Genetics Concepts Inventory

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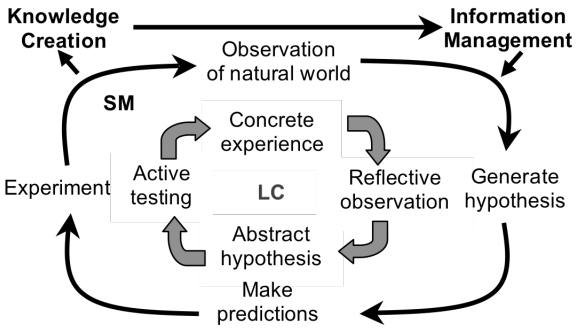
Project Rationale

A genetics concept inventory is being created as a tool to measure students understanding (or misunderstanding) in different learning environments. In particular, it is being developed as one of several assessment strategies for evaluating literature-based case study (LBCS) approach. Case studies will use the primary literature to focus student learning on the fundamental concepts of genetics in the context of scientific discovery. Students will learn genetic concepts through deliberate engagement in the learning cycle and the process of scientific inquiry, i.e., "*scientific learning.*" Thus, a pedagogical model based on constructivist learning will be employed to create the literature-based case studies and associated learning materials.

The figure below provides an overview of Kolb's Learning Cycle (1), which is foundational to constructivist learning theory. This cycle combines experience, perception, cognition and behavior. The cycle (Learning Cycle, LC; inner grey arrows in figure) begins with the learner experiencing something new (concrete experience) then beginning to search for meaning (reflective observation). Learners next formulate questions and predictions about the experience (abstract hypotheses) then seek answers to their questions (active testing). Zull (2) describes how the learning cycle is linked to recent studies in neurobiology. Thus, the learning cycle has a direct link to brain function, i.e., learning happens as an individual moves iteratively through this cycle.



Coincidentally, the scientific method has four phases that mirror the learning cycle (Scientific Method, SM; black outer arrows in figure); they both involve observation or sensing, knowledge identification and integration, and action (prediction and testing). Also, both require inputs of information that must be managed and organized in the process of creating new knowledge. In science, the iterative process of scientific research culminates in the generation of theories that become part of the published literature. Thus, it makes sense that students in science classes should be more deliberately engaged in the learning cycle to enhance learning and to improve and internalize their understanding of the scientific process. Handelsman *et al.* reiterate the call for science education reform stating the need for "engaging students in discovery and scientific process improves learning and knowledge retention" (3). Physics education researchers have led the charge and developed several successful methods known collectively as "interactive engagement" (4); in physics classes that are more active (i.e., in a studio or workshop format where lecture and hands-on laboratory work are combined), students show significant increases in conceptual understanding (5, 6).

Genetics Concept Inventory Development

The genetics concept inventory (GCI) is one tool being employed for assessing student learning gains in LBCS vs. non-LBCS BIO 351 (Principles of Genetics) classes. The GCI is modeled after the physics Force Concept Inventory, which has been an effective tool for evaluating the conceptual learning gains in more active learning environments (7). A pilot GCI was constructed based on:

1) case study content and learning outcomes,
2) published misconceptions/misunderstandings of genetics and
3) misconceptions/misunderstandings of genetics as determined from an open-ended, written exam given to Cal Poly students.

The primary published documentation of student misconceptions/misunderstandings in genetics is regarding common 9th grade or high school student understanding (8-15). However, this body of information is useful because student understanding may not change much between high school and college. Besides being useful for the development of this assessment tool, I also thought it would be interesting to test the hypothesis that student understanding of basic genetic concepts doesn't change much from high school to college. Collectively, these papers document that young learners commonly:

1) state that DNA and chromosomes are made of protein or that DNA is composed of genes,
2) are confused over the difference between chromosomes and chromatids and don't correlate alleles with chromatids,
3) think that cells contain only the genetic material they need to carry out their functions or that only gametes contain chromosomes, and
4) are unclear on the concept of an allele,
5) state that a gene is a trait or that DNA produces proteins.

However, one study has been published on college student understanding. Fisher (16) found that 50-75% of introductory biology and genetics students at a major research university could not correctly identify proteins as the product of translation; the majority of wrong answers were either "amino acids" or "messenger RNA."

During spring quarter 2005, an open-ended, short-answer test was given to upper division Cal Poly biology students and future science teachers (n=44). This test was primarily constructed using basic genetics concepts being used to develop case studies (Appendix A) in addition to the published literature (above). The written test was comprised of eight questions and also asked students to draw a concept map using 20 key genetics terms (Appendix B). Anonymity was maintained by assigning each student an identification number. The exam was administered during regular class time and students were given one hour to complete the exam. The exam was given as part of an assignment.

Taking these results into consideration, along with the published literature, an selected response GCI was developed that consisted of 38 questions: 36 multiple answer/choice, true-false, fill-in-blank, matching and 2 short answer questions. Questions relevant to this discussion are shown in Appendix C. It was piloted in BIO 351 (Principles of Genetics) during spring 2006 in which the LBCS approach was used for half of the 10-week quarter. Students in this class were predominately junior-level biology, biochemistry, microbiology majors. It was deployed using the Blackboard course management system. Students taking both tests signed human subjects research consent forms as well.

Preliminary Results

Results from the open-ended, written exam were interesting in two ways. First, the results provided a glimpse into the language that students use to articulate their genetic understandings. A big part of genetics (and biology, in general) is gaining a working knowledge of the language. Without this, students can't participate in the discourse of the discipline or move into more complex understanding levels. For example, when asked "what is an allele?" some students defined as "half the information of a trait." Additionally, the results provided insight into students' conceptual understanding. For example, very few students could properly draw a diploid cell with 4 chromosomes containing two different alleles of a gene.

During the first week of class, 49 students took the objective GCI test. The results of the pre-test and post-test are shown in Table 1.

Test	**Average**	**Std Dev**	**High/Low**
Pre-test	50% (38.3/76 points)	11	63.75/16
Post-test	65% (49.3/76 points)	9	68/25.25

Table 2 shows the results for the questions that were answered with greater than 70% correct answers. These are concept areas where a solid majority of students demonstrated understanding. There were 11 questions in this category (29% of questions) and these questions tended to be about reproductive genetic concepts.

Table 2. Questions answered with a high degree of correctness (greater than 70% correct):

Q #	***Question Content***	***Pre %***	***Post %***
27	Number of chromosomes found in sperm compared to egg	96	100
37	Physical constitution of an organism is called a phenotype	94	100
24	Similarity of genetic information in mother and daughter cell after cell division	86	94
3	Results of DNA replication	84	90
11	Chromosomes that determine sex in mammals	84	91
7	Cell types in body where genes are found	82	84
23	Number of chromosomes present in a cell after cell division	80	88
25	Number of chromosomes in egg cell produced from an ovary cell	76	72
21	Fertilization or meiosis, as they happen in animals, also happens in plants	74	81
28	Number of chromosomes found in embryo given number of chromosomes in egg	73.5	75
10	Where chromosomes are located within eukaryotic cells	71	91

Table 3 shows the results for the questions that were answered with a moderate degree of correctness, based on the pre-test ranges. These are concept areas where 48-70% of the students demonstrated understanding. There were 8 questions (21% of questions) in this category.

Table 3. Questions answered with moderate degree of correctness (pre-test between 48-70%)

Q #	***Question Content***	***Pre %***	***Post %***
22	Process by which bacterial cells divide	63	63
12	What each line of an X illustration of a chromosome represents	61	88
35	Products of transcription are RNA molecules	59	88
6	Composition of genes	51	75
13	Sets of homologous chromosomes found in a diploid cell, given chromosome number	49	59
20	Process by which a zygote is formed	49	63
26	Relationship of genetic information in egg and ovary cell after oogenesis	49	50

Table 4 shows the results for the questions that were answered with a low degree of correctness, again based on the pre-test ranges. These are concept areas where less than half of the students demonstrated understanding. There were 18 questions (<48% of questions) in this category. Not all questions in this category are shown; those not shown were not very well constructed and thus difficult to analyze.

Table 4. Questions answered with low degree of correctness (pre-test less than 48%)

Q #	***Question Content***	***Pre %***	***Post %***
2	Template strands for DNA synthesis	47	53
36	Location of transcription in eukaryotic cells	45	78
14	Nature of homologous chromosomes	43	59
31	Nature of genetic recombination	42	75
1	Composition of DNA	41	81
15	Nature of linked genes	37	66
34	Products of translation are proteins	37	75
33	Nature of the genetic code	35	47
5	Cellular structure that contain DNA	33	31
16	Nature of allele	31	81
9	Composition of chromosomes	31	52
38	Identification of drawing with two alleles on chromosomes within a diploid cell	30	43
4	Where DNA is found in animal cells	24	35
29	Cell types that contain genetic information for eye color	20	52

The concept areas in Tables 3 and 4 tend toward the more abstract as well as the molecular.

Discussion

It is useful to examine student responses in detail in order to better understand the results. Below is a preliminary analysis of some of the questions from this pilot exam. In the following tables and analysis, percentages are shown for the most common or relevant answers.

Question #4 reveals perhaps a bias of instruction toward the nucleus as the holder of all genetic information. Even after the genetics course, only 35% of students recognized that the mitochondria within cells contain DNA. Interestingly, this question asked students to identify the structures within animal cells that contain DNA and a small percentage included the chloroplast in their answer. It will be interesting to see if these percentages are different in classes where a larger amount of class time is spent on organelle genetics.

Possible Answer	**Pre %**	**Post %**
Nucleus	41	32
Nucleus & mitochondria	24	35
Nucleus & mitochondria & chloroplast	12	10

Both questions #13 and #14 deal with the nature of homologous chromosomes and both show pre-test percentages just below half that move to only around 60% at the end of the course. The nature of homologous chromosomes (as well as chromatids) is critical for students to understand.

Question #26 deals with the results of meiosis during gametogenesis. It is interesting that students are essentially split between answering that the genetic information in the ovary cell that produces an egg cell is the same or different. Perhaps students are confused with the intent of the

question, i.e., an egg cell is an ovary cell. Perhaps they truly are confused about the relationship between the genetic information in these two different cell types. An interesting contrast to these results are those from #25: greater than 70% of students accurately answer that an egg has half the chromosomes as an ovary cell. Interviews with students will hopefully shed some light on the reasons for their incongruous answers. And, better developed statistical tools (beyond those available in Blackboard) will allow correlations between pre- and post-test answers. For example, it would be nice to know whether the students who still think that eggs contain the same genetic information as ovary cells are the same students who cannot correctly identify the number of chromosomes in a egg cell (question #25).

Question #29 is interesting as it relates to whether or not students understand that all cell types contain the same genetic information, a misconception identified from the 9th grade/high school research. Below is a breakdown of some of the possible answers for this question:

Possible Answer	Pre %	Post %
All	20	52
Eye & gamete	12	0
Gamete	55	32

It appears that a significant number of college juniors maintain this idea. Even by the end of the term, a large number of students (32%) still think that gametes are the only cell type that contains genetic information for eye color. Interestingly, responses to question #7 offer a contradiction: over 80% of students correctly identify that various cell types contain genes at the beginning and end of the term. Many of the same cell types were listed as possibilities in both questions. Student interviews will be required to tease out this misunderstanding or misconception. Again, better developed statistical tools will allow correlations between pre- and post-test answers. Here, it would be nice to know whether the students making up the 32% who still think that gametes are the only cell type to contain eye color genes are the same students who are confused regarding which cell types contain genes (question #7).

Question #34, the products of translation, deserves some attention in this report due to previously published misconceptions of college students by Fisher (21) as well as the responses to its parallel question on transcription, #35. A breakdown of responses to possible answers are shown below:

Possible Answer	Pre %	Post %
Proteins	37	75
mRNAs	33	9
Amino acids	18	0
DNA	8	3

One possible explanation for the high level of mRNA responses is that students are mixing up the terms translation and transcription. Fisher (21) observed that nearly half of students responded with amino acids to a similar question. That isn't the case here: <20% give this response. Fisher's question was worded slightly differently and had "activating enzymes" instead of "proteins," which may contribute to the observed difference. Alternatively, perhaps instruction has changed over the past decades to clear up the misconception originally described. It may also be that students really don't know what happens in translation.

The breakdown of possible responses to question #35, the products of transcription, are shown below.

Possible Answer	Pre %	Post %
mRNA	59	88
Protein	18	9
DNA	14	3
Amino acids	6	0

While students generally have the right idea, especially at the end of the term, the prevalence of "protein" as an answer in the pre-test begs the question of whether they are mixing up the word transcription with the word translation. Whatever the cause, significant shifts in understanding the general outcomes of translation and transcription were reached by the end of the term. Student interviews on this topic, including the origin of amino acids (as in Fisher) will be instructive. Given that students generally take genetics before biochemistry, they may be unclear on metabolic pathways, including those involved in amino acid production. Finally, perhaps adding a question that asks students to identify which cellular process gives rise to amino acids would also be useful.

One of the essay questions asked students to complete the phrase, "One gene encodes…" in a short answer format. The answers students gave with the corresponding percentages are shown in the table below.

Possible Answer	Pre %	Post %
A trait or characteristic	43	10
Many traits	10	6
One enzyme	0	10
One protein or polypeptide	19	30
Many proteins	0	23
A transcriptional unit…	0	20
Other	28	1

Other responses were unique, such as "2 alleles" or "other different genes" or "a phenotype or genotype" or "one ssRNA" or nonsensical, like "another." Overall, the responses to this question reveal that student thinking became more complex over the course of the term; before the class, they were more likely to say that a gene encoded a trait or a protein and after class, they were less likely to say that a gene encoded a trait and more likely to say that a gene encoded many proteins or a transcriptional unit that could produce many different products. However, it is disturbing that the percentage of students who still believe that one gene encodes one protein or polypeptide increased over the course of the quarter. Perhaps they are still holding on to the famous phrase "one gene, one enzyme." Do we use this phrase too much? Is it reinforced in textbooks? Interestingly, three responses in the post-test stated that a gene encodes many amino acids. This ties back to question #34 regarding students understanding of translation. Even though there were no students giving amino acids as the products of translation in #34 at the end of the quarter, a few revealed their lack of full understanding, or mental slippage, in this short answer question.

There were several questions that revealed significant conceptual gains in this preliminary instrument.

Question #	% gain from pre- to post-test
16	50
1	40
34	38
31	33
36	33
29	29

If the instrument is valid and reliable, then these gains are good news. In particular, the gains observed in #16 – the nature of an allele – are heartening because much of class time was devoted to this concept.

Challenges Encountered

Besides the statistical challenges with the development of these types of tests, it seems that the biggest challenge is identifying the "big ideas" or concepts to be included. Then, there is the issue of terminology. For example, if a student knows that transcription results in mRNAs, does that mean that they really understand transcription? If students know that an allele is a different form of a gene, do they really understand what different alleles mean for the functioning of an organism or the evolution of a population? Perhaps there are different levels, starting with the terminology then moving to more complex topics. Or, another way to think about it may be the structural versus functional aspects of biological systems. Terminology and structure are critical for students to understand in order to move to higher levels of understanding regarding function. Also, it seems that there is value in pairing questions to delve deeper into student understanding (e.g., #25 & 26; #7 & 29).

The term "misconception" also needs defining and refining in the biological realm. Misconceptions are deeply held incorrect ideas that are difficult for people to let go of even when faced with compelling evidence regarding the correct idea. They interfere with learning because they are so tightly held. In order for effective teaching to occur, these misconceptions must be identified. How many true misconceptions are there in biology? I suspect there are fewer true misconceptions than we might think. More common are misunderstandings or naïve ways of thinking. However, it is useful to identify these as well. It might be useful to employ a developmental framework to think about student's intellectual journey, such as Perry's learning hierarchy (17), to help us better understand what is really happening. For example, freshman are more likely to be dualistic thinkers where they see problems as black or white, yes or no, and to rely heavily on external sources to provide them with answers (textbooks, teachers, parents). As young learners mature, they move to more dialectic thinking where problems are seen as complex with no simple answers. Solutions require an intellectual struggle and students learn to rely more on their own abilities and knowledge. Given this scheme, we can ask whether an incorrect answer to a question is the result of naïve reasoning or a true misconception. For example, student statements that a "gene is a trait" or a "gene encodes a trait" aren't necessarily incorrect, they are just unsophisticated. They have some idea of what genes do, but lack the erudition to articulate a more complex answer. Students who answer with more finesse and nuance, e.g., "one gene encodes one transcriptional unit that can be spliced differentially into different mRNAs," have demonstrated more sophisticated understanding.

Another struggle I faced is how many questions to include in the test and how to deploy it. I used Blackboard because that is the course management system at my disposal. It does not adequately support this type of research. I had to export the test results to Excel then manipulate the spreadsheet manually. This took lots of time. Also, it would be useful to have a statistical tool that could correlate student answers. For example, I would like to more easily answer the question, "did all the students who answered incorrectly for #29 answer incorrectly for #7?" or to correlate pre- and post-test answers for individual students. This ability will be particularly critical if paired questions are used. Or, it would be interesting to correlate answers with gender, major or class level. Perhaps there is a tool available that I am unaware of (or maybe need to hire a consultant!). I believe that it is also best to make the test part of an assignment so students take it seriously. However, anecdotally, many students enjoyed seeing whether their performance on the test improved over the course of the term.

Future Plans

The development of this test is in the early phases and this analysis is **very** preliminary. I have redesigned the test to eliminate the multiple answer, fill-in-blank as well as the poorly written or seemingly confusing questions. Also, choices that were rarely or never chosen were also removed from the answer possibilities. I have mixed feelings about eliminating the multiple answer questions; they seem to reveal a level of discrimination and sophistication that cannot be revealed by forcing students into one choice. Additional questions will also be considered and further testing at other institutions and in other types of classes will be sought. For example, there are big concepts missing – e.g., dominance, variation, evolution, epigenetics. I plan to do some more open-ended testing on these concepts in order to tease out the nuances and subtleties of student language and understanding. The 9th grade/high school research did not extend into these areas, so doesn't help as a foundation in these areas.

The new version of the test will be given to both BIO 351 (Principles of Genetics) and introductory cell & molecular biology students during the 2007-8 academic year. Validity and reliability testing needs to be done on the items as well. In addition, interviews with students will be conducted to provide further insight into their answers. For example, the only way to understand the conundrum of #7 & 29 will be to talk to students.

After further development, the plan is to use it as a pre- and post-test in LBCS and non-LBCS classes as one method used to determine if there are differences in student understanding as a result of the LBCS method. The test will also be given at other types of institutions in order to control for Cal Poly-specific issues. I hope to also use the instrument in high school classes and with future K-12 teachers.

I believe the test will be useful to drive course content in addition to helping evaluate different learning environments. For example, some striking misconceptions/misunderstandings were revealed (e.g., a significant number of students do not understand that all cell types contain the genetic information for eye color). If the results remain consistent, genetics instructors should be made aware of them in order to adjust their course content. Certainly, the results will inform the development of literature-based case studies in genetics, which was the original impetus for the development of the instrument. Finally, it would be nice to have an instrument that could be used for longer term testing, e.g., senior level tests to determine whether students have retained the understanding they gained.

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Appendix A. Basic Genetic Concepts

(modified from references 8-15)

Genes:

Genes are the basic unit of biological inheritance; made of DNA; located on chromosomes

Genes may take on different forms, which are called alleles; alleles are composed of slightly different sequences of DNA and encode gene products of different sequence as determined by the changes in DNA; gene products from different alleles may have drastically or moderately different functions

DNA:

DNA is composed of deoxyribonucleotides (ACGT); RNA of ribonucleotides (ACGU); nucleotides are composed of a 5-carbon sugar, base, phosphate group

DNA is the primary information storage molecule within cells

DNA replication is semi-conservative

Gene Expression:

A single gene encodes a gene product that can be a protein or RNA molecule

Genes are units of DNA that code for products, such as proteins (polypeptides), that help determine traits within cells and organisms; enzymes are an example of one class of proteins; enzymes catalyze chemical reactions within cells; chemical reactions result in the production of molecules used for various cellular processes (e.g., amino acids used to make proteins); abnormal gene expression can lead to disease (e.g., cancer); one gene, one gene product (not enzyme, protein, polypeptide)

Central dogma (transcription and translation) describes how genetic information functions within the cells of an organism; transcription results in the production of RNA; translation results in the production of proteins

The genetic code refers to a triplet sequence of DNA that codes for a specific amino acid during protein synthesis; one codon specifies one amino acid in a polypeptide chain

Inside cells, different genes are expressed over the course of development, in different cell types and in response to environmental stimuli specifying type, shape and function

The physical composition of an organism is called the phenotype; genetic composition called the genotype

Most traits are determined by the action of many different genes, as well as the interaction of gene products with their environment; genes and the environment interact to determine phenotype

Alleles:

Allelic relationships can be complete dominance and recessive, incomplete dominance, semi-dominant, co-dominant; dominance means that trait is observed in the phenotype of a diploid organism regardless of the nature of the homologous allele; recessive means that trait is not observed in a diploid organism if the homologous allele is dominant

For a given gene, diploid organisms can be homozygous (same alleles) or heterozygous (different alleles)

Diploid organisms may contain only two different alleles for any given gene at a specified locus

Chromosomes:

All cells have chromosomes (all living organisms are made up of cells)

Biological inheritance information is located in the chromosomes, which are made of DNA and proteins and located in nucleus of eukaryotic cells

Mitochondria and chloroplasts contain their own DNA

Somatic cells of an organism carry the same number of chromosomes and the same inheritance information

Every somatic cell contains all the chromosomes of a particular organism and so carries the entire inheritance information of an organism; all the somatic cells of an organism carry the same inheritance information

There are two types of chromosomes, autosomal and sex (e.g., X and Y); all animal cells contain sex chromosomes; eggs of mammals contain a single X and sperm can contain either an X or a Y

Chromosomes in diploid organisms are grouped in pairs, which called homologous chromosomes; homologous chromosomes contain gene pairs, located in the same position on each homologue (locus)

Each homologous chromosome is inherited from one of the diploid organism's parents'; homologous chromosomes separate from one another during meiosis (Principle of Segregation); different chromosomes (and thus genes and alleles) will separate independently of one another during meiosis (Principle of Independent Assortment), however, genes (alleles) located close to one another on a chromosome are linked and more are likely to be

inherited together than those farther apart or on another chromosome; recombination disrupts linkage relationships

Reproduction:

Meiosis is the process by which genetic information is passed from generation to generation in sexually reproducing organisms; however, mitosis (asexual reproduction) is used by some organisms as a means of reproduction

Gametes carry half the chromosomes and, consequently half the inheritance information; the combination of alleles (or inheritance information) in each gamete is unique and different from the parents

A zygote is formed by the process of fertilization of two gametes in both plants and animals

Plants also use mitosis and meiosis for production of daughter cells and gametes, respectively; bacteria reproduce by a process known as fission which is different from mitosis as well as meiosis

Variation:

Mutations are heritable changes in the sequence of DNA; can involve single or a few DNA base pairs or large regions of chromosomes; spontaneous or environmental agents (chemicals, radiation)

Processes that cause individuals of a species to be genetically unique: recombination, independent assortment, and mutation

Cells contain mechanisms for repairing damage to DNA

Evolution:

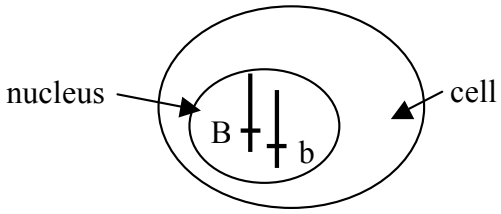
Genes and environment together are responsible for the variation between species; natural selection acts upon genetic variation within populations resulting in changes in gene frequencies, and thus evolution

Appendix B. Written Genetics Concept Test (Questions and Model Answers)

1. What is DNA and what does it do?
DNA is composed of deoxyribonucleotides and is the repository of genetic information in cells; it directs the synthesis of RNA and protein molecules that have cellular functions, like rRNA or enzymes, respectively.

2. What is a gene and what do genes do?
A gene is a nucleotide sequence in DNA that contains the code for specific RNA or protein molecules that have cellular functions, like rRNA or enzymes, respectively.

3. What is an allele? Draw 2 alleles for different eye color in a cell.
Genes can be in multiple forms that potentially give rise to different phenotypes (dominant, recessive); different alleles are found on homologous chromosomes; diploid organisms have sets of homologous chromosomes. B and b represent alleles of an eye color gene at a particular locus (represented by -) on homologous chromosomes in the nucleus of a cell.



4. What is a chromosome?
A chromosome is composed of DNA + protein and contains a linear order of genes that is generally constant and is located in the nucleus of eukaryotic cells and in the nucleoid region of bacteria.

5. How is genetic information passed from one generation to the next?
The process of *mitosis* occurs in somatic cells to give rise to daughter cells of the same type. The process of *meiosis* in reproductive organs generates gametes that have a haploid number of chromosomes that have been randomly separated and recombined. Mature gametes are produced during the process of gametogenesis. Haploid gametes come together in the process of fertilization to recreate a diploid organism.

6. How does genetic information function within a single organism? Where does genetic information exist within cells?
Genetic information is located in the nucleus of cells. Genes (on chromosomes within the nucleus) are transcribed in the nucleus and translated in the cytoplasm into functional products within each cell.

7. What makes individuals of a species unique (in their appearance, ability to respond to different environmental conditions)?
Individuals are genetically unique, meaning they contain genetic variation generated during recombination and chromosome assortment (and mutation) during the process of meiosis. So, each individual has a slightly different complement of genetic information. This may lead to different patterns of functionality (e.g., gene expression) under different circumstances ultimately leading to differences in appearance or responses to environmental conditions.

8. What role does genetic information play in evolution?
Genetic variation that exists in individuals within a population forms the foundation of a population's ability to survive and, ultimately, evolve. Natural selection (limiting food supply, changes in food supply, predation, etc) acts on that variation to alter allele frequencies as the population reproduces over time.

9. Draw a concept map using the following 20 terms. It is acceptable to use plural forms of words; words can be used more than once but try to avoid this:

Allele	Amino acid	Diploid
DNA	Protein	Cell
Gene	Enzyme	Organism
Meiosis	Trait	Transcription
Mitosis	Nucleotide	Translation
Chromosome	Gamete	Replication
mRNA	Haploid	

Appendix C. Pilot Selected Response Genetics Concept Test

Notes: Questions are multiple choice unless otherwise indicated: (MA) means multiple answer question, (FIB) means fill-in-blank question; bold answers are correct.

1. (MA) What is the chemical composition of DNA?

protein	traits	nucleus
nucleotides	cells	alleles
genes	amino acids	chromosomes

2. During DNA replication, what serves as the template for synthesis of a new strand?
   - one of the two strands of the double helix
   - **each of the two strands of the double helix correct**
   - random pieces of the both strands of the double helix

3. After DNA replication of a DNA double helix molecule, two DNA double helices result. Which of the following statements best describes the composition of the two resulting double helices?
   - Both strands in one of the two helices are new and both strands in the other helix are old
   - **In each of the two helices, one of the two strands is new**
   - Random pieces along each strand of both helices are newly synthesized

4. (MA) Where can DNA be found within animal cells?

nucleus	chloroplasts
ribosomes	endoplasmic reticulum
mitochondria	

5. Which of the following cellular structure(s) contains its own DNA?

ribosome	vacuole
endoplasmic reticulum	none of the above
chloroplast	

6. What are most genes made of?

protein	chromosomes	amino acids
RNA	alleles	nucleus
DNA	cells	

7. (MA) In which of the following cell types within your body are genes found?

brain	heart
blood	reproductive (e.g., gametes)
eye	**all of the above**

9. (MA) What are chromosomes are made of?

DNA	amino acids
Proteins	cells
RNA	nucleus

10. (MA) Where are chromosomes located within eukaryotic cells?

chromosomes	cytoplasm
nucleus	**mitochondria**
nucleolus	**chloroplasts**

11. Sex (in humans and other mammals) is determined by
    - genes on autosomal chromosomes
    - multiple pairs of chromosomes
    - **a single pair of chromosomes**

12. When chromosomes are drawn as an X structure, each of the lines in the X represent
    - homologous chromosomes
    - **identical sister chromatids**
    - non-homologous chromosomes
    - the X chromosome

13. If an organism is diploid, and has 16 chromosomes, how many sets of homologous chromosomes does it possess?

32	4
16	2
8	

14. Which of the following is true of homologous chromosomes?
They aren't usually the same size and shape
They are inherited from different parents
They do not pair during meiosis
They contain different set of genes
They contain identical DNA sequences

15. Linked genes
assort randomly
are allelic
co-segregate
segregate independently
none of the above

16. What is an allele?
part of a gene (e.g., half of a gene)
one of two genes in a diploid organism
an alternate form of a gene
a region of a chromosome where a gene is located
a chromatid or chromosome

20. A zygote is formed by which of the following processes?
Mitosis
Meiosis
Fertilization
Fission
Replication
Cloning
Splicing
None of the above

21. Does the same type of cell division, for a similar purpose as in the previous question, occur in plants?
yes
no
I'm not sure

22. Bacterial cells use which of the following processes to give rise to new generations? Mitosis
Meiosis
Fission
Fertilization
Splicing
None of the above

23. If a skin cell starts with 24 chromosomes, what number of chromosomes will it have at the end of cell division?
12
24
36
48

24. After cell division in skin cells, the genetic information present in the mother and daughter cell will be
the same
different
depends on the age of the organism

25. (FIB) If a human ovary cell contains 24 chromosomes, what number of chromosomes will be present in an egg cell that is produced from it? **12**

26. After oogenesis, the genetic information present in an egg and an ovary cell will be
the same
different
depends on the age of the organism

27. If there are 6 chromosomes in an egg cell, how many chromosomes are in a sperm cell for this organism?
fewer than the egg
the same number as the egg
more than the egg

28. (FIB) If there are 6 chromosomes in an egg cell, how many chromosomes will be present in the cells of an embryo derived from this egg? **12**

29. (MA) Which of the following cell types contain genetic information for the eye color of an organism?
brain
blood
eye
heart
gamete

31. Genetic recombination refers to
relationship between genes on the same chromosome
independent assortment of alleles during meiosis
the process of mutation
co-segregation of genes during meiosis

splicing of RNA molecules
sorting of alleles into new combinations
relationship between alleles of a gene

33. What is meant by the 'genetic code'?
the differences in DNA that make individuals unique
the specific sequence of DNA that codes for an amino acid
the order of DNA bases within an individual
the order of RNA bases that code for a protein

34. Which of the following molecules are the products of translation?

DNA	**proteins**
amino acids	cells
messenger RNAs	chromosomes

35. Which of the following molecules are the products of transcription?

DNA	proteins
amino acids	cells
messenger RNAs	chromosomes

36. In eukaryotic cells where does transcription occur?

Ribosomes	**Nucleus**
Cytoplasm	Vacuole

37. What is the term for the physical constitution of an organism?

Genotype	Character type
Dominant trait	**Phenotype**

38. (FIB/MA) Below are several drawings of chromosomes and alleles inside a cell. Which correctly illustrate two different alleles for an eye color gene in a diploid organism with 4 chromosomes (2n=4)? (Squared answers are correct)