the popular press and to engage in social conversation about the validity of conclusions.
4. Identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed.
5. Evaluate the quality of scientific information on the basis of its source and the methods used to generate it.
6. Pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.

Note. *From the National Science Education Standards (NRC, 1996, p. 22)*

It becomes apparent upon analysis of the NRC's statements that an understanding of the nature of science is an important contributor to an individual's level of science literacy. Other attempts to list components of science literacy also emphasize the importance of understanding nature of science concepts (Bybee et al, 1991; Pella, O'Hearn, & Gale, 1966; Showalter as cited in Rubba and Andersen, 1978). If students are expected to advance along the continuum that is science literacy, incorporating instruction aimed at teaching nature of science concepts seems like an appropriate intervention.

The Nature of Science

Saying that the nature of science will help to increase students' degree of science literacy begs the question, "What *is* the nature of science?" Obviously, a detailed discussion of the nature of science is beyond the scope of this article, and perhaps the primary author's expertise. However, a few brief comments will serve to outline aspects of the philosophy of science that influenced the study's design.

In general, the nature of science relates directly to the epistemology of science, or how scientists develop and justify knowledge claims about the natural world. Knowing how scientific knowledge is constructed, how it is justified, and how it changes will help individuals make informed decisions related to the validity and application of science-derived knowledge. Herein lie the ties to science literacy, individual fulfillment, and the improvement of society through science.

When learning about the nature of science, students should be exposed to the idea that scientific understanding may be constrained within paradigms of thought. When asking questions, seeking observations, interpreting observations, and going about other aspects of the daily business of science, existing paradigms influence decisions. Fundamental changes in the way we interpret the natural world, such as the heliocentric universe and evolving species, come about only when the operating paradigms change. Such ideas about the nature of science are often attributed to Thomas Kuhn (1996/1962).

Because of its emphasis on competing paradigms and the theoretical context of science, Eflin, Glennan, and Reich (1999) agree that students should be exposed to some of Kuhn's ideas. Abd-El-Khalick (1999) explains such ideas about the nature of science when he writes, "Observations are theory-laden, that is, observations are never neutral or theory-free; rather they are filtered through the expectations that ensue from theory – the lens through which scientists examine the natural phenomena relevant to their investigations" (p. 18). While scientists assume a real world, their interpretations of sensory observations as well as the actual observations they seek are predetermined, guided by a preexisting paradigm or theoretical framework. As a result, any interpretation of that set of data, the scientific understanding itself, exists entirely within the paradigm that guided the observation collection. Schwab (1962) puts it this way:

> What facts to seek in the long course of an inquiry and what meaning to assign to them are decisions that are made before the fact. The scientific knowledge of any given time rests not on *the* facts but on the *selected* facts – and the selection rests on the conceptual principles of the inquiry (p. 199).

It is interesting to note that Schwab's comments were made in the same year as Kuhn's original publication of *The Structure of Scientific Revolutions*.

The guiding paradigms in science are not the result of an absolute-truth-producing machine called the "scientific method." Instead, AAAS (1990) explains that the formulation of scientific knowledge "depends both on making careful observations of phenomena and on *inventing* [italics added] theories for making sense out of those observations" (p. 2). To unify observations, scientists must contemplate and creatively interpret those observations' meanings. Schwab (1962) states, "Scientific knowledge . . .

is of the facts *interpreted*" (p. 199) and Bronowski (1965), emphasizing the creative nature of this interpretation, declares, "There is a likeness between the creative acts of the mind in art and in science" (p. 7). Such an emphasis on the interpretive and creative nature of science adds a human component to the enterprise that would be lost to students without an understanding of the nature of science. Understanding science as a creative, human enterprise is an important component of science literacy and helps to combat many absolutist, mechanist misconceptions many people harbor regarding science.

Once established, a given paradigm is not heralded as the absolute truth. Furthermore, competing paradigms may exist at the same time. Controversies in science arise because not all individuals operate within the same paradigm. Different theoretical frameworks cause individuals to pay attention to different sets of data or to interpret the same set of data differently, resulting in different perceptions of nature. Mayr's (1988) description of scientific controversies illustrates this point perfectly:

> In scientific controversies, there is rarely any argument about facts. It is rather their interpretation that is controversial. A careful study of such controversies will almost always reveal a difference in conceptual framework among the parties in dispute (pp. 489-490).

In the end, theoretical frameworks can be judged based on observational confirmation, logical consistency, falsifiability, and ability to withstand the parsimonious blade of Occam's razor. Theoretical frameworks that at one time seemed intuitive and insurmountable have been rejected and replaced. Particulate inheritance and the replacement of the notion of blending inheritance provides one such historical example of a paradigm shift and is the focus of this study. Today's scientific paradigms are and must remain open to the same sorts of judgments and possible refutations.

Rubba's *Nature of Scientific Knowledge Scale* (*NSKS*) was used to assess students' acquisition of nature of science concepts in this study (Rubba, 1977). This scale was developed to align with Rubba's 6-factor model (see Table 2 below) of the nature of science. Its use does not imply any absolute acceptance of Rubba's views and the model was not introduced to students as *the* nature of science. However, Rubba's model does include many of the aspects of the nature of science mentioned above, specifically the importance of creativity, the tentative and contextual nature of scientific understanding, parsimony, and the importance of testing understanding against empirical observations. The model is presented here to provide a context within which to analyze students' NSKS scores.

Table 2
Rubba's model of the nature of scientific knowledge

Scientific knowledge is:	
Amoral	Scientific knowledge provides man with many capabilities, but does not instruct him on How to use them. Moral judgment can be passed only on man's application of scientific knowledge, not the knowledge itself.
Creative	Scientific knowledge is a product of the human intellect. Its invention requires as much Creative imagination as does the work of an artist, a poet or a composer. Scientific knowledge embodies the creative essence of the scientific inquiry process.
Developmental	Scientific knowledge is never "proven" in an absolute and final sense. It changes over time. The justification process limits scientific knowledge as probable. Beliefs which appear to be good ones at one time may be appraised differently when more evidence is at hand. Previously accepted beliefs should be judged in their historical context.
Parsimonious	Scientific knowledge tends toward simplicity, but not to the disdain of complexity. It is comprehensive as opposed to specific. There is a continuous effort in science to develop minimum number of concepts to explain the greatest possible number of observations.
Testable	Scientific knowledge is capable of public empirical test. Its validity is established through repeated testing against accepted observations. Consistency among test results is a necessary, but not a sufficient condition for the validity of scientific knowledge.
Unified	Scientific knowledge is born out of an effort to understand the unity of nature. The knowledge produced by the various specialized sciences contribute to a network of laws, theories and concepts. This systematized body gives science its explanatory and predictive power

Note: From Rubba, P. A. (1977). Nature of scientific knowledge scale: Test and user's manual. ERIC Document No. ED 146 225, pp. 4-5; Rubba, P. A., & Andersen, H. O. (1978). Development of a instrument to assess secondary school students' understanding of the nature of science. Science Education, 62(4), p. 456.

Using Science History to Teach the Nature of Science

Helping students understand nature of science concepts will help them to better understand the construction and application of science-derived knowledge. Unfortunately, although they may make sense to the educated and science literate, it is nearly impossible for those who are having their first experience with science (i.e. introductory science students) to learn abstract nature of science concepts in their abstract form. AAAS (1990) explains, "Generalizations about how the scientific enterprise operates would be empty without concrete examples" (p. 145). Fortunately, science history can provide concrete examples to help students understand difficult science and/or nature of science concepts.

To summarize the reasons for incorporating history into science curriculum Matthews (1994) developed the list presented in Table 3. Many of the reasons presented support the use of science history as a means to teach nature of science concepts. Interestingly, Matthews mentions science history as a means to teach the body of scientific knowledge and scientific methods. Given the limited time classroom teachers have to "cover the curriculum," efficient methods are needed and welcome.

Table 3
Summary of reasons for incorporating history in science instruction

1. History promotes better comprehension of scientific concepts and methods.
2. Historical approaches connect the development of individual thinking with the development of scientific ideas.
3. History of science is intrinsically worthwhile. Important episodes in the history of science and culture – the Scientific Revolution, Darwinism, the discovery of penicillin and so on – should be familiar to all students.
4. History is necessary to understand the nature of science.
5. History counteracts the scientism and dogmatism that are commonly found in science texts and classes.
6. History, by examining the life and times of individual scientists, humanizes the subject matter of science, making it less abstract and more engaging.
7. History allows connections to be made within topics and disciplines of science, as well as with other academic disciplines; history displays the integrated and interdependent nature of human achievements.

Note: From Matthews, M. R. (1994). Science teaching: The role of history and philosophy of science. New York: Routledge, p. 50.

Research Studies Examining the Effectiveness of a Science History Approach

The rationales for incorporating science history into science instruction have been outlined. Several research studies have provided empirical evidence to support these claims. Klopfer and Cooley (1961 & 1963) performed the largest study of its kind, with 108 biology, chemistry, and physics classes participating. The study's results showed that the History Of Science Cases (HOSC) group significantly outperformed the control group on a nature of science assessment. However, the biology students participating in the HOSC group scored lower on a biology content exam than students without the history emphasis. The chemistry and physics classes showed the same achievement levels on their respective content exams. Oliver (as cited in Ramsey & Howe, 1969) also used history of science cases and found that students in the experimental groups made significantly higher gains on a nature of science assessment than the control. Students showed no significant differences on content exams.

Next, Irwin (2000) qualitatively examined the difference in achievement on a nature of science assessment between a "historical theme group" and a "final form group." The "historical theme group" was exposed to historical material related to atomic theory. The group exposed to the historical material performed better when asked about nature of science concepts. The groups performed at the same level on a content examination.

Yager and Wick (1966) compared textbook, MRL (multireference-laboratory approach), and MRLI (multireference-laboratory and idea group) approaches to see which could best improve students' conceptions of nature of science concepts. The MRLI, with its emphasis on history and the contextual development of ideas, helped students to produce significantly higher scores on a nature of science assessment than the other groups. Gennaro (as cited in Lederman, 1992, p. 336) and Sorensen (as cited in Lederman, 1992, p. 336) also studied the effects of MRL and MRLI approaches and produced results similar to Yager and Wick's.

Providing more empirical evidence supporting the effectiveness of including science history in classroom instruction, Solomon, Duveen, and Scot (1992) performed science-history-related action research in five middle school classrooms. From questionnaire and interview data, the researchers report that they had "substantial evidence that (the) units for teaching the history of science within the normal school curriculum made a valuable contribution to the pupils' understanding of the nature of science" (p. 418). Also, the interview data led them to conclude, "Studying the history of a change in theory may make the process of conceptual change a little easier" (p. 419).

Finally, Roach (1993) studied the effectiveness of incorporating historical vignettes in changing undergraduate non-science majors' conceptions of the nature of science. Findings indicate that the experimental group, those exposed to the vignettes, showed significantly higher gains in their understanding of nature of science concepts than the group without the vignettes. Both groups performed at the same level on a content knowledge exam.

On the flip side, some studies have shown that incorporating history into instruction does not lead to increases in students' understanding of nature of science concepts. Abd-El-Khalick and Lederman (2000) found that history of science courses had only small effects on college students' and preservice teachers' knowledge of nature of science concepts. Huybrechts (2000) studied the effects of integrating science history into a middle school science curriculum. A series of five lessons was written, each including a short biography and instructions as to how to repeat important scientists' experiments. One group was exposed to the history material while the other was not. The two groups showed no significant differences in pre- to posttest gains on a researcher-developed attitude survey.

Purpose of this Study

The purpose of this study was to see if an explicit emphasis on the historical and epistemological foundations of an influential scientific idea can increase student understanding of nature of science concepts without detracting from content knowledge acquisition. The rationale for incorporating science history into science instruction is solid and studies have yielded statistically significant student gains on nature of science assessments. However, statistical significance tests "do *not* evaluate the probability that sample results describe the population" or "bear on whether the sample results are replicable" (Thompson, 2002, p. 65). Even when effect sizes are presented, it is difficult to generalize to the overall population given the diverse nature of students, teachers, and intervention strategies. As a result, a single group of studies may, justifiably, be irrelevant to actual classroom teachers, destroying any link between research, practice, and student achievement. Replication in a wide variety of contexts will provide a better idea of the intervention's effectiveness. Consistent statistically significant results and palatable effect sizes will increase confidence in science history integration's effectiveness, leading to interventions extending beyond short vignettes, human-interest stories, and other surface level approaches. Such extensions will help teachers and students achieve the goals of science history integration, helping students along the path to science literacy.

Motivation for this study came in large part from Monk and Osbornes' (1997) statement:

> Put simply, it is clear that too many of the justifications for use of the history of science are provided by historians and philosophers with little knowledge of primary or secondary pedagogy rather than by teachers with a reasonable knowledge of history and philosophy (pp. 407-408).

Others argue, "formal research findings are too generalized for classroom teachers" (Pekarek, Krockover, & Shepardson, 1996, p. 111). This study attempts to show that small, content-specific, teacher-designed and implemented, realistic changes can positively influence students' perceptions of nature of science concepts. Encouraging results could help reluctant teachers, those currently unmotivated by overly generalized and/or academic justifications, feel confident enough to design and incorporate meaningful science-history content into their own instruction. The study is not large in its scope or sample size and makes no claims as to the necessity of implementation. It simply tries to show science history's potential, within a limited context, to help students develop a more sophisticated understanding of the nature of science. In this way, this study can serve to improve classroom instruction and contribute to our overall understanding of this approach.

Methodology

Population, Sample, and Context

The population examined consists of high school introductory biology students. The sample consisted of 107 students (ages 14-17) attending Blue Valley North High School in Johnson County, Kansas. Most students were in the ninth grade, although three tenth graders who were also taking the class participated in the study. The school is in an affluent area and expectations placed on students with regard to academics are often very high. All students were enrolled in Introductory Biology and were taught by the primary researcher. The sample was almost entirely Caucasian and consisted of 54 females and 53 males. The two groups in the study consisted of two intact classes each.

Time Frame

The study occurred in the spring semester of 2001 during a four-week genetics unit. The genetics unit lasted eighteen instructional periods, including testing days. The instructional periods varied in length from 25 to 90 minutes. The beginning and ending times of the two different treatments were the same.

Research Design

The study was a quasi-experimental, nonequivalent-groups pre-posttest design aimed at testing the effects of the integration of science history into science instruction on students' content knowledge and their knowledge of the nature of science. The four classes were randomly assigned to their groups using a random numbers table. The history integration group and the "normal" instruction group both consisted of two intact classes each. The research design is similar to other studies that have investigated the effects of science history integration on student acquisition of nature of science concepts, especially those that also included a content acquisition analysis (Irwin, 2000; Klopfer & Cooley, 1963; Oliver, as cited in Ramsey & Howe, 1969; Roach, 1993; Solomon, Duveen, & Scot, 1992; Yager & Wick, 1966).

The *NSKS* was used to gather pre- and posttest data on students' knowledge of nature of science concepts while a researcher designed genetics exam (see Appendix) tested students' content knowledge acquisition. To help establish the validity of the genetics unit exam, three other high school biology teachers analyzed the exam by taking the questions, comparing the questions to a core list of *National Science Education Standards*, and assigning a Bloom's taxonomy ranking to each question. The teachers agreed that the test measured the listed *Standards* and did so at an average Bloom's taxonomy ranking of 2.7. This result was interpreted as between "comprehension" and "application" on Bloom's taxonomy, arguably consistent with a typical teacher-designed unit test. Analysis of covariance (ANCOVA) was used to judge the significance of the difference between groups on pre- and posttest scores for both the *NSKS* and the genetics unit exam. An effect size estimate (partial ?[2]) was used to calculate the percentage of any variance between groups accounted for by the science history integration. The *NSKS* and genetics pretests were administered on the first and fourth days of the study, respectively. The genetics posttest was taken on the second to the last day of the study while the *NSKS* posttest was taken on the last.

The Units

The primary researcher taught both the "normal" instruction unit and the history integration unit. In the history integration group, lectures, small group work, and discussions addressed key aspects of the history of genetics. Specifically, on the third day, students were presented Hippocrates' pangenesis-like explanation of inheritance and were asked to work together to evaluate his ideas. Aristotle's views on inheritance were then presented, often echoing student-generated questions regarding Hippocrates' ideas. Such ideas may be more philosophizing than actual science but offering alternatives to our modern understanding of inheritance may help make aspects of the nature of science more obvious to students.

On the same note, some of Bacon and Descartes' ideas were also presented, specifically those related to inductive reasoning, experimental method, mechanist philosophy, and reductionism. These were not presented to indoctrinate students or to force them to memorize details about these philosophers' ideas. Instead, students were simply asked to consider how these ideas could have fundamentally affected the way individuals viewed the natural world. This was meant to introduce students to philosophical principles that contributed to a change in the way ideas about the natural world were developed and defended.

While both groups were presented the ideas of blending inheritance and particulate inheritance, only the history integration group discussed the difference as a paradigm shift. On day seven, a paradigmatic view of science was taught as "thinking outside of the box," with Mendel serving as an example of an original thinker. Along these lines, on day ten, students were asked why Mendel's paper sat unnoticed, despite its significance, until the 20th century. As had been hoped, students created thoughtful responses related to Mendel's isolation, poor communication technology, others' troubles understanding Mendel's work, and a general unwillingness to recognize the importance of the work. The instructor then mentioned that advances in other realms of science may have helped Mendel's ideas to stick.

In addition to strategies mentioned above, on day fifteen, the history integration group completed an activity called "Standing on the Shoulders of Giants" (BSCS, 1997). This activity helped emphasize the historical development of ideas in genetics and stress the importance of scientists working together to develop ideas. Such an activity was included to help students see how scientists work together to fine tune knowledge and to add to understanding within a given paradigm. It also shows how paradigms guide lines of inquiry, and how paradigms guide question formulation and data interpretation.

Since it took time to expose students in the history integration group to the genetics history content, it was necessary to make modifications to the "normal" instruction group's unit other than simple omission of the science history material to ensure that both units were the same length. For example, the "normal" instruction group did the majority of their work in class while the history integration group was often assigned the same work as homework. Furthermore, the “normal” instruction group spent more time working examples of concepts and reviewing material that they had already covered. This is not to say that the “normal” instruction group went into more depth than the history integration group. They were simply exposed to more examples and spent more time reviewing. Another difference was the length of time spent on patterns of inheritance. The history integration group was only briefly introduced to patterns of inheritance and pedigree analysis while the normal instruction group not only spent more time on these concepts but also constructed their own pedigrees. In place of the pedigree construction, the history integration group completed the “Standing on the Shoulders of Giants” activity.

Efforts to keep the class time spent on each of the two units equal were successful. Unfortunately, no evidence exists to prove that students actually did the work assigned to them outside of class. Thus, an assumption was made that the history integration students participated in the unit as the primary researcher had planned. The genetics unit exam scores do indicate that the students were acquiring the content, supporting the validity of the assumption.

Adding related variables to the experiment, the “normal” instruction and history integration groups spent different amounts of time on science and nature of science concepts. However, such variations were expected. After all, the main question asks whether or not a teacher can use history to, without spending any more precious class time, increase students’ understanding of nature of science concepts while maintaining the current level of content knowledge acquisition.

Results

Participants

Only study participants who took both the pre- and posttest for a given exam were considered in that part of the data analysis. 107 students participated in either the history integration or the "normal" instruction unit. 93 students took both the *NSKS* pre- and posttest, 48 in the history integration unit and 45 in the "normal" instruction unit. 104 students took both the genetics unit exam pre- and posttest, 51 in the history integration group and 53 in the "normal" instruction group. Table 4 reports the number of students in each group considered for analysis.

Table 4
Number of students considered for analysis.

	Exam	
Group	Genetics	NSKS
Total	104	93
History Integration	51	48
"Normal" Instruction	53	45

NSKS Whole Test and Subscale Group Comparisons

One-way ANCOVA was conducted to assess the significance of differences between the history integration and "normal" instruction groups' *NSKS* posttest scores for the whole test and each of the subscales. The independent variable (group assignment) consisted of two levels, the "normal" instruction group and the history integration group. The dependent variable was the posttest scores and the covariate was the related pretest scores. Prior to the ANCOVA, the homogeneity of slopes assumption was confirmed for the whole test and subscale data. Related effects sizes were small.

Table 5 provides *NSKS* mean and standard deviation comparisons, including adjusted means from the ANCOVA's. Table 6 summarizes each test's ANCOVA data, including effect size measures.

Table 5
NSKS total and subscale means, standard deviations, and adjusted means

Variable	Group	M (Pre)	SD (Pre)	M (Post)	SD (Post)	M^a
Total	H	162.23	12.80	169.29	13.45	170.31
	N	164.84	10.43	165.62	10.43	164.54
Amoral	H	26.96	3.48	27.73	3.53	27.59
	N	26.51	3.91	26.62	4.49	26.77
Creative	H	25.27	5.93	27.29	6.08	27.34
	N	25.42	4.3	26.38	5.24	26.33
Developmental	H	28.67	3.70	28.92	2.83	29.23
	N	30.02	2.75	29.31	3.89	28.97
Parsimonious	H	22.85	3.79	24.27	3.84	24.05
	N	22.02	3.79	22.82	3.61	23.05
Testable	H	28.98	3.56	30.52	4.07	30.98
	N	30.62	3.57	29.87	3.51	29.38
Unified	H	29.52	4.83	30.56	3.94	30.74
	N	30.24	3.74	30.62	3.86	30.43

N(Total) = 93; N(H) = 48; N(N) = 45
Note: "H" = history integration group; "N" = "normal" instruction group.
240 points total and 40 points on each subscale were possible.

Table 6
Summary of NSKS total and subscale ANCOVA data

Variable	F (1, 90)	partial ?^{2}
Total	8.039**	0.082
Amoral	1.448	0.016
Creative	1.132	0.012
Developmental	0.167	0.002
Parsimonious	2.331	0.025
Testable	5.378*	0.056
Unified	0.218	0.002

*p<.05 **p<.01 N = 93
Note: Each row summarizes a separate ANCOVA.

The history integration group's adjusted means were greater than the "normal" instruction group's on the whole test and on all subscales. The history integration group statistically significantly outperformed the "normal" instruction group on the total *NSKS* score, F (1, 90) = 8.039, MSE = 94.83, p = .006, and on the "testable" subscale, F (1, 90), MSE = 10.45, p = .023. The effect sizes for the whole test and "testable" subscale were medium, with partial $?^2$ values of .082 and .056, respectively. This means that the intervention accounted for 8.2% of the variance between group means on the whole *NSKS* and 5.6% of the variance on the "testable" subscale. The remaining subscales showed small effect sizes and no statistically significant posttest mean differences between groups.

Genetics Unit Exam Group Comparisons

One-way ANCOVA was also used to assess the statistical significance of group mean differences on the genetics unit exam posttest. The dependent variable was the genetics unit exam posttest scores, the independent variable was again the two-level group assignment, and the covariate was the pretest scores. Homogeneity of slopes was confirmed and the related effect size was small.

Table 7 compares both groups' means, standard deviations, and adjusted means from the ANCOVA.

Table 7
Genetics unit exam means, standard deviations, and adjusted means

Variable	Group	N	M (Pre)	SD (Pre)	M (Post)	SD (Post)	M^a
Exam	H	51	13.59	3.68	19.65	5.8	19.53
	N	53	13.32	4.29	20.98	6.15	21.09

N(Total) = 104
Note: "H" = history integration group; "N" = "normal" instruction group.
37 points were possible on the exam.

The “normal” instruction group’s adjusted mean for the posttest was 1.56 points, or 4%, greater than the history integration group’s. However, as the ANCOVA results in Table 8 show, this difference was not statistically significant and the effect size was small.

Table 8
Genetics unit exam ANCOVA data

Variable	F (1, 101)	Partial ?^{2}
Total	2.612	0.03

*p<.05 **p<.01 N = 104

Overall, the history integration group performed statistically significantly better than the “normal” instruction group on the *NSKS* posttest overall and “testable” subscale mean scores, both showing moderate effect sizes. No statistically significant difference was found between the two groups on any of the other *NSKS* subscales. The two groups also showed no statistically significant difference in genetics unit exam posttest performance despite a 4% larger adjusted mean score for the “normal” instruction group.

Discussion

The results indicate that incorporating science history into “normal” classroom instruction has the potential to increase students’ knowledge related to nature of science concepts without significantly detracting from their acquisition of examinable science content knowledge. The results also suggest that science history may be particularly effective at helping students realize that scientific knowledge is testable rather than absolute.

Study Limitations

Although attempts were made to control extraneous variables and use appropriate, valid, and reliable measurements, limitations exist that must be considered when interpreting the study's results. These limitations dealt primarily with the units, research design, and data analysis.

First, the discussion used in day three of the history integration unit may not have been effective. In fact, because of a series of unanswered questions and the primary researcher's inability to help students link the new ideas with their own experiences, the "discussion" centered on reductionism and experimental methods turned into simple direct instruction. The unanswered questions and blank stares should have been a clue to the primary researcher to steer a bit off of the lesson plan and spend more time trying to link the abstract with concrete examples. The difference between the two groups on the *NSKS* might have been larger had the primary researcher done a better job helping the students understand the significance of the material. This is especially true given the length of the study.

Also, despite knowing that "we should do school science without committing ourselves to a particular philosophical line," the primary researcher may have put too much emphasis on the idea of paradigm shifts (Ray, 1991, p. 87). However, as stated earlier, Eflin et al. (1999) do say that exposing students to the ideas of competing paradigms and the development of ideas within a theoretical context is important. Furthermore, in addition to addressing paradigmatic thought, attention was also placed on the progression of ideas in genetics, development of questions and hypotheses, experimental design, and communication among scientists. Thus, although some may see the possible overemphasis on paradigmatic thought as restrictive, students were exposed to a variety of other ideas related to the nature of science in an effort to mature the students' conceptions of scientific understanding.

Next, some instructional days were exactly the same between the units, creating smaller differences between the groups than possible. This was the result of the primary researcher's efforts to make sure that the students were exposed to approximately the same amount of genetics content in the same period of class time, thereby controlling for time across groups and showing that history integration can be done without taking time away from content instruction. Although the primary researcher's difficulties making this happen may make it seem that using science history forces teachers to slow down, this is not necessarily the case. The unit took place at the end of the year and students had not been taught that DNA carries the genetic information to make proteins. Because of the enormous applicability of this concept, omitting it from the year's material was not acceptable. In short, the primary researcher, in his role as a teacher, panicked because too little time was allotted for the genetics unit in general. Long-term semester planning proved to be the issue, not science history integration.

On a related but slightly different note, both groups were introduced to a series of experiments that led to the acceptance of DNA as the genetic material. The series was presented as a turning point in our understanding of nature and as an example of how science works to develop understanding. Given the relatively short duration of the study, the inclusion of history content in the "normal" instruction group's unit may have been significant. However, the *NSKS* results show that the history integration students were still able to perform better on a nature of science assessment. One interpretation of this could be that even small amounts of history inclusion make a difference in students' performance on nature of science assessments. On the other hand, the small difference between the groups' treatments invites warranted speculation that variables other than the unit differences affected the *NSKS* results.

The avoidable similarities between the groups bring up an interesting point in that the primary researcher had a difficult time separating the role of the researcher from the teacher. Irwin (2000) states, "The disadvantage of being a teacher-researcher . . . is that it is difficult to *refrain from teaching*" (p. 13). Irwin was discussing the difficulty of withholding information in discussion but the same issue applies in this case to incorporating history material into the "normal" instruction unit. The experiments are fantastic examples of posing hypotheses and designing experiments to address them. The researcher as a teacher could not, despite the possibly negative impact on the study, omit this material from the "normal" instruction group's lessons. Given that efforts at controlling the exposure to historical material fell short in this respect, the study's results must be interpreted conservatively.

In addition to individual day similarities between the groups, the sequencing of material was also the same. Although history does not show it happened this way, the textbook used at the research site presents meiosis before Mendel and uses related concepts to explain Mendel's work. Instead of presenting Mendel's ideas prior to meiosis in both units, it may have been more helpful to flip the order of instruction for the "normal" instruction group. This would have created more of a difference between the two groups and could possibly have increased the *NSKS* score differences. Although both groups were taught Mendel's ideas before meiosis, only the history integration group discussed the connections between cytology and genetics and the significance of the rediscovery of Mendel's work.

Furthermore, the fact that the "normal" instruction group was able to spend more time reviewing and working examples may cause concern to some considering implementing this approach. In addition, the "normal" instruction group was able to construct pedigrees while the history integration group was not. Thus, in this particular instance, the "normal" instruction group was able to go into more depth than the history integration group. Despite this, no statistically significant differences in gains existed between the two groups on the genetics unit exam. Since the history integration group actually spent less time on the science concepts, one possible interpretation of these results could be that science history *helped* teach the science content knowledge. This would be encouraging to teachers and indicates a possible area of future study. Another interpretation could be that there is room for incorporating science history instruction without jeopardizing students' acquisition of content knowledge.

Subconscious differences in the primary researcher/teacher's approach may have also affected the data. More enthusiasm may have been shown towards the history integration group, increasing student interest and raising achievement. If such a factor did play a part in student performance, it most likely increased the history integration group's mean score relative to that of the normal instruction group.

Finally, it is likely that longer units including similar material would have produced larger discrepancies between the two groups. Bateson (1990) showed that students in all-year classes performed better on a nature of science assessment than students who had taken the same material in semester classes. Exposing students to science history material for a longer period of time would probably have provided a better indication of the approach's effects on students' understanding of science concepts.

Research Design and Data Analysis

The non-equivalent pre-posttest design of this study was appropriate. However, interpretation of the data must be done with caution. House (1991) explains, “Traditional experimental design often mistakes the program for a sufficient condition, one that will produce the outcome by itself” (p.7). Extraneous variables other than those described above may have influenced the study’s outcome. House goes on to say, “Even the same program can produce different results because of the complexity and interaction of all the structures that affect the results” (p. 7).

Stating the importance of addressing factors other than the treatment that could affect a study’s data, Lederman (1992) explains, “It is not adequate to simply correlate instructional sequences with students’ conceptions of science without also investigating the students’ perceptions of instructional tasks and activities or their recollections of factors which have influenced their conceptions” (p. 352). Qualitative rather than quantitative approaches are suggested to address these perceptions. This is because qualitative research can “avoid the problems created by limiting responses to an a priori set of categories or viewpoints” (p. 351). Limiting student responses provides researchers only a restricted view of students’ knowledge. It is possible, however, that a researcher’s interpretation of student responses would also create variables, resulting in the trade of one problem for another. Furthermore, although some argue that qualitative studies could provide richer and more valid data, “The results of recent qualitative investigations have not outwardly contradicted the results of prior quantitative approaches” (p. 352).

The fact that the research hypothesis related to genetics content acquisition was the same as the null also creates issues related to data interpretation. It is much easier to "disprove" than to "prove" the null. Stated differently, it is harder to prove equality than difference. The number of students participating in the study would have to be much larger to ensure that the null had actually been "proven." The results show that actual differences did exist between the two groups on the genetics content exam and that the effect size, $?^2 = .03$, was nearly moderate. Although the groups did not show statistically significant differences on their genetics unit exam gains, accepting the null may represent Type II error. If this is the case, incorporating science history into science instruction may slow down the pace of instruction and restrict acquisition of science content knowledge.

Flaws in the implementation of the genetics unit exam present other possible limitations to the study. For example, both groups were given the genetics unit exam as a pretest on day four after some exposure to or review of Mendelian inheritance. Although this was the case for both groups, allowing more time between the tests could have increased the score separation between the groups and produced statistically significant differences. This is particularly possible since the "normal" instruction group's posttest scores were 4% higher, on average, than the history integration group's. Furthermore, a problem with the genetics history data was that students in the history integration group that took both the pre- and post genetics tests but missed part of the in-class history integration were still counted in the analysis. However, a student making up work before or after school was taught a way that matched the individual's group assignment.

Also, the validity and reliability of the genetics unit exam were not firmly established. However, despite its possible flaws, the genetics unit exam (see Appendix) is probably no better or worse than a typical science-teacher-developed exam. Teachers operate within their own spheres of influence and consider performance on their own exams to represent actual gains in understanding. A test need not come with validity and reliability estimates for a teacher to consider the results an indication of his/her or the students' success or failure. So, even though the exam is not perfect, the genetics unit exam data provide an approximation of what might happen in a typical teacher's classroom.

Finally, the sample in this study may have affected the results. The students in the study were above average in intelligence and, in no small way, extrinsically motivated to learn the content. If they had not been under the impression that the history material was going to be on the test, they might have blown it off, minimizing the approach's impact. Kauffman (1989) states that it is often the case that "students will not take seriously and will fail to study material that is subordinate to the main concern of the course, especially if it is not included on examinations" (p. 86). Students that are not interested in or compelled to learn the material might disregard the history content, nullifying the effect of the approach. This might not be true, however, if the argument that history is intrinsically interesting has any merit. Also, as Kauffman explains, students might enjoy the material more if it *isn't* on the exam, perhaps because the pressure to learn has been removed.

Overall, when interpreting the data, one must consider study limitations arising from the units, research design, and assessment tools used as well as the implementation of those tools and the students participating in the study.

Conclusions

This study shows that the incorporation of science history into normal classroom instruction may be a way to increase students' understanding of nature of science concepts. At the very least, it shows that incorporating the history of science does not detract from students' content knowledge acquisition. In light of the potential of science history to teach nature of science concepts and the attention given to the nature of science in science education reform documents, such findings are important.

If a teacher chooses to integrate science history content, (s)he must do so in a way that respects the history itself. It must not be skewed simply to better fit the ends that the teacher desires. Arguments against the incorporation of history often center on the fact that the history taught is not historically accurate. Matthews (1994) states the effect of this practice, "Where quasi-history is substituted for history, the power of history to inform the present is nullified" (p. 75). Teachers must use actual history and point out instances within it to provide students concrete examples of the nature of science concepts being taught. Also, when using history, it must not be presented as a sequence of events that has led to today's "correct" understanding. This practice reduces the rich historical context to simple memorization and fact recitation. Unless history is used appropriately, it may only serve to reinforce student misconceptions and perpetuate the lack of science literacy in the population.

The decision to integrate science history into instruction ultimately rests with the classroom teacher. Unfortunately, some teachers may feel uncomfortable using science history. Unlike science concepts, the history and nature of science “(encompass) several scholarly fields of study” making incorporating these topics into instruction seem like a “daunting prospect” (SSEC & BSCS, 1994, p. 17). Furthermore, “Teachers are . . . naturally reluctant to consider topics that expose weaknesses in their own knowledge and understanding, which additionally erodes their status as an authority that justifies their actions in the classroom” (Monk & Osborne, 1997, p. 417). These barriers are significant and must be overcome. Only then can teachers feel comfortable enough to approach the subject confidently. Once confident, they can produce the contagious enthusiasm that brings kids into activities and makes learning meaningful.

The fact that nature of science concepts are not explicitly addressed on the student examinations that are used to judge many teachers’ performance also prevents teachers from incorporating instruction related to nature of science concepts. However, teachers should realize that just because something is not tested or tangible does not mean that it is meaningless. Try to convince someone who has just fallen in love that the abstract means nothing.

Matthews (1998) provides words that could alleviate the fears of those who are interested but reluctant to incorporate history into their instruction:

> It is unrealistic to expect students or . . . teachers to become competent historians, sociologists, or philosophers of science. We should have limited aims in introducing epistemology and nature of science questions in the classroom: a

> more complex understanding of science, not a total or even a very complex understanding (p. 168).

Incorporating science history into instruction does not require an obsessively detailed understanding of all aspects of a certain idea to use its historical development to teach nature of science concepts. A quick internet search, a trip to the library or the bookstore, and a few hours of reading could transform a unit from hum-drum same-old to thought-provoking, effective, and meaningful. Kauffman (1989) explains, "Even though they may not be included on tests, well-chosen and pertinent items of history, thoughtfully introduced into our science courses will . . . often be remembered by students long after they have forgotten the technical details" (p. 84).

Bronowski (1965) provides a compelling statement that can be directly applied to incorporating the history of science into instruction when he states:

> The great poem and the deep theorem are new to every reader, and yet are his own experiences, because he himself re-creates them. They are the marks of unity in variety; and in the instant when the mind seizes this for itself, in art or in science, the heart misses a beat (p. 20).

Guiding students through the development of ideas can help them recreate them and experience the thrill of understanding. Once they feel what it is like to create ideas and know that they can comprehend such things, they will want to experience the thrill again and again. This will lead to feelings of self-efficacy and a desire to continue to learn science. Thus, science history can be a powerful tool in helping students become science literate, life-long learners.

In sum, although the size and scope of the study were not large, the investigation has provided some evidence that incorporating science history into "normal" science instruction helps students develop an understanding of nature of science concepts without detracting from content knowledge acquisition. Interventions that help teach nature of science concepts are important, as they can help students move a few steps closer to being science literate, personally fulfilled, and contributing members of society.

References

Abd-El-Khalick, F. S. (1999). Teaching science with history: Using Mars and Saturn to teach about the relationship between theory and observation. *The Science Teacher, 66*(9), 18-22.

Abd-El-Khalick, F. S., & Ledernam, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching, 37*(10), 1057-1095.

American Association for the Advancement of Science [AAAS]: Project 2061. (1990). *Science for all Americans*. New York: Oxford University Press.

Bateson, D. J. (1990). Science achievement in semester and all-year courses. *Journal of Research in Science Teaching, 27*(3), 233-240.

Bronowski, J. (1965). *Science and human values (Revised Ed.)*. New York: Harper & Row.

Bybee, R. W., Powell, J. C., Ellis, J. D., Giese, J. R., Parisi, L., & Singleton, L. (1991). Integrating the history and nature of science and technology into the science and social studies curriculum. *Science Education, 75*(1), 143-155.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582-601.

Eflin, J. T., Glennan, S., & Reisch, G. (1999). The nature of science: A perspective from the philosophy of science. *Journal of Research in Science Teaching, 36*(1), 107-116.

House, E. R. (1991). Realism in research. *Educational Researcher, 20*(6), 2-9; 25.

Huybrechts, J. M. (2000). Integrating the history of science into a middle school science curriculum. *Dissertation Abstracts International, 61*(01A), 127.

Irwin, A. R. (2000). Historical case studies: Teaching the nature of science in context. *Science Education, 84*, 5-26.

Kauffman, G. B. (1989). History in the chemistry curriculum. *Interchange, 20*(2), 81-94.

Klopfer, L. E., Cooley, W. W. (1961). *Use of case histories in the development of student understanding of science and scientists.* Cambridge, MA: Harvard University Graduate School of Education.

Klopfer, L. E., Cooley, W. W. (1963). The *history of science cases for high schools* in the development of student understanding of science and scientists: A report on the HOSC Instruction Project. *Journal of Research in Science Teaching, 1*, 33-47.

Kuhn, T. S. (1996/1962). *The structure of scientific revolutions* (3rd Ed.). Chicago: University of Chicago Press.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84*, 71-94.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331-359.

Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science.* New York: Routledge.

Matthews, M. R. (1998). In defense of modest goals when teaching about the nature of science. *Journal of Research in Science Teaching, 35*(2), 161-174.

Mayr, E. (1988). *Toward a new philosophy of biology: Observations of an evolutionist.* Cambridge, MA: Harvard University Press.

Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education, 81*(4), 405-424.

National Research Council (NRC). (1996). *National science education standards*. Washington, DC: National Academy Press.

Pekarek, R., Krockover, G. H., & Shepardson, D. P. (1996). The research-practice gap in science education. *Journal of Research in Science Teaching, 33*(2), 111-113.

Pella, M. O., O'Hearn, G. T., & Gale, C. W. (1966). Referents to science literacy. *Journal of Research in Science Teaching, 4*, 199-208.

Ramsey, G. A., & Howe, R. W. (1969). An analysis of research on instructional procedures in secondary school science. *The Science Teacher, 36*(4), 62-70.

Ray, C. (1991). Breaking free from dogma: Philosophical prejudice in science education. *Science Education, 75*(1), 87-93.

Roach, L. E. (1993). Use of the history of science in a nonscience majors course: Does it affect students' understanding of the nature of science?. *Dissertations Abstracts International, 55*(03A), 0525.

Rubba, P. A. (1977). Nature of scientific knowledge scale: Test and user's manual. East Lansing, MI: National Center for Research on Teacher Learning. (ERIC Document Reproduction Service No. ED 146 225).

Rubba, P. A., & Andersen, H. O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. *Science Education, 62*(4), 449-458.

Schwab, J. J. (1962). The concept of a structure of a discipline. *The Educational Record, 43*(3), 197-205.

Social Studies Education Consortium [SSES], & Biological Sciences Curriculum Study [BSCS]. (1994). *Teaching about the history and nature of science and technology: Teacher resource edition (Field Test Ed.)*. Boulder, CO: SSEC.

Solomon, J., Duveen, J., & Scot, L. (1992). Teaching about the nature of science through history. *Journal of Research in Science Teaching, 29*(4), 409-421.

Thompson, Bruce. (Winter 2002). "Statistical," "practical," and "clinical": How many kinds of significance do counselors need to consider?. *Journal of Counseling and Development*, 80, 64-71.

Winchester, I. (1989). Editorial – History, science, and science teaching. *Interchange, 20*(2), i-vi.

Wolfsberg, T. G., McEntyre, J., & Schuler, G. D. (2001). Guide to the draft human genome. Nature, 409(6822), 824-826. (Cited in Appendix)

Yager, R. E., & Wick, J. W. (1966). Three emphases in teaching biology – A statistical comparison of results. *Journal of Research in Science Teaching, 4*, 16-20.

About the authors…

Justin Lonsbury graduated with a Bachelor's degree from the University of Kansas in 1998 and completed his Master's degree at the same university in 2001. Currently, he is teaching at Chamblee Charter High School in Chamblee, GA.

James D. Ellis is an Associate Professor in the Department of Teaching and Leadership at The University of Kansasin Lawrence.

Appendix

Genetics Unit Exam

Directions – Read each question carefully and circle the letter of the best answer. There is only one correct answer per question. If you are unsure of the correct answer, guess. All questions have the same point value.

1. Which of the following statements best describes the function of DNA?
  a. DNA transforms solar energy into chemical energy.
  b. DNA puts the energy stored in glucose into small energy packets called ATP.
  c. DNA transports substances from one side of the cell membrane to the other.
  d. DNA contains the genetic information that runs the cell.
  e. DNA digests molecules that the cell no longer needs.

2. In eukaryotic cells, why is it necessary for the nucleus to contain the DNA?
  a. The nucleus produces many enzymes that break down and synthesize DNA.
  b. The nucleus contains ATP required for DNA construction and breakdown.
  c. The nucleus prevents mRNA molecules from entering the cytosol.
  d. The nucleus protects the DNA and allows for controlled modification of RNA.
  e. The nucleus prevents the cell from dividing too early in the cell cycle.

3. What is the name for the structure that is made up of a DNA molecule and its associated proteins?
  a. Centriole
  b. Spindle Fiber
  c. Chromosome
  d. Centromere
  e. Membrane

4. Which of the following causes different pieces of DNA to do different things?
  a. The carbon-carbon bonds of DNA's sugar molecules.
  b. The sequence of nucleotides in DNA.
  c. The phosphate bonds in DNA.
  d. The helical structure of the DNA molecule.
  e. The size of the proteins associated with DNA.

5. Which of the following structures is a small length of DNA that determines a specific sequence of amino acids?
  a. Chromosome
  b. Centriole
  c. Spindle Fiber
  d. Gene
  e. RNA

6. Changing the structure of tRNA would probably result in which of the following?

a. The DNA transcript would not be accurate.
b. Replication of DNA would not be as accurate.
c. The mRNA would not be read correctly.
d. The DNA would be broken apart.
e. The ribosome would change shape.

7. Changing the structure of mRNA would probably result in which of the following?

a. The DNA transcript would not be accurate.
b. Replication of DNA would not be as accurate.
c. The mRNA would not be read correctly.
d. The DNA would be broken apart.
e. The ribosome would change shape.

8. What is the order of steps in the construction of protein from DNA?

a. DNA – Translation – mRNA – Transcription – rRNA – Protein
b. DNA – Transcription – rRNA – Translation – mDNA – Protein
c. DNA – Translation – tRNA – Transcription – mRNA – Protein
d. DNA – Transcription – mRNA – Translation – tRNA – Protein
e. DNA – Translation – rRNA – Transcription – tRNA – Protein

9. Which of the following types of reactions puts together the growing polypeptide chain?

a. Hydrolysis
b. Rearrangement
c. Dehydration synthesis
d. Electron transfer
e. Functional group transfer

10. Which of the following figures comes closest to the number of genes in a typical human cell? **** This question is invalid, as "recent estimates have placed the number of human genes at 25,000 – 35,000" (Wolfsberg, McEntyre, & Schuler, 2001, p. 824).*

a. 1000
b. 10,000
c. 100,000
d. 1,000,000
e. 1,000,000,000

11. Which of the following is a consequence of controlled gene expression?

a. Cells are not able to adapt to their environment.
b. Cells in developing multi-cellular organisms differentiate.
c. Cells can undergo aerobic respiration in the absence of oxygen.
d. Cellular variety within a population of organisms increases.
e. Cells are unable to reach equilibrium or maintain homeostasis.

12. Which of the statements below explains why gene expression is controlled?

a. Gene expression is controlled so that cells can regulate the production of specific proteins.
b. Gene expression is controlled so that cells can speed up the production of all proteins.
c. Gene expression is controlled so that cells can speed up the production of specific proteins.
d. Gene expression is controlled so that cells can slow down the production of all proteins.
e. Gene expression is controlled so that cells can slow down the production of specific proteins.

13. Why do X-rays, UV rays, and chemical carcinogens cause cancer?

a. These types of light or chemicals have so much energy that molecules move too fast, causing tumor production instead of normal cell division.
b. These types of light and chemicals change the structure of the DNA within genes that are involved in cell division, causing tumor production.
c. These types of light and chemicals stop cell division before the cytoplasm divides, causing the formation of very large cells called tumors.
d. These types of light and chemicals alter the DNA so that the only types of proteins that are made are tumor-producing proteins.

14. Which of the choices below would bond to this single-stranded piece of DNA, making it double-stranded: 5'-ATTTCGCGTACCGATAGCGGCAG –3'?

a. 3'– TAAACGCGATCCGTATGCGGCTG –5'
b. 3'– ATTTGCGCATGGCATACGCCGAC –5'
c. 3'– TAAAGCGCATGGCTATCGCCGTC –5'
d. 3'– CGGGATATGCAATCGCTATTACA –5'
e. 3'– GCCCTATACGTTAGCGATAATGT –5'

15. Which of the following types of biomolecules controls DNA replication?

a. Carbohydrates
b. Lipids
c. Fatty acids
d. Enzymes
e. Amino acids

16. Why are crossing over and the random alignment of homologues in meiosis important to a population's survival?

a. They keep reproductive cells exactly the same as the parent cells.
b. They make sure all organisms get the right number and type of chromosomes.
c. The mix up the genes of the parents and add variety to the gene pool.
d. They make sure that somatic cells are exact copies of their parents.
e. They prevent mutations in the DNA from being passed to offspring.

17. Which of the following statements accurately describes DNA replication?

a. Old DNA strands are broken into pieces and then put back together to produce new molecules of DNA.
b. Each new molecule of DNA is produced by randomly assembling pieces of old DNA strands.
c. Each strand of both of the new DNA molecules has pieces of the old DNA mixed in with new DNA.
d. One molecule of DNA consists only of the old DNA strands while the other has entirely new DNA strands.
e. Both new DNA molecules have one of the old DNA strands and one of the new DNA strands.

18. The behavior of chromosomes in meiosis explains which of the following?

a. The production of proteins using different types of RNA molecules.
b. The mechanism by which more copies of DNA are made.
c. The difference between autosomal dominant and autosomal recessive traits.
d. Incomplete dominance and codominant relationships among alleles.
e. Mendel's laws of segregation and independent assortment

The following chart shows the dominant and recessive forms of traits common in Mendel's pea plants. Use the information in this chart to answer questions 19-23.

Trait	Dominant Form of the Trait	Recessive Form of the Trait
Seed Shape	round	wrinkled
Seed Color	yellow	green
Pod Color	green	yellow
Pod Shape	inflated	constricted
Height	tall	short

19. What is the probability that the self-fertilization of two plants heterozygous for seed color will produce offspring with green seeds?

a. 0/4
b. 1/4
c. 2/4
d. 3/4
e. 4/4
f. It's impossible to tell with the information provided.

20. A true-breeding tall plant is crossed with a plant heterozygous for the height trait. What is the probability that the offspring will be tall?

a. 0/4
b. 1/4
c. 2/4
d. 3/4
e. 4/4
f. It's impossible to tell with the information provided.

21. What is the probability that a cross between a plant with wrinkled seeds and a heterozygous plant with round seeds will produce offspring with wrinkled seeds?

a. 0/4
b. 1/4
c. 2/4
d. 3/4
e. 4/4
f. It's impossible to tell with the information provided.

22. What is the probability that a cross between a plant with inflated pods and a plant with constricted pods will produce offspring with inflated pods?

a. 0/4
b. 1/4
c. 2/4
d. 3/4
e. 4/4
f. It's impossible to tell with the information provided.

23. A pea plant has a green seedpod but the genotype is unknown. You run a testcross and discover that the phenotypic ratio of green to yellow seedpods is 4:0. Which of the following describes the unknown genotype?

a. Homozygous dominant
b. Heterozygous
c. Homozygous recessive
d. Sex-linked
e. It's impossible to tell with the information provided.

24. Homozygous dominant snapdragons are red, heterozygotes are pink, and homozygous recessive individuals are white. What type of relationship is shown between the alleles in this example?

a. Complete dominance
b. Incomplete dominance
c. Codominance
d. Pleiotropy
e. Epistasis

25. When A and B blood type alleles are present, both are expressed. This is an example of which type of relationship between alleles?

a. Complete dominance
b. Incomplete dominance
c. Codominance
d. Recessive lethal
e. Epistasis

26. If a trait is determined by the interaction of several genes, how many different phenotypes will be present?

a. Two different phenotypes will be present, both being expressed with about the same frequency.
b. Two different phenotypes will be present, with one being expressed a lot more often than the other.
c. Many different phenotypes will be present, with the frequency of phenotypes making a bell curve.
d. Many different phenotypes will be present, with the most individuals showing the extreme phenotypes.
e. A single phenotype will be present.

27. Which of the following statements best summarizes Mendel's law of segregation.

a. Pairs of alleles stay together when reproductive cells are produced.
b. Pairs of alleles become separated when reproductive cells are produced.
c. Inheritance of a given pair of alleles is not related to the inheritance of other pairs of alleles.
d. Inheritance of a given pair of alleles depends on to the inheritance of other pairs of alleles.
e. Dominant and recessive alleles are never inherited together.

28. Which of the following statements best summarizes Mendel's law of independent assortment?

a. Pairs of alleles stay together when reproductive cells are produced.
b. Pairs of alleles become separated when reproductive cells are produced.
c. Inheritance of a given pair of alleles is not related to the inheritance of other pairs of alleles.
d. Inheritance of a given pair of alleles depends on to the inheritance of other pairs of alleles.
e. Dominant and recessive alleles are never inherited together.

29. Of the 46 chromosomes found in a human body cell, how many are autosomal?

a. 1
b. 2
c. 23
d. 44
e. 45

30. Cystic fibrosis skips generations, may be carried without being expressed, and is equally likely in males and females. This disease follows which of the following patterns of inheritance.

a. Autosomal dominant
b. Autosomal recessive
c. X-linked dominant
d. X-linked recessive

31. Huntington's disease rarely skips generations, is always present in an individual that carries the gene, and can be transmitted from a male to a male. This disease follows which of the following patterns of inheritance.

a. Autosomal dominant
b. Autosomal recessive
c. X-linked dominant
d. X-linked recessive

32. Color blindness is more common in males than females and cannot be passed from a male to a male. This disease follows which of the following patterns of inheritance.

a. Autosomal dominant
b. Autosomal recessive
c. X-linked dominant
d. X-linked recessive

33. Hypophosphatemia may or may not be passed from a female with the trait to her offspring, never passes from a male to a male, and is always passed from a male with the trait to his daughters. This disease follows which of the following patterns of inheritance.

a. Autosomal dominant
b. Autosomal recessive
c. X-linked dominant
d. X-linked recessive

34. Which type of mutation would have the smallest effect on the protein?

a. Base pair insertion mutation
b. Base pair deletion mutation
c. Chain-termination mutation
d. Base pair substitution mutation
e. Frameshift mutation

35. Why are mutations important to a population's survival?

a. Remove the weaker members of the species
b. Prevent unwanted variations from becoming dominant
c. Increase the amount of variety within the population
d. Keep organisms with abnormal DNA from reproducing
e. Lower the amount of competition within the population

36. Why do some bacteria reduce the accuracy of DNA replication when they are under severe environmental stress?

a. Decreasing the accuracy of DNA replication requires less energy.
b. Decreasing the accuracy of DNA replication increases the rate of mutation.
c. Decreasing the accuracy of DNA replication speeds up protein production.
d. Decreasing the accuracy of DNA replication helps to establish equilibrium.
e. Decreasing the accuracy of DNA replication prevents cell division.

37. Of the following characteristics an organism might possess, which one can be passed to the next generation?

a. Mutated reproductive cells.
b. An amputated arm.
c. Pancreatic cancer.
d. A suntan.
e. Well-developed muscles.