Biocore Genetics Assessment Study
Summary Report

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Abstract
This report summarizes a study on genetics education in the Biology Core Curriculum (Biocore) funded by the Provost's Office University Assessment Grant. The general goal of this study was to assess learning of genetics in association with demographic attributes, attitudes and behaviors for students enrolled in Biocore and a non-Biocore curriculum progression (Biology 151/152 and Genetics 466). Guided by the UW Essential Learning Outcomes as the principle framework for the study, we used a cross-sectional, quantitative assessment design. During the 2009-2010 academic year, we administered a 22-item pre- and post-test survey of student performance, the Genetics Concept Assessment (GCA), and a 27-item Attitude and Behavior Survey (ABS) to 1629 students enrolled in Biocore 301, 303, 333 and Biology 151, 152 and Genetics 466. Following analysis of survey data, our results indicate that: 1) Biocore and 151/152→466 course progressions are equivalent in genetics education, 2) males score higher than females on the GCA, regardless of course progression, 3) AP Biology provides good preparation for introductory genetics coursework, 4) students' perception of competition in the classroom is associated with poor academic performance on the GCA, 5) students generally believe chemistry and math coursework is useful, but that physics and mathematics is less useful in their learning of biology, and 6) that Biocore students feel confident and very well prepared with essential intellectual and practical skills upon completion of Biocore coursework. Based on our findings, we propose to continue this work, to include both quantitative and qualitative assessment strategies in an introductory biology cross-curriculum assessment study to better inform instruction, curricular goals, and improve student learning.

This study was done in partnership with and the help of:
Biology 151/152: Jean Heitz, Cynthia Giffen, Kerry Martin, Brian Parks ; Genetics 466 Instructors: Allen Laughon, Chris Day, Qiang Yang; Biocore Instructors: Janet Branchaw, Evelyn Howell, Jeff Hardin, Amy Moser, Phillip Simon; ICBE director: Teri Balser

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Introduction

This report summarizes a study on genetics education in the Biology Core Curriculum (Biocore) funded by the Provost's Office University Assessment Grant. The general goal of this study is to assess student-learning gains of fundamental genetics concepts through the Biocore sequence. As part of this study, we report learning gains among students in Biocore relative to students enrolled in a non-Biocore sequence (Biology 151/152 and Genetic 466) understanding that most bioscience majors at UW-Madison consider these two course sequence progressions equivalent in terms of genetics instruction.

Biocore is a cross-college honors program intended to immerse students in foundation and emerging concepts of biology with an emphasis on scientific discovery. Biocore students receive honors credit for four semesters of introductory to intermediate level coursework, 4 lecture and 3 lab courses, progressing at a faster pace and higher expectations than comparable courses. Admission to Biocore is competitive, with students beginning the first semester of Biocore in the fall of their sophomore year. Students move through four semesters of coursework in the sequence as a cohort of 120-150 students.

Biocore is distinguished from other introductory biology course sequences (Biology 151/152; Zoology 101/102 and Botany 130) by its 1.) its two-year structure, 2.) high expectations of students to connect and integrate course material over multiple semesters, 3.) emphasis on research and the process of scientific discovery, 4.) frequent high student-instructor contact and a cohesive student learning community, and 5.)transition from introductory to intermediate course content, and 6.) extended extracurricular learning and leadership opportunities such as Biocore Peer Mentors, mentored independent research, and the Biocore Outreach Ambassadors.

Students who complete all four semesters of Biocore should have a solid understanding of fundamental genetics concepts and have confidence in their ability to use their knowledge to address 'real-world' problems. Although we believe students who take Biocore are well prepared to think critically and use their scientific reasoning skills to communicate their understanding, we did not have evidence for this beyond traditional assessments within the context of a course, and final course and program evaluations. We began this study in order to provide a more rigorous evaluation of student learning gains associated with genetics and to identify variables related to student success. In consultation with literature, we recognized several models for assessment of learning outcomes across curriculum in multiple courses (Leathwood and Phillips 2000, Jacobs and Koehn 2004, Smith and Bath 2006, Hubball and Burt 2007, Harris et al. 2010), and from this developed an approach for the study.

In brief, our approach utilized a cross-sectional design, capturing a 'snap-shot' of student genetics performance, attitudes, study habits, and beliefs at the beginning, middle and end of Biocore and Biology 151/152 into Genetics 466 (151/152→466), aggregated at each time point during the academic year 2009-10. This was a quantitative study adapting previously validated questions from the Genetics Concept Assessment (GCA) developed by Smith et al. (2008) at University of Colorado to evaluate student performance on fundamental genetics questions.

The UW-Madison four Essential Learning Outcomes (ELOs) (http://www.provost.wisc.edu/content/WI_exp_ELOs.pdf) served as a framework for this study, helping us focus on important attributes of Biocore that make the curriculum unique and had potential to contribute to differences in performance on the GCA. The UW-ELOs were adapted from those identified by American Association of Colleges and Universities (AACU), Liberal Education for America's Promise (LEAP) (https://www.aacu.org/leap/students/elo.cfm). The UW-ELOs are institution-wide expectations to prepare

our graduates to enter the working world with 1.) knowledge of human cultures and the physical and natural world, 2.) intellectual and practical skills, 3.) personal and social responsibility, and 4.) the ability to integrate their learning to solve 'real-world' problems. Given the integrated nature of the Biocore curriculum, and focus on students' intellectual development as scientists over two years, we adopted the UW-Madison ELOs as the principle and translational framework for this study. We defined "Biocore ELOs" that are aligned with our program and study goals, and are consistent with those outlined in UW-ELO literature (Table 1). We attempted to measure one aspect of "Knowledge of Biological Concepts and the Natural World" with the GCA. Other aspects of the ELOs were measured with an Attitude and Behavior Survey (ABS) we developed using previously validated questions from the National Survey of Student Engagement (NSSE), where possible, and additional questions targeting specific program attributes and demographic variables that have potential effects on GCA performance.

To summarize, our study examines:

1. Student understanding of foundational genetics concepts
2. Demographic and attitudinal variables associated with student performance
3. Cross-curricular similarities and differences in demographics and attitudes about educational experience

Table 1. Biocore Genetics Assessment project framework. Measureable outcomes of the study are organized and aligned with Biocore program goals and UW-Biocore Essential Learning Outcomes. Example learning experiences highlight specific aspects of the program where intended goals are implemented. Survey questions on the ABS were divided among Intellectual and Practical Skills and Integrative Learning with additional demographic questions that may be associated with performance on GCA (e.g. gender, year in school, AP Biology experience).

UW- Biocore Essential Learning Outcomes	Biocore Program Goals: Cognitive Knowledge, Processing Skills, and Affective Behaviors	Biocore Learning Experiences	Genetics Assessment Project Measurable Outcomes
Knowledge of Biological Concepts and the Natural World	1. Understand and comprehend foundation and emerging concepts in biology at the introductory to intermediate level 2. Use terminology accurately and effectively within appropriate conventions of the discipline.	• **Foundation and emerging concepts of biology:** Faculty instructors in lecture courses engage students in learning foundation concepts in addition to the most recent discoveries and understanding of biological phenomenon • **Biology Immersion (H!):** Honors course work where students learn introductory to intermediate level material at a faster pace with higher expectations and receive honors credit; admittance into Biocore requires application and evidence of high achievement in prerequisite Chemistry and Math courses	**Genetics Concept Assessment (GCA) instrument** (adapted from U Colorado instrument)- 22 multiple choice questions focused on basic concepts of cell division, transmission genetics, molecular genetics, population genetics and evolution. Grounded in general genetics learning objectives articulated by UW Madison faculty and genetics instructors. Results compared with comparable students in alternative curriculum (i.e. Bio151/152→Gen466)
Intellectual and Practical Skills Scientific Inquiry and Reasoning Scientific Communication Group Learning	3. Understand how we know what we know in biology through study of the nature of science, the primary scientific literature, and historical experiments. 4. Build a logical argument based on evidence, learn to think critically, be skeptical, look at evidence before believing, and understand that there is not always just one right answer to a question. 5. Develop novel sophisticated biological questions, formulate testable hypotheses, design and carry out experiments, make logical conclusions based on evidence. 6. Express ideas clearly and logically in oral and written form. 7. Know how to find and evaluate information. 8. Utilize quantitative approach to solve problems and make conclusions about data 9. Work as a member of a productive, collaborative research team	• **Emphasis on research and inquiry**- Focus on the nature of science and research approach in lecture & lab courses (e.g. design experiment, integrated "Biocore-type questions"); doing research and finding/ reading primary research literature (e.g. Biocore labs and Biocore 333 capstone lecture- critique of primary literature; Biocore 699 student research at Biocore Prairie and in physiology lab) • **Inquiry based laboratory curriculum-** student intellectual development of science reasoning skills over 3 semesters • **Scientific Reasoning and Problem Solving:** articulate knowns and unknowns, identify assumptions explicitly, sort relevant information, troubleshoot, recognize exceptions and develop solutions that are simple to complex (e.g. Biocore lecture course in-class worksheets/ activities; Biocore group lab projects) • **Written and Oral Communication Intensive** laboratory curriculum developed systematically over three semesters curriculum develop professional communication skills (e.g. informal and formal presentations, research proposals, final papers, scientific posters, grant proposal, peer review, *Biocore Writing Manual*) • **Quantitative reasoning**: emphasis on *statistics* across the three semester laboratory curriculum (e.g. *Biocore Statistics Primer*); data analysis and modeling through lecture courses; integration of bioinformatics into cell biology lab • **Group learning** in lecture class (building through 4 semesters)- instruction and expectations on group development and dynamics (e.g. Group effort analysis feedback); Group research projects in lab courses; peer review and constructive critique among students, staff and faculty promoting interpersonal skills	**Student attitude and behavior survey (ABS v. D)-** Likert scale survey questions addressing group learning (6 questions); engagement and confidence in doing scientific research (4 questions); confidence and value of scientific writing (6 questions); coursework emphasis on high level thinking skills (e.g. synthesis, analysis, interpreting and making judgements) (5 questions)
Integrative Learning	10. Draw on past experience, accumulated knowledge, and creativity to solve complex biological problems 11. Analyze a problem using a systems approach ("systems thinking") recognizing levels of biological organization, and emergent properties of the whole.	• **Integrated Curriculum:** Four semester connected *sequence* of courses which expects students to integrate their biology, chemistry, physics, mathematics and statistical understanding to address complex issues/questions (e.g. critique of primary literature in capstone Biocore 333; doing independent research projects in 3 Biocore labs) • **Faculty course chairs** providing leadership in each course, responsible for integrating course content and pedagogy within and between courses	**Student attitude and behavior survey (ABS v. D)- -** Likert scale survey questions addressing integrative learning (4 questions)
Personal and Social Responsibility Community involvement and leadership Personal responsibility in classroom and in research	12. Develop interpersonal communication and leadership skills 13. Recognize and make judgments regarding ethical issues in research	• **Focus on positive learning environment and student/ instructor feedback –** smaller class size and high instructor/student ratio (e.g. regular instructor student two-way dialog regarding learning environment, clicker polls, course evaluations) • **Biocore Peer Mentoring program** – experienced Biocore students lead voluntary study groups for first and second semester (301 & 303) students • **Biocore Outreach Ambassadors**- Biocore students work with K12 teachers and students to bring inquiry – based science to rural schools & serve as representatives of the UW-Madison in the community • **Biocore course Board of Directors**- Small group of Biocore student representatives meet with instructors in each course to provide input and constructive critique on course progress • **Biocore Honor Code** agreement to avoid academic misconduct and pledge compliance • **Ethics in research** discussed (e.g. Galapagos finches; 333 stem cells/ cloning) and implemented (e.g. students develop 324 human subjects consent forms (IRB) & RARC-approved vertebrate projects)	**Student attitude and behavior survey (ABS v. D)- -** Likert scale survey questions addressing competitive learning environment (1 question).

Teaching and Learning of Genetics in Biocore

Genetics instruction in Biocore is not confined to one course. Instead, genetics is integrated into all courses, in particular Biocore 301 /302 (lecture and lab) introduces students to transmission genetics, quantitative genetics, population genetics and evolution; Biocore 303/304 (lecture and lab) introduces students to molecular genetics; in Biocore 323/324 little genetics is taught explicitly, however, Biocore 333 (Biological Interactions- capstone course) brings genetics back in an integrated way through the critical reading and analysis of primary literature focused on the genetics of cancer, epigenetics, and metagenomics. Table 2 outlines the progression of coursework in Biocore with emphasis on topics associated with genetics.

Table 2. Biocore courses by semester and Topics Associated with Genetics

Semester 1 - Fall
Biocore 301/302- Ecology, Genetics, and Evolution (3 cr/ 2 cr) Ecological genetics and conservation biology, transmission genetics, Mendelian and non-Mendelian inheritance, population genetics and mechanisms for evolution, biodiversity
Semester 2- Spring
Biocore 303/304- Cell Biology (3 cr/ 2 cr) Molecular genetics, genomics, proteomics, central dogma, protein trafficking, introductory bioinformatics, cellular signaling
Semester 3- Fall
Biocore 323/324- Organismal Biology (3 cr/ 2 cr) Animal and plant physiology emphasizing organismal structure-function relationships that result from genetic adaptation
Semester 4- Spring
Biocore 333 [capstone course]- Biological Interactions (3 cr) Genetics of colon cancer, horizontal gene transfer in soil microbial communities, stem cells and cloning, cancer and viral vectors (HPV)

Teaching and Learning of Genetics in Biology 151/152 and Genetics 466

Over half of biological science majors on the UW-Madison campus take Biology 151/152, a two-course lecture and lab sequence taken during freshman or sophomore year (~1100/semester) (http://www.zoology.wisc.edu/courses/151-152/). Many of these students then take Genetics 466 during their junior or senior year (~320/semester) to fulfill their genetics coursework requirements.

Biology 151 is a 5-credit introductory course that exposes students to cellular biology and molecular genetics, transmission genetics, evolution and the diversity of organisms through lectures and active learning class meetings. Biology 152 is a 5-credit course that introduces students to animal and plant anatomy and physiology, and ecology, with little to no genetics taught explicitly. A highlight of this course is the Independent Research Project (IP), where students have the opportunity to engage in faculty –mentored research experience. Enrollment in each course section is approximately 250 students. Although the majority of students take both 151 and 152, students who have achieved a high school Advanced Placement (AP) Biology score of 4 or 5 can opt out of Biology 151 and enroll directly into Biology 152.

Genetics 466 is a 3-credit intermediate course covering the breadth of genetics concepts including transmission genetics, quantitative genetics, molecular genetics, gene regulation, and population genetics using model systems of viruses, bacteria, plants, fungi, insects, and humans (http://www.genetics.wisc.edu/node/192).

Many biological science majors, especially students in Nursing and Anthropology, opt to take Zoology 101/102 and/ or Botany 130 to fulfilled pre-requisite requirements for Genetics 466 and their major with approximately 1/3 of students in Genetics 466 coming from this population. As a starting point for this

study, we choose to concentrate on Biology 151/152 to Genetics 466 rather than Zoology 101/102-Botany 130 as a comparison sequence, although we do include some attitudinal data from the latter.

Both course sequences, Biocore and 151/152→466 offer introductory to intermediate biology lecture and lab courses including whole courses or units on genetics, as well as opportunities for group learning and research (in lab courses and/or faculty lab experiences). The sequences differ in the integrated nature of the curriculum, continuity and progressive increase in expectations throughout curriculum, the development of a biology learning community, repeated of opportunities for inquiry based research projects, the nature of writing and oral presentation assignments, and focused and repeated opportunities to practice critical thinking and problem solving.

Methods

Construction of UW-Genetics Concept Assessment Instrument (GCA):

The GCA was developed and validated by Michelle Smith, William Wood and Jennifer Knight at University of Colorado following extensive literature review, interviews and testing (Smith et.al. 2008). The questions on the GCA are intended to assess conceptual understanding of learning goals found in Appendix A.

In order to measure learning gains, we adapted a 22-item version of the GCA instrument originally constructed by the University of Colorado team. Prior to giving the instrument to students in Fall 2009, all GCA items were paired with learning goals and reviewed by 15 faculty associated with undergraduate instruction in genetics at UW Madison. Faculty were asked to comment on 1.) whether the question tested the achievement of the specified learning goal, 2.) if the information given in the question was scientifically accurate, 3.) whether the question was written clearly and precisely, and 4.) whether the question was an important learning goal for undergraduate genetics education. In addition, faculty were asked to contribute additional learning goals that they felt were missing or to comment on the balance of learning goals tested.

Following the faculty review, each member of our research team classified questions based on Bloom's Taxonomy (Crowe et al., 2008, Anderson and Krathwohl, 2001). Questions that were intended to demonstrate knowledge and comprehension were classified as level 1-2; application and analysis questions level 3-4; and synthesis and evaluation questions level 5-6. We classified GCA Q1,3,5,6,7 and 9 as low level (1-2) (i.e. knowledge and comprehension questions); Q 2, 4,8, 10-16, 18 and 20 as intermediate (3-4) level (i.e. application and analysis questions); and Q19,21, and 22 as high level (5-6) (i.e. evaluation and synthesis questions) (see Appendix A).

The UW-GCA was piloted with students taking Genetics 466 in Summer 2009 with slight wording changes made prior to the initiation of the study in Fall 2009.

Construction of Attitude and Behavioral Survey (ABS):

In addition to the UW-GCA instrument, students were given an Attitude and Behavioral Survey (ABS) that aimed to measure 1.) their confidence in generating research questions and implementing experiments, 2.) students' self-reported participation and value in group learning, 3.) their beliefs associated with the value of scientific writing to their understanding of biology, and 4.) their beliefs associated with the value of general chemistry, physics, mathematics and statistics to their learning of biology. The survey questions were constructed to align with four emphases of the Biology Core Curriculum: 1.) learning through research and inquiry, 2.) learning through collaboration, 3.) learning through communication, and 4.) learning through integration of STEM concepts. During the term of this study, two major versions of the ABS were constructed (Appendix B and C). ABS v. B (Appendix B) was an early version given to Fall 2009 courses

(Biocore 301, Biology 151, Genetics 466). ABS v. D (Appendix C) was constructed in better alignment with ELOs and in consultation with UW Survey Center. ABS v. D was given to Spring 2010 courses (Biocore 303, Biocore 333, Biology 152, and Genetics 466).

Strategy, Schedule, and Implementation of GCA and ABS Surveys

The general strategy and schedule of assessment is outlined in Figure 1.

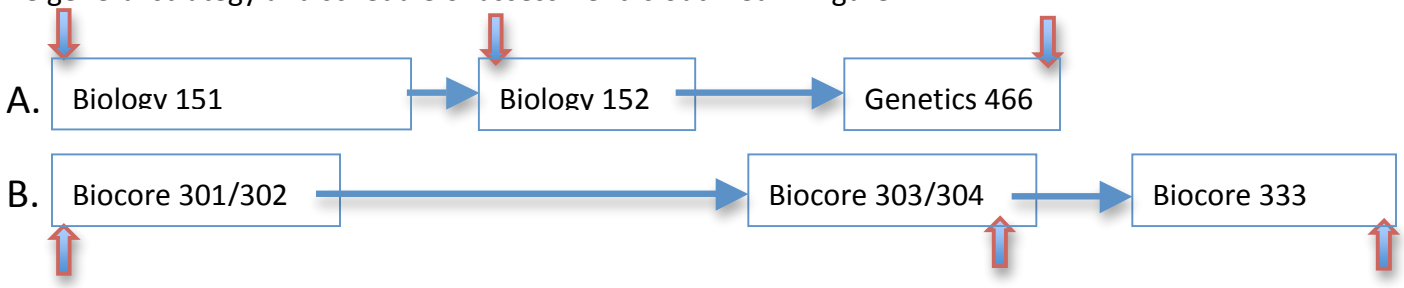

Figure 1. Two curricular sequences (A & B) associated with genetic instruction. Genetics curriculum within these two sequences are deemed equivalent for most bioscience majors at UW-Madison. Courses in curriculum A & B are spaced relative to one another along a developmental gradient based on students' hypothetical understanding of genetics. Red arrows indicate when GCA survey was given to students. Red arrows close to the beginning of a course box are 'pre-tests'. Red arrows close to the end of a course box are 'post-test' given at the end of that course.

Based on the curriculum sequence, the material presented in the Biocore and 151/152→466 sequences, student development, and the student demographic, we hypothesized an equivalent learning gain on a standard genetics assessment among students in Biocore 303/304 and Genetics 466. Once students have progressed into Biocore 333, we predicted that students would have additional learning gains in genetics as indicated by performance on the GCA. We did not include Biocore 323/324 in the survey schedule as this course does not focus on genetics to any great extent.

In all cases, students were given 30 minutes to take the GCA as an in-class paper and pencil survey and 10 minutes to complete the ABS. Survey administration was proctored either by a teaching assistant or a project assistant for this study. Given difficulties with scheduling, Spring 2010 Genetics 466 students were only given an on-line version of the ABS (v. D), not the GCA.

Sample Size

Table 3. Course populations, date when survey was implemented and samples size included in this analysis.

Student Population	Timing of Survey	Sample Size (consenting students only)
Biocore 301 Fall 2009	Pre-test (Sept. 2009)	111
Biocore 303 Spring 2010	Post-test (May 2010)	96
Biocore 333 Spring 2010	Post-test (May 2010)	93
Biology 151 Fall 2009	Pre-test (Sept. 2009)	756
Biology 152 Spring 2010	Pre-test (Feb. 2010)	420 (61 did not take Bio 151)
Genetics 466 Fall 2009	Post-test (Dec. 2009)	153
	Total	1629

In total, 1629 students took the GCA and ABS surveys (Table 3). The actual number of individual students was lower since some students took surveys repeatedly as pre- and post-tests in two courses in a sequence (i.e. Biocore 301->303; Biology 151->152). Of the 420 Biology 152 students, 293 took the UW-GCA both semesters.

Data Analysis

Pre-and posttests for these students and all Biocore 301->303 student were paired for an analysis of normalized learning gains [100*(post test score –pre test score)/(total points available-pre test score) (Hake,1998)]. In addition, we conducted item analysis for each class population where we calculated:

1.) item difficulty (P):

$$P = (N_1)/ \text{ total number of responses}$$

where N_1 is the total number of correct responses.

2.) item discrimination (D) to determine how well each question distinguishes between students whose total score identifies them as generally strong or weak (Adams et al. 2006).

$$D = (N_H - N_L)/(N/3)$$

where N_H is the number of correct responses by the top 33% of students, N_L is the number of correct responses for the lowest 33% of students, and N is the total number of student responses.

We used linear regression analysis to identify attributes from the ABS survey associated with variation in student GCA performance.

Institutional review board (IRB) protocol

We received approval for administration of pre- and post-tests in the courses included in this study (exempt status; Protocol number SE 2009-0228). Based on the protocol, we could not ask for permission to obtain student records and therefore, we could not implement a matching process by which students with similar academic demographics (i.e. GPA, AP biology score, math and introductory chemistry course grade) in each course sequence could be compared.

Results and Discussion

Student Performance, Learning Gains and Genetics Understanding

It is assumed that most *introductory* genetics content is covered in Biology 151, Biocore 301 and Biocore 303 including topics such as cell division, transmission genetics, the Central Dogma, population genetics, and evolution, whereas Biology 152 covers ecology, and plant and animal physiology with little to no genetics taught explicitly. *Intermediate* genetics content is covered in Biocore 303, Genetics 466 and Biocore 333. Given that genetics is taught at different time points in different contexts through the two curricular progressions, we believe that the learning gains must be viewed relative to student progression through the specific curricular stream.

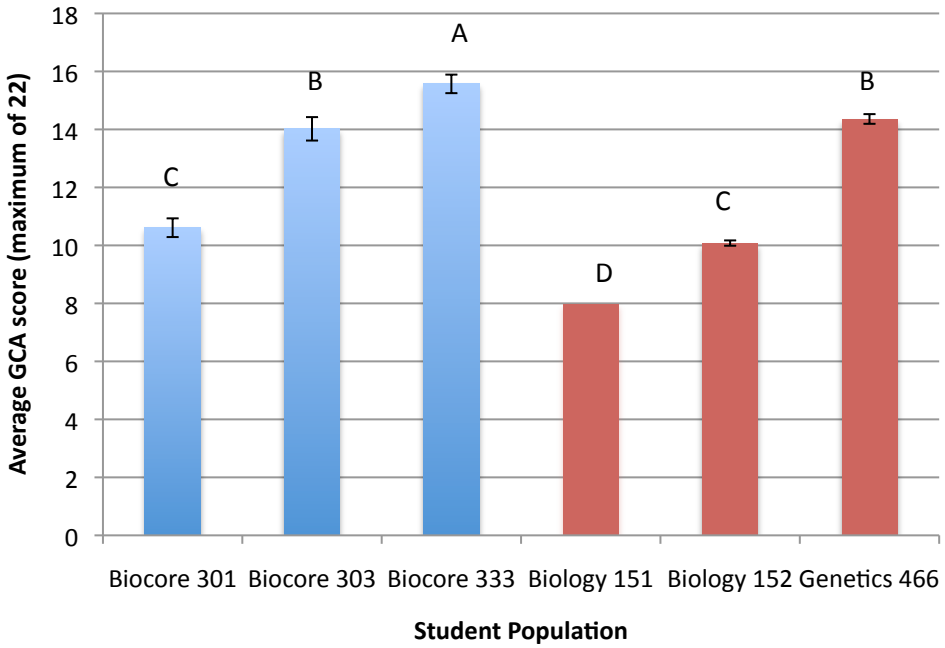

Figure 2. Average score ± 1SE on UW-GCA for students in each class population. Maximum possible GCA score is 22. Means labeled with different letters are significantly different at alpha = 0.05.

We report an average GCA score for each course population in Figure 2. Overall differences were highly significant (F ratio=207.48 p< 0.0001) with mean comparisons differences indicated by different letters in Figure 2. Biocore cohorts scored progressively and significantly better in each course with a 3.28 average learning gain between Biocore 301 and 303 where identical student pre- post-tests were given. Biocore students showed an average 4.96 point improvement on the GCA by the end of Biocore 333. Students in 151/152->466 demonstrated significant improvement scoring an average of 6.38 points higher on the GCA by the end of Genetics 466. The small population (roughly 14%) of students who did not take 151 *but did take Biology 152* (received AP Bio course credit) scored an average 10.38 ± 0.39, no different than their counterparts who took Biology 151 (10.03± 0.20). Student achievement on the GCA is slightly but significantly lower on average for Genetics 466 (14.36) than Biocore 333 (15.57), as the ending point for this study. We found no statistically significant difference between Biocore 303 and Genetics 466 GCA score.

When GCA items were analyzed for difficulty based on Bloom's level, both Biocore 301 and Biology 151 students had high achievement on Bloom's lower level (1-2) questions, with statistically significant lower achievement on intermediate (3-4) and higher level (5-6) questions (p< 0.001). Both student populations improve significantly on both intermediate and high level questions in Biocore 333 and Genetics 466 (Figure 3).

Based on the item analysis, *Biocore* students appeared to have sustained difficulty (below 0.5 P value) learning the following concepts based on their achievement on the these questions:

- ✓ [Question 11] Compare different types of mutations and describe how each can affect genes and the corresponding mRNAs and proteins. – More specifically, students may have difficulty in

understanding that a base change causing changes in codon (e.g. encoding or interrupting STOP codon) does not affect the length of mRNA transcript but rather the protein resulting from translation. After learning Central Dogma basics, students faced with a DNA mutation problem may be too quick to skip through processes of transcription and move right to results of translation.

- ✓ [Question 8] Calculating the *conditional* probability of inheritance of genetic traits using information from genetic crosses. Students do not factor in the condition, when calculating probabilities. *Genetics 466 students scored significantly better on this question.
- ✓ [Question 13] Analyze phenotypic data and deduce patterns of inheritance from family histories. *Genetics 466 students scored significantly better on this question.
- ✓ [Question 16] Calculate the probability of inheritance of sex-linked genetic traits using information from genetic crosses. Solving this question is helped by diagramming a pedigree and tracking sex-linked inheritance. If pedigree interpretation is challenging (as found for question 13 above) then,

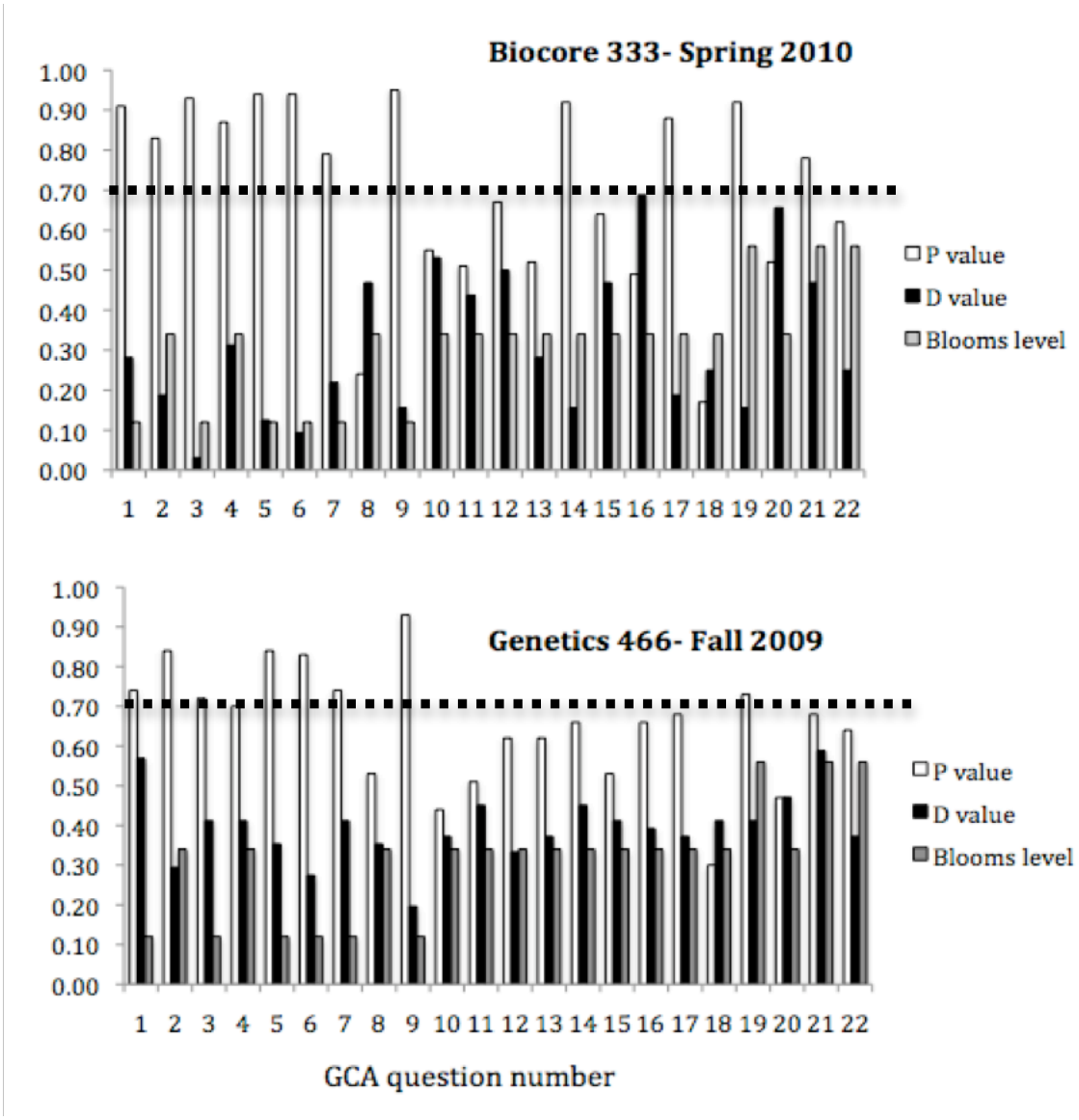

Figure 3. Item analysis for each GCA question in Biocore 333 (Spring 2010) and Genetics 466 (fall 2009). P value is the proportion of students who answered the question correctly. D is the item discrimination index, distinguishing the performance of generally higher versus lower achieving students or strength of the question. Bloom's level is given as a reference to lower level (1-2) questions indicated on this scale as 0.12, intermediate level (3-4) indicated as 0.34 on this scale, and high level (5-6) indicated as 0.56 on this scale. Horizontal dashed line is given to reference 70% achievement (P value=0.70) on any given question.

this question may be even more challenging.

Questions that appeared problematic in wording or interpretation by students include:

- ✓ [Question 18] Describe the process of nondisjunction and implications for progeny. This question was left out of the overall analysis.

Demographics, Attitudes and Behaviors (ABS)

Based on the demographic questions asked in the ABS, the Biocore class populations studied were predominately male or equal in gender ratio (Biocore 333), with a majority (>60%) having completed AP Biology in high school, and a steep increase in involvement in faculty research labs by their junior year (~80%). Students in the 151/152 class populations were predominately female, with a more equal gender ratio in Genetics 466. Approximately one-third to one half of the students in 151/152→466 completed AP Biology in high school, and greater than 50% of these students are involved in faculty research labs by their junior year (Table 4).

Table 4. Student demographics by class population

Class population	**% Female**	**Year in school**	**% completed AP Bio in high school**	**% worked in faculty research lab**
Biocore 301- F2009	*40.5*	*93% soph*	*68.5*	*35.1*
Biocore 303-Sp2010	*42.7*	*95% soph*	*61.5*	*58.3*
Biocore 333-Sp 2010	*54.8*	*91% junior*	*71.0*	*79.6*
Biology 151- F2009	*59.1*	*77% soph*	*44.9*	*19.1*
Biology 152- Sp2010	*57.6*	*70% soph*	*45.6*	*43.8*
Genetics 466-F2009	*54.7*	*82% junior*	*55.1*	*52.3*
Genetics 466- Sp2010	*52.0*	*78% junior*	*30.0*	*65.0*

Group Learning

During Class: The majority of students (86-95%) in Biocore 303 and 333 report working in groups at least once/week during class time. Similarly, 78% of students in Biology 152 report that they engage in group work at least once/week and are very comfortable doing it. Most Biocore and Biology 152 students feel that their group time is somewhat (50%) to very productive (~32%). About 80% of the students would prefer to work in groups during class time than to work on their own. Note: students took the survey in Biocore 304 and Bio152 lab where group work is common, so it is unclear if students were considering lecture class in their responses. In Genetics 466, <15% of students reported doing any type of group work during class.

Outside of Class: Greater than 50% of Biocore 301 students are part of a formal study group (led by a peer mentor), with students switching to informal study groups that meet once a week or once a month in Biocore 303 (46%) and Biocore 333 (85%). In 152, ~15% of students report meeting in formal study groups led by a peer leader or mentor, while 45% report studying at least once/month with an informal study group. Consistently, 46% of Genetics 466 students report studying in an informal study group at least once/month.

Integrative learning

When asked the question "How useful do you believe coursework in the following disciplines is to your learning of biological science?", the majority of students in all class populations (>60%) believe that general and organic chemistry is at least somewhat useful to their learning of biological science (Figure 4). Unfortunately, >65% of students in both curricular streams believe that physics is of little to no use in their learning of biological science. Similarly, >48% of Biocore 303, 333, and Biology 152 students believe that mathematics is of little to no use, while Genetics 466 students (including those who took Zoology 101/Botany 130 and Biology 151/152) value mathematics to a greater extent. Note that at least one semester of calculus is a prerequisite to Biocore coursework. Not all students in Genetics 466 have taken calculus, and therefore their reference to mathematics may be different. Student opinion about the value of statistics seems to vary depending on the class population, however students generally rated statistics as at least somewhat useful in their study of biological science. Note that >50% students in Biocore 303 and Genetics 466 rated statistics as very to extremely useful.

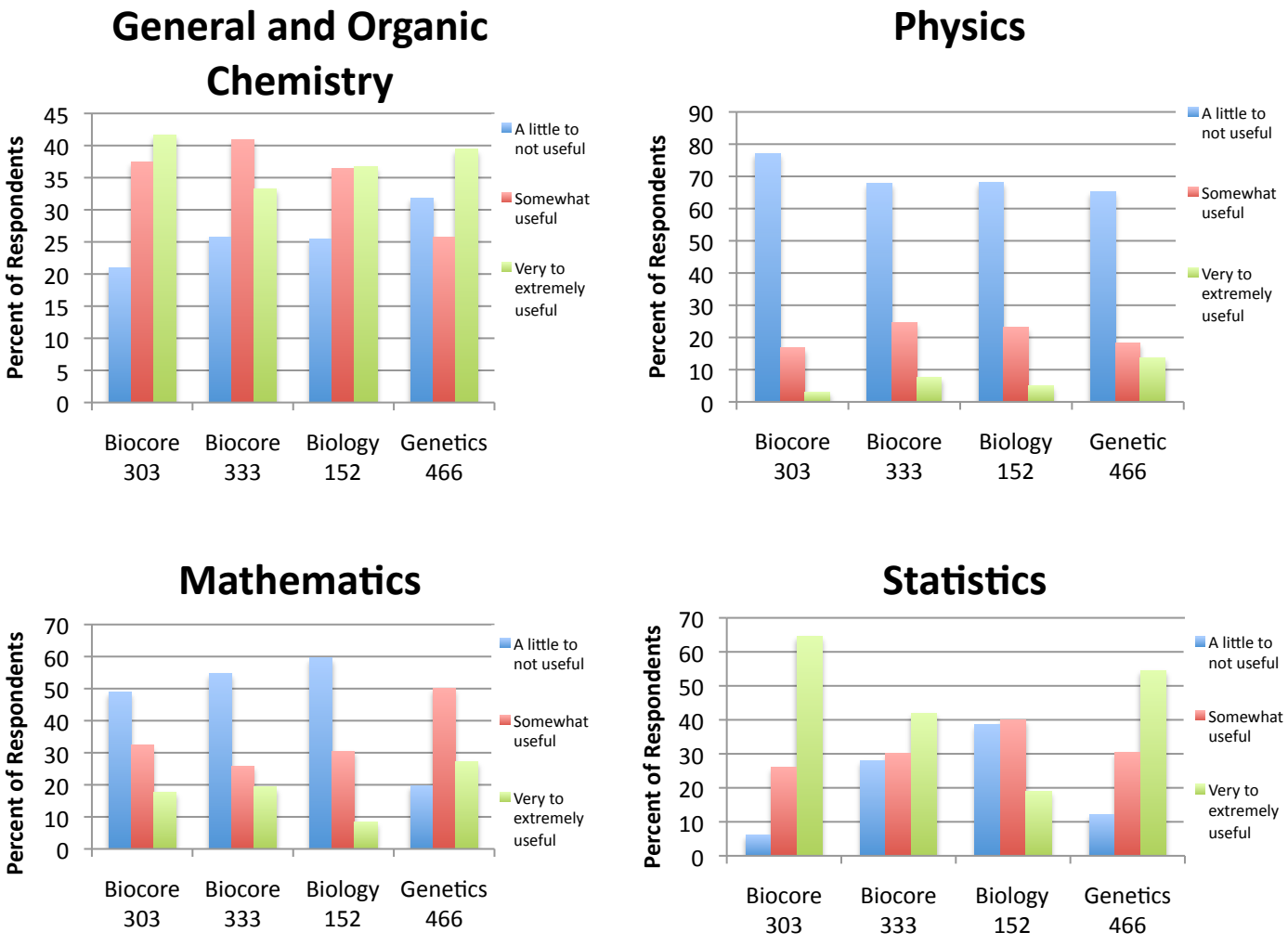

Figure 4. Percent of respondents by class population to the question "How useful do you believe coursework in the following disciplines is to your learning of biological science?"

When students in Biocore 333 and Genetics 466 were asked the question "How useful has your introductory to intermediate course sequence been to your learning in other biological science courses?",

almost all students found their introductory biology coursework to be somewhat useful (Figure 5). Almost 90% of students in Biocore 333 responded that their Biocore coursework was very to extremely useful to their learning in other biology courses.

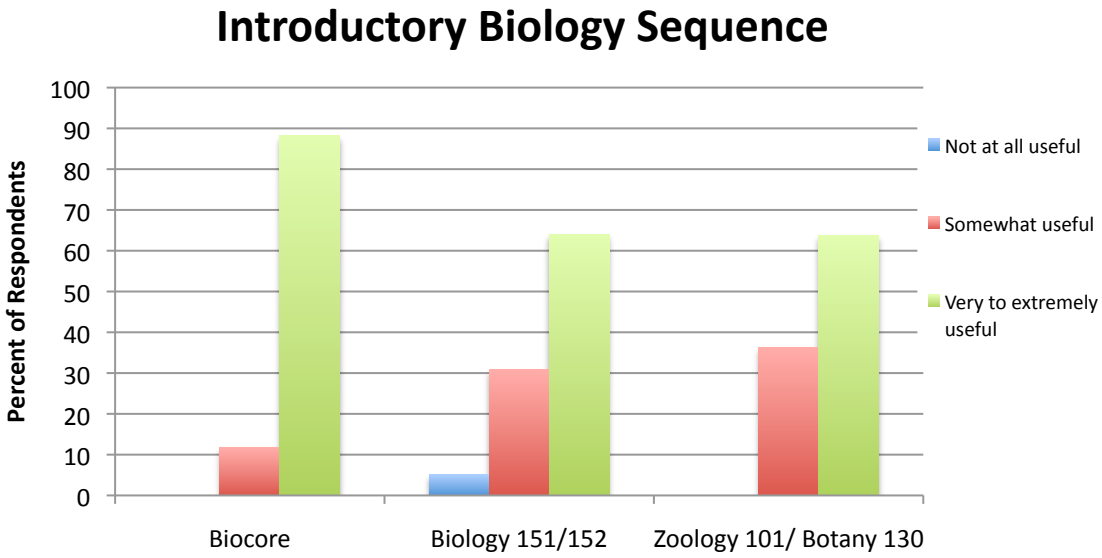

Figure 5. Percent of respondents in final course Biocore 333 and Genetics 466 to the question "How useful has your introductory to intermediate course sequence been to your learning in other biological science courses?". Sample size for Biocore (N=93) includes the entire course; there were N=64 students in Genetics 466 who took 151/152 and N=34 students in Genetics 466 who took Zoo 101 or Botany 130 .

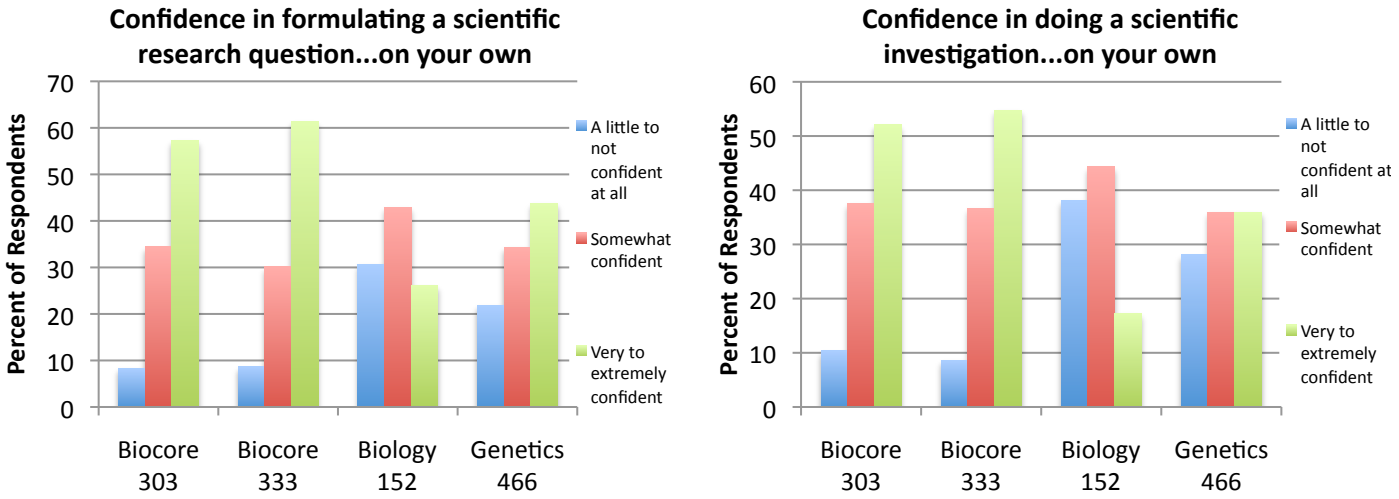

Figure 6. Percent of respondents by class population to the question: "How confident are you in your ability to do the following activities on your own? -formulate your own scientific research question; -conduct a scientific investigation"

Learning through research and inquiry

Over 80% of Biocore students and one-half to two-thirds of 151/152→466 students have had the opportunity to formulate a scientific research question and do a scientific investigation with or without guidance from a mentor or instructor. Students confidence in asking questions and doing research on their

own was quite high for both Biocore 303 and 333, with about 70% in Biology 152 and Genetics 466 that were at least somewhat confident in their capacity to generate research questions and conduct research on their own (Figure 6).

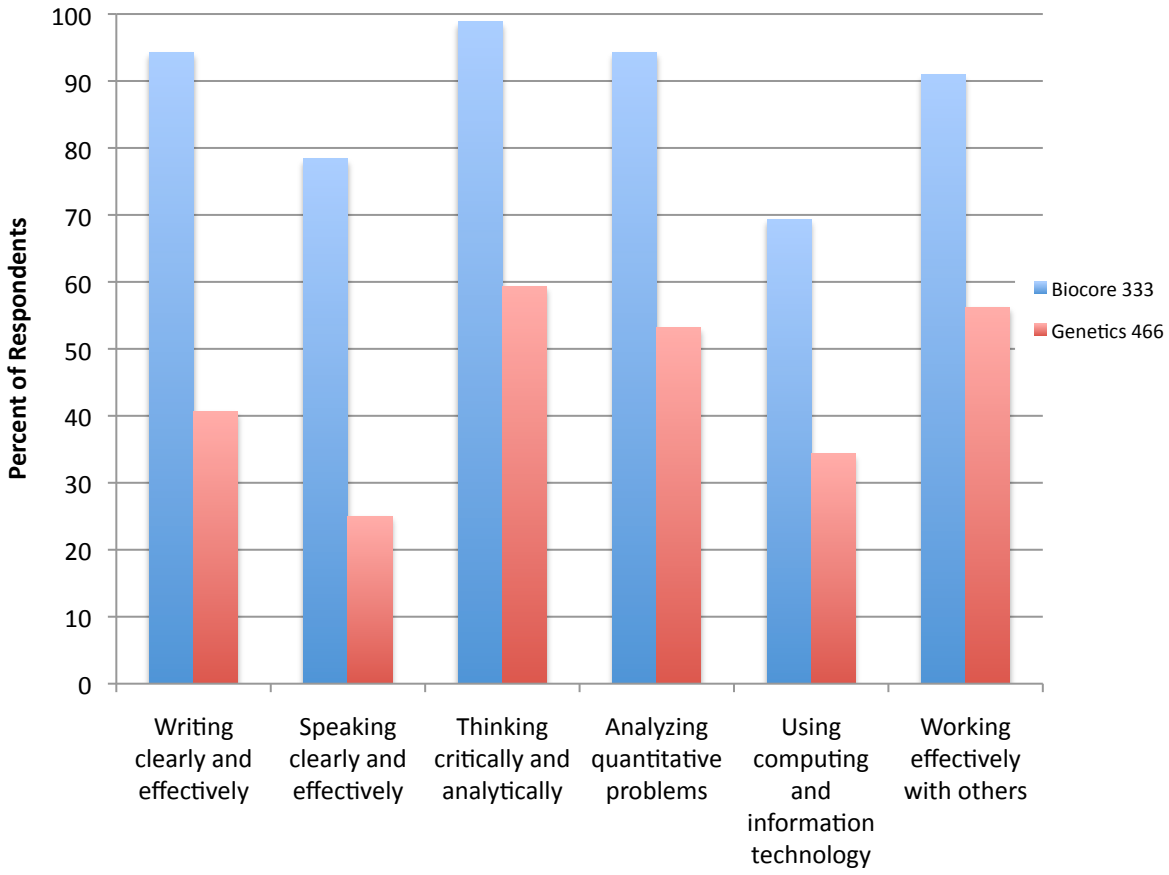

Figure 7. Percent of respondents by class population that responded **quite a bit to very much** to the question: "To what extent has your introductory to intermediate biology course sequence work (in Biology 151/152 or Biocore or Zoology 101/102 and/or Botany 130) contributed to your knowledge, skills, and personal development in the following areas?" as listed on the horizontal axis. Biocore N=63; Genetics 466 N=103.

Intellectual and Practical Skills

Students in Biocore recognize the contribution of their coursework to higher level thinking skills including writing, speaking, critical thinking, quantitative problem solving, use of computer technology and working effectively with others (Figure 7). These skills are central to the Biocore program goals (see Table 1) and repeatedly emphasized through four semesters. Although students in Genetics 466 do not connect their introductory biology coursework to these skills as directly, there are many students who recognize the connection, especially for critical thinking, quantitative problem solving and group work. Regardless of the curriculum, the majority of students in all courses (80%) are at least somewhat confident in their ability to write a scientific paper (data not shown here). Students in Biocore 303 and Biology 152 report that writing is more helpful to their understanding of the process of science than to their understanding of science concepts.

Table 5. Preliminary Analysis of covariates from ABS associated with performance on GCA grouped by demographic factors and UW-ELOs Survey questions on the ABS were divided among Intellectual and Practical Skills, Integrative Learning, and Personal and Social Responsibility with additional demographic questions that may be associated with performance on GCA. Marginal linear regression analysis p-values are reported together with significance * (p <0.05), ** (p<0.01), *** (p<0.001) ; preceded by a negative symbol (-) if the association resulted in decreased achievement on the GCA. (--) indicate that data is either not available or unreliable based on low sample sizes on response variables.

Demographic variables	**Potential Covariates**	**Biocore 301**	**Biocore 333**	**Biology 151**	**Genetics 466**
	Male gender	**0.0380***	**0.0468***	**0.0190***	**0.0022****
	Completed AP Bio	**0.0120***	0.7111	**0.0000*****	0.3069
	Research lab experience	0.6310	0.9941	0.2275	0.2090
UW- Biocore Essential Learning Outcomes					
Intellectual and Practical Skills	Helpfulness of:				
	Formal study groups	**0.0037****	--	**(-) 0.0358***	0.2282
	Informal study groups	0.7744	0.4887	0.3702	0.1296
	Study alone	0.1309	--	0.1036	**0.0050****
	Studying with classmate	0.1689	0.2725	0.9177	0.9889
	Making Flashcards	0.1439	--	0.8663	**(-) 0.0058****
Integrative Learning	Usefulness of:				
	Chemistry	--	0.3558	--	--
	Physics	--	0.2887	--	--
	Mathematics	--	**(-) 0.0467***	--	--
	Statistics	--	0.4340	--	--
Personal and Social Responsibility	Perceived level of competition	0.257	--	**(-) 0.0000*****	**(-) 0.0285***

Covariates from ABS as indicators of achievement on GCA

Limitations of the present study

We present Table 5 as a preliminary analysis of covariates that we analyzed from the Fall 2009 ABS version B and Spring 2010 ABS version D (Appendices B and C, respectively). Given the progression of this project and development of the ABS, the Fall 2009 courses (Biocore 301, Biology 151, and Genetics 466) were given similar questions, while the Spring 2010 Biocore 333, Biocore 303, Biology 152 courses were given a slightly different set of questions. Because limited Spring 2010 Genetics 466 instructional time prevented us from giving an in-class paper and pencil GCA, we could not matchABS to GCA performance for these students. In short, alignment of the same ABS questions to GCA data across all courses was not possible with this data set.

Given limitations in our IRB protocol, no matching process was implemented to pair course populations based on similar academic demographics (i.e. GPA, AP biology score, math and introductory chemistry course grades). The Biocore program is application based with a strong academically oriented, highly motivated student population. Students admitted to Biocore report high average, first year cumulative GPA of 3.42 upon enrollment in Biocore 301. The 151/152->466 course progression is not application based and, although many high achieving students choose this track, they are a smaller proportion of the total population. A matching model would be desirable in future studies given the unique demographic of each course population.

The demographic variables and potential covariates from the ABS are a subset of those analyzed, those that were the most reliable given the sample size on response variables. We plan to continue the analysis, combining variables in a multivariate model, but have not completed to this date.

Lastly, the number of student participants to total class size varied, with the Biocore student population having highest participation, with lower participation by students in 151/152→466. Given the sample sizes reported in Table 1, we feel that the study is sound, but not as representative for 151/152→466 as for the Biocore student population.

We recognize these limitations in the present study and encourage readers to interpret associations and conclusions below with caution.

Gender and Math

Regardless of course population, male students performed significantly higher on GCA than females, by 1.3 points by the end of Biocore 333 and 1.9 points by the end of Genetics 466 (Table 5). In Smith et al. (2008) and a companion study by Knight and Smith (2010) using the GCA, no analysis of gender was indicated. We have observed challenges in learning genetics similar to those outlined by Knippels et al. (2005), recognizing 1.) the complexity of probabilistic reasoning in the context of biological phenomena and 2.) the difficulty of thinking at different levels of biological organization over time, from molecular genetics, to cellular and organismal genetics, to population genetics and evolution. Although Knippels does not mention gender differences in learning genetics, there is a substantial literature base on gender disparity in math performance and science learning finding lower performance by females (Hyde et al. 2008, Sanchez and Wiley 2010). Interestingly, the students in Biocore 333 who reported mathematics as very to extremely useful for learning of biology scored, on average, 2 points *worse* on the GCA. Nevertheless, the gender differences reported here are concerning and deserving of further study, particularly given the consistent differences, maintained even at the end of each course progression in Biocore 333 and Genetics 466.

AP Biology, Course progression and Blooms

Students who have completed AP Biology in high school, score an average of 1.75 and 0.85 points higher on the GCA for Biocore 301 and Biology 151, respectively (Table 5). Based on an item analysis for these courses similar to that shown in Figure 3, AP Bio students outperform non-AP Bio students on lower level Blooms (1-2) questions only. By the time students complete each course progression, in Biocore or 151/152→466, there is no difference between AP and non-AP Bio students on the GCA. In addition, we found that Biology 152 students who did not take Biology 151, but used AP Bio course equivalents instead, scored no different than students who took Biology 151 (Figure 2). This suggests that AP Biology is good preparation for basic genetics concepts and problem solving consistent with Blooms low level 1-2 questions (i.e. knowledge and comprehension) but does not necessarily take students to the higher level. Our data indicate that introductory to intermediate level genetics college coursework helps solidify foundation concepts, allows non-AP Biology students to gain par with AP Biology students, and to reach higher level processing skills (i.e. application, analysis, synthesis and evaluation) in the context of genetics.

Faculty Lab Research Experience and Inquiry Based Courses

Whether a student has had experience working in a faculty research lab did not appeared to contribute to student performance on the GCA (Table 5). This result is not surprising given that the expected outcomes of a research experience would not necessarily align with their learning of genetics fundamentals, unless they worked in a genetics lab. The intellectual and practical skills gained in a research experience would be more consistent with those highlighted in Figure 7 (i.e. writing, speaking, critical thinking, quantitative problem solving, computer technology, team work) and Figure 6 (i.e. formulating questions and doing scientific investigations). Although we have not done question correlation within the ABS, it would be interesting to analyze how research experience in a faculty lab is synergistic with student development of these skills in their coursework, and in particular, inquiry based laboratory courses such as Biocore 302, 304, 324 and Biology 151/152 lab courses.

Group Learning and Study Habits

We found some evidence that GCA performance was significantly related to students' self-reported habits and attitudes about studying with others in both formal and informal settings, and that these trends were sometimes contradictory between the two curricular streams. Biocore 301 students have the highest portion of students (51.4%) that study with a formal study group led by a peer mentor one or more times each month. This is likely a reflection of participation in the formal peer-mentoring program available to all incoming Biocore 301 students. In contrast, 30% of Biology 151 students, 20% of Genetics 466 students, and 8.6% of Biocore 333 report that they study within formal study groups at least once per month. Smith and Bath (2006) found strong association of social learning skills and achievement of Australian University learning outcomes. In our study, we are hesitant to interpret this data further without a greater sample size and consistent ABS survey. However, further study on the influence of group learning and student learning outcomes should be considered.

Rote Learning and Flash Cards

We do have some evidence that students who favor rote memorization techniques to learn science perform worse on our GCA assessment. Specifically, we found that Genetics 466 students who do not use flashcards in their UW-Madison science courses did significantly better on the GCA by ~1.8 questions compared to students who reported using flashcards. We did not, however, find any relationship between flash card use and GCA performance in the Biocore 301 or Biology 151 cohorts. According to the National Research Council (NRC)'s *How students learn: science in the classroom* (2005), one of the three fundamental principles of learning is that "students must understand factual knowledge as it relates to a

larger conceptual framework, and organize facts/ideas within this framework". It may be that flashcard usage exacerbates students' natural tendency to compartmentalize their learning of scientific facts, and thus discourages students from linking ideas and applying them to address novel problems. Billing (2007) reviewed over 700 papers to address the question of how transferable core/key cognitive skills such as problem solving are, and concluded that transfer of key skills to address novel problems is discouraged by "rote learning of facts". Although our evidence is not strong, we believe it deserves further study.

Learning Community and Competition

Students in Biology 151 and Genetics 466 who perceived moderate to high levels of competition towards their classmates did worse on the GCA compared to their classmates who felt no or a little competition (Table 5). Perceived competition levels among Biocore 301 students did not, however, explain a significant amount of variation in GCA scores. (Biocore 333 students were not asked this question.) In all seven Biocore courses, students earn final grades based on a "straight" scale, i.e., all students who achieve a stated level of performance will earn the corresponding grade. This policy is stated in all Biocore course syllabi, and is announced clearly on the first day of class each semester. Further, Biocore students are frequently encouraged to work with their peers inside and outside of class to promote learning of the entire class community. In an elegant study by Bergin (1995), competitive environments were shown to decrease student classroom performance, particularly for students with weaker academic records. Competition also has a negative influence on metacognition skills (Billing 2007), one of the 3 fundamental principles of learning (National Research Council 2005).

Main Findings

The main goals of this project were to assess:

1. Student understanding of foundational genetics concepts

   We measured significant learning gains for students enrolled in Biocore and 151/152→466 courses, with students in Biocore 303 having similar achievement to their peers in Genetics 466, and further gains for students in Biocore 333. We conclude that Biocore coursework provides equivalent preparation, and in some cases exceeds that of the typical 151/152→466 course progression.
2. Demographic and attitudinal variables associated with student performance
   - *Gender difference:* We found that females do not perform as well as males on the multiple-choice Genetics Concept Assessment (GCA) in the same courses. We believe that this difference may be associated with documented gender differences in mathematics performance.
   - *AP Biology:* In their first semester of college Biology course work (Biocore 301, Biology 151), students who report completing AP Biology in high school out perform non-AP Biology students on the GCA, most significantly on low-level Blooms questions. Upon completing Biocore and Genetics 466, there is no difference in AP Biology and non-AP Biology students GCA scores. We conclude that AP Biology provides good preparation for intermediate level coursework where foundation principles are extended into higher-level thinking and problem solving in genetics.
   - *Competition and Learning Community:* Students who reported feeling a moderate to high degree of competition with their classmates had lower levels of achievement on the GCA. We believe that a positive, supportive learning community similar to that fostered in Biocore may decrease the achievement gap among low and high achieving students.
3. Cross-curricular similarities and differences in demographics and attitudes about educational experience

- *Value of STEM coursework:* Most students, regardless of course progression, consider statistics and general chemistry to be very useful to their learning of biological science. Conversely, most students believe that mathematics and physics coursework is only somewhat or of little use to their learning of biology. We conclude that the biology, math and physics instructional communities need to work together to demonstrate the integration and complementation of these disciplines in the study of biology.
- *Intellectual and practical skills:* The majority of students in Biocore report that their course work has contributed greatly to their development of writing, speaking, thinking critically, quantitative problem solving, computer technology, and working effectively with others—all of which are central to Biocore program goals. We conclude that Biocore courses provide ample opportunities to develop these skills, and plan to continue supporting course curriculum that does so.
- *Confidence in inquiry and doing research:* Biocore students report high confidence in their ability to ask research questions and conduct scientific investigations. Although their confidence is not associated with their performance on the GCA, we believe that confidence in inquiry is essential to students' intellectual development and critical thinking.

Future Studies

Based on the initial findings of this study, we are interested in diving deeper to go beyond concept assessment in genetics. Although foundation concepts tested on the GCA are important, we expect students to connect and integrate concepts in novel ways, communicate their understanding, and work with others to propose solutions to complex problems. We would like to investigate students' development of these types of higher-level "Blooms" problem solving skills associated with their demographics, their attitudes and beliefs, and their undergraduate biology experience. Since we have begun a study in genetics, we initially plan to examine problem solving in genetics, but we hope our approach will be generalizable to any conceptual domain in biology (e.g. evolution, ecology, or physiology) for which concept inventories have been or are being developed (Anderson et al. 2002, Bowling et al., 2008, Garvan-Doxas et al., 2007, D'Avanzo 2008).

Our general approach would be to combine qualitative and quantitative data collection strategies. Qualitative methods would include interviews that ask student participants about their experiences in biology coursework. In addition, we propose to measure students problem-solving skills using 'talk-aloud' or 'verbal explanation' protocols paired with a well defined rubric to assess student responses similar to Michelle Harris et al. (2009). All students enrolled in the introductory biology sequences (Zoology 101 and/or Botany 130, Biology 151/152 and Biocore; as well as the new Biology 375 Exploring Biology course) would be invited to take surveys (GCA and ABS). Study participants for interviews and 'talk aloud' observations would be selected from the surveyed populations, matching for demographics and academic achievement. As we gather data in the short-term, through cross-sectional analysis, and learn more about specific elements of the curriculum that fosters higher level problem solving skills, we hope to continue this study with a longitudinal analysis by following the same students all the way through 3-4 years of course work. Our expected outcomes are to create a clinical interview protocol to observe the development of problem solving skills over time, develop a 'talk aloud' rubric to measure students approach and progression through a problem, and to identify essential elements of the three introductory to intermediate biology curricula that foster the development of these skills.

In order to fully develop a proposal, we feel it is necessary to engage and forge essential partnerships within a group of course directors, instructors, faculty and staff, and administrators for Zoology 101/102,

Botany 130, Biology 151/152, Genetics 466, Biocore and ICBE. We hope this report will provide a starting point for those conversations.

Conclusion

We offer this report to 1.) inform course instructors about student learning and guide curriculum decisions, 2.) guide development of research questions for high quality assessment of learning goals (e.g. critical thinking and scientific reasoning), 3.) inform students about their learning, 4.) inform the science education community at large of learning outcomes and critical elements associated with teaching genetics. We have found this project to be a very valuable professional development experience for Biocore faculty and staff. We are encouraged by the cross-curriculum conversations and partnerships we have formed with Biology 151/152 and Genetics 466 instructors, and hope to continue working together to develop questions and an approach that will guide future assessment.

We found the UW-Madison Essential Learning Outcomes to be invaluable in providing a framework for this study. Alignment of UW ELO's with Biocore program goals and learning experiences affirmed that our 40+ year-old honors biology program is in step with UW-Madison expectations for undergraduates. Our data indicate that the Biocore program is providing a strong foundational learning experience, allowing Biocore students to achieve many essential ELO's by graduation.

The current study was not intended to be an Introductory Biology cross-sequence program evaluation. However, the data reported here may serve as a starting point to guide the development of research questions aligned with recent recommendations for cross-sequence assessment of the impact and outcomes of educational practices put forth in the UW-Madison Introductory Biology Initiative MIU (Balser, Wilcots, Bednarek). With new partnerships, we hope to develop a model for cross-curriculum assessment and evaluation to better inform instruction and curricular goals, and improve student learning.

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Appendix A.

UW Genetics Concept Assessment

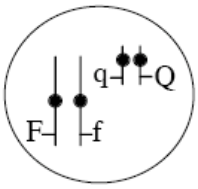
Question number, Blooms level and Learning Goal followed by Question

1. (Blooms 1-2)
Distinguish between a cell genotype and phenotype, and explain why all cells in an organism are genetically equivalent but may vary in phenotype.

Which of the following human cells contains a gene that specifies eye color? a) Cells in the eye.
b) Cells in the heart.
c) Gametes (sperm and egg).
d) Cells in the eye and gametes.
e) All of the above.

2. (Blooms 3-4)
Describe the mechanisms by which genes are assorted, segregated, and recombined during meiosis to generate unique genotypes in the next generation.

In the germline cell below there are two pairs of chromosomes on which are shown the locations of two different genes. F and f represent two different alleles (versions or variants) of one gene, and Q and q represent two different alleles of another gene. If this cell divides normally to produce sperm, what are the possible sperm genotypes?



a) F, f, Q, q
b) Ff, Ff, Qq, Qq
c) FQ, fq, Fq, fQ
d) Ff, Qq, FQ, fq, Fq, fQ

3. (Blooms 1-2)
Define the concept of genetic mutation and describe how mutations can affect genes and the corresponding mRNAs and proteins.

Suppose that a single DNA base change of an A to a T occurs and is copied during replication. Is this change necessarily a mutation?
a) Yes, it is a change in the DNA sequence.
b) Yes, if the base change occurs in a gamete (sperm or egg cell); otherwise no.
c) Yes, if the base change occurs in the coding part of a gene; otherwise no.
d) Yes, if the base change occurs in the coding part of a gene and alters the amino acid sequence of a protein; otherwise no.
e) Yes, if the base change alters the appearance of the organism (phenotype); otherwise no.

4. (Blooms 3-4)
Determine the nature of a genetic mutation through analysis of a complementation test.

Starting with a population of genetically identical mice, you discover two new independent mutant strains in which all of the animals have epileptic seizures. In both strains, you know that the epileptic seizures are due to a single DNA mutation. You cross a mutant mouse from one strain to a mutant mouse from the second strain and find that none of their many offspring undergo spontaneous seizures. From this experiment you would conclude that the two mutant strains of mice most likely have mutations in: a) the same DNA base position within a particular gene.
b) the same gene, but not necessarily the same DNA base position.
c) two different genes.

5. (Blooms 1-2)
Distinguish between somatic and germ-line cells, and describe if/how mutations in these cells lines are inherited in offspring.

A young man develops skin cancer that does not spread to any other tissues; the mutation responsible for the cancer arose in a single skin cell. If he and his wife (who does not have skin cancer) have children after the skin cancer diagnosis, which of the following statements is most likely to be true?

a) All the man's children will inherit the mutation.
b) All the man's children will inherit the mutation if the mutation is dominant.
c) Some of the man's children may inherit the mutation depending on which of his chromosomes they inherit.
d) None of the man's children will inherit the mutation.

6. (Blooms 1-2)
Differentiate between gene and allele, and describe the significance of a diploid versus a haploid life stage to genetic recombination.

The *MLH1* gene is located on chromosome 3 in humans and four different alleles have been identified. The maximum number of alleles a single normal individual can have is:

a) one
b) two
c) three
d) four

7. (Blooms 1-2)
Describe the processes that can affect the frequency of phenotypes in a population over time.

A population of buffalos is geographically isolated such that no new buffalos can come into their territory. Which of the following is primarily responsible for the appearance of new alleles in this population?

a) Reassortment of chromosomes during the process of creating sperm or eggs.
b) Mutations in cells that will become sperm or eggs.
c) Changes in the environment that favor some buffalo traits over others.
d) Random mating between the buffalos in the population.

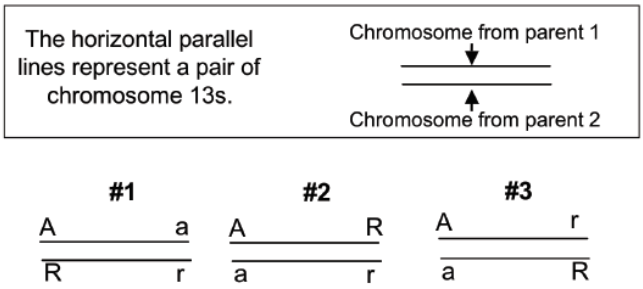
8. (Blooms 3-4)
Calculate the probability of inheritance of genetic traits using information from genetic crosses.

Cystic fibrosis in humans is caused by mutations in a single gene and is inherited as an autosomal (non-sex chromosome) recessive trait. A normal couple has two children. The first child has cystic fibrosis, and the second child is unaffected. What is the probability that the second child is a carrier (heterozygous) for the mutation that causes the disease?

a) 1/4
b) 1/2
c) 2/3
d) 3/4
e) 1

9. (Blooms 1-2)
Describe the phenomenon of linkage and how it affects assortment of alleles during meiosis.

A man is a carrier for Wilson's disease (Aa) and Rotor syndrome (Rr). Assume the genes involved in these two disorders are both on chromosome 13 (a non-sex chromosome). Below are possible representations of his genotype (labeled #1, #2, and #3). Which of them could be correct?



a) #1 only
b) #2 only
c) #3 only
d) #2 and #3 only
e) #1, #2 and #3

10. (Blooms 3-4)
Describe the molecular anatomy of genes and genomes.

You have identified a previously unknown human gene that appears to have a role in autism. It is similar enough in DNA sequence to a known mouse gene that you believe the two genes may be evolutionarily related. You determine and compare the DNA sequences, the predicted mRNA sequences, and the predicted amino acid sequences corresponding to the two genes. You would expect to find the greatest sequence similarity from comparisons of the two:

a) DNA sequences.
b) mRNA sequences.
c) amino acid sequences.
d) All three comparisons are likely to show the same degree of sequence similarity.

11 & 12. (Blooms 3-4)
Compare different types of mutations and describe how each can affect genes and the corresponding mRNAs and proteins.

The following DNA sequence (coding strand) occurs near the middle of the coding region of a gene.

DNA

50 55 60 65
5'—A A T G A A T G G G A G C C T G A A G G A G —-3'

The corresponding mRNA sequence is shown below. Note that the coding strand of DNA has the same sequence as the mRNA, except that there are U's in the mRNA where there are T's in the DNA. The first triplet of nucleotides AAU (underlined) is in frame for coding, and encodes Asparagine as the codon table above indicates.

mRNA

50 55 60 65
5'—A A U G A A U G G G A G C C U G A A G G A G —3'

11. Suppose there was a mutation in the DNA sequence where the G at position 53 was changed to an A. What is the most likely affect on the mRNA?

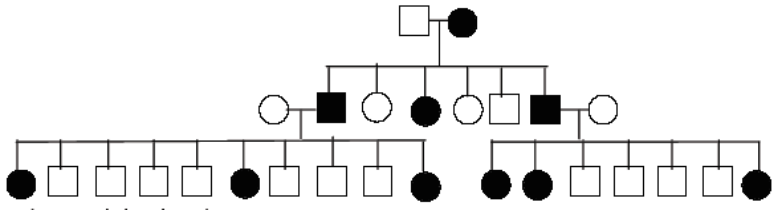
a) No change to the length of the mRNA
b) The mRNA will be longer
c) The mRNA will be shorter
d) The mRNA will not be produced

12. For the same original DNA sequence, suppose there was a mutation that inserted an additional G after the G at position 54. What is the most likely affect on the protein?

a) No change to the length of the protein
b) The protein will be longer
c) The protein will be shorter
d) The protein will not be produced

13. (Blooms 3-4)
Analyze phenotypic data and deduce patterns of inheritance from family histories.

This pedigree shows a family afflicted with a rare genetic disease (circles represent females, squares represent males, and individuals with filled symbols have the disease; assume that any people who marry into the family are not carriers for the disease). The genetic mode of inheritance that is most consistent with this pedigree is:



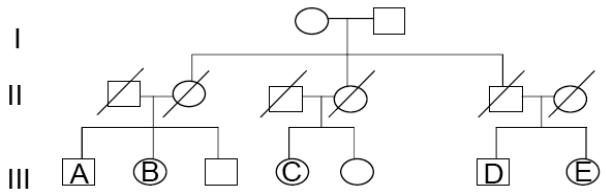
a) autosomal dominant
b) autosomal recessive
c) X-linked dominant
d) X-linked recessive

14. (Blooms 3-4)
An isolated population of prairie dogs has longer than average teeth. As a result they can eat more grass with less effort and are better able to survive. The mutation(s) that resulted in longer teeth:

a) allowed the teeth to grow longer over several generations until they reached an optimal length for eating grass.
b) arose in many members of the population at the same time.
c) happened by chance.
d) occurred because the prairie dogs needed to be more efficient at eating grass to survive and reproduce.
e) would only occur in a prairie dog population that eats grass and would not occur in a population that lives on seeds.

15. (Blooms 3-4)
Analyze phenotypic data and deduce patterns of inheritance from family histories.

Below is a pedigree of a family in which all the people in generation II are dead (indicated with a slash) because of political unrest in their country. Circles represent females, squares represent males.



Which children in generation III could be traced to the grandmother in this pedigree by using only mitochondrial DNA sequences:

a) A and D
b) A, B, and C
c) B, C, and E
d) A, B, C, D, and E

16. (Blooms 3-4)
Calculate the probability of inheritance of sex-linked genetic traits using information from genetic crosses.

A woman who is a carrier for X-linked hemophilia (she does not have the disease) marries a man who does not have hemophilia. They have a daughter, named Angela, who does not have the disease. Angela marries George, who also does not have hemophilia. Angela and George have a son named Robbie. What is the chance that Robbie has hemophilia?

a) 0

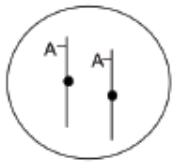
b) 1/8
c) 1/4
d) 1/3
e) 1/2

17. (Blooms 3-4)
Describe the difference between allele frequency, genotypic frequency, and phenotypic frequency in a population, and explain how allele frequencies change in a population over time.

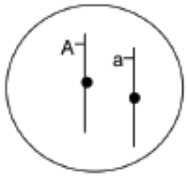
In a population of squirrels, most of the squirrels have long tails. Very few of the squirrels have short tails. Which of the following is true?
a) The allele for long tails is dominant to the allele for short tails.
b) Eventually, all of the squirrels in this population will have long tails.
c) Both answers a) and b) are correct.
d) You need more information to determine the inheritance of tail length.

18. (Blooms 3-4)
Describe the process of nondisjunction and implications for progeny.

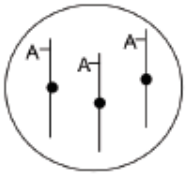
Sue's chromosome #18 pair looks like this:



Bob's chromosome #18 pair looks like this:



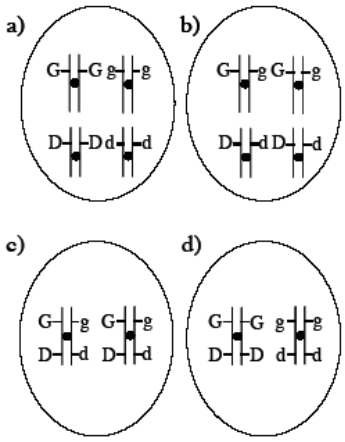
Bob and Sue have a stillborn son with three copies of chromosome #18 that look like this:



In which parent did the chromosome separation problem occur?
a) Sue
b) Bob
c) Could be either Sue or Bob
d) Chromosomal abnormalities skip a generation, so the problem occurred in Sue's parents

19. (Blooms 5-6)
Describe how genetic sequence similarity relates to similarity in protein function. Apply the results of molecular genetic studies in model organisms to understanding aspects of human genetics and genetic diseases.
You are interested in studying a gene called CFTR because mutations in this gene in humans cause cystic fibrosis. You have made a line of mice that lack the mouse CFTR gene. These mice are unable to clear bacteria from their lungs, so they get lung disease. You put a normal human CFTR gene into some of these mice and discover that the mice with the human gene are able to clear bacteria from their lungs and no longer get lung disease. From this experiment, you can conclude that:
a) The DNA sequences of the mouse CFTR gene and human CFTR gene are identical.
b) The amino acid sequences of the mouse CFTR protein and the human CFTR protein are identical.
c) The mouse CFTR gene and human CFTR gene encode proteins that can serve a similar function.
d) Both answers b) and c) are true.
e) All of the above are true.

20. (Blooms 3-4)
Describe the process of DNA replication and diagram the arrangement of chromosomes as a cell undergoes meiosis. Suppose there are two genes on two different chromosomes, one gene called G and the other called D. An individual has the genotype GgDd. Which of the following drawings correctly shows cells in this individual after DNA replication but before cell division of the first meiosis? Assume no recombination/crossing-over occurs between the chromosomes. (answer a.)



21. (Blooms 5-6)
Describe the phenomenon of linkage and how it affects assortment of alleles during meiosis.
Two different genes are located on the same chromosomal pair in rabbits. A particular female rabbit is heterozygous for alleles of both these genes, with the alleles arranged as shown in the diagram to the right. Scientists know that the two genes are on the same chromosome, but do not know their exact position, as indicated by the dashed line.

Suppose this female mates with a male rabbit in which the same chromosome pair looks like this:

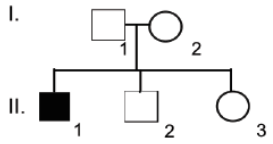
How likely is it that this pair of rabbits would have offspring with a chromosome pair that looks like this:

a) Not likely, because the R and e alleles are not on the same chromosome in either parent.
b) Very likely, because the random assortment of chromosomes during cell division to make sperm or eggs allows for the mixing of all alleles.
c) More likely if the two genes are very close together on the chromosome.
d) More likely if the two genes are not very close together on the chromosome.

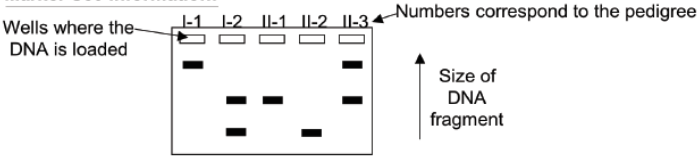
22. (Blooms 5-6)
Interpret the results from both inheritance patterns and molecular data to determine the molecular basis of genetic traits.

Mutations in the *shin* gene result in a bone disease called Shingularia. The *shin* gene is located next to a DNA marker called S50, which exists in three variants of different sizes in humans. Below is a pedigree of a family with Shingularia and a gel showing the Marker S50 size for each person. All bands on the gel are equally intense.

Pedigree:



Marker S50 Information:



Which mode of inheritance for the disease Shingularia is most consistent with the pedigree and the information on Marker S50?

a) X-linked dominant.

b) X-linked recessive.
c) Autosomal dominant.
d) Autosomal recessive.
e) More than one mode of inheritance is possible.

Appendix B. ABS version B given to Fall 2009 Biocore 301, Biology 151, and Genetics 466 students

1. Do you consent to have your data included in the study?
    0) yes
    1) no

2. Are you 18 years of age or older?
    0) yes
    1) no

3. What course are you taking this survey in?
    0) Biology 101
    1) Biology 151
    2) Biology 152
    3) Biocore 301
    4) Biocore 333
    5) Genetics 466

4. Gender
    0) male
    1) female

5. What is your race/ethnicity? Please choose one.
    0) Asian
    1) Black or African American
    2) Hispanic
    3) Native American or Alaska Native
    4) Native Hawaiian or Pacific Islander
    5) White or Caucasian
    6) Other

6. How many semesters of undergraduate coursework have you completed?
    0) None
    1) One
    2) Two
    3) Three
    4) Four
    5) Five or greater

7. In high school, did you take Advanced Placement (AP) Biology, International Baccalaureate (IB) Biology, or other similar honors Biology coursework?
    0) yes
    1) no

8. Do you have any experience working in a research laboratory (not including undergraduate laboratory courses)? For example: independent research, summer internships, research apprenticeships etc.
    0) yes
    1) no

How frequently do you study in each of the following ways in your University of Wisconsin-Madison science courses?

9. Study alone
   0) Never
   1) Once a month
   2) Once a week
   3) Several times a week

10. Study with a classmate
   0) Never
   1) Once a month
   2) Once a week
   3) Several times a week

11. Study with an informal study group with classmates
   0) Never
   1) Once a month
   2) Once a week
   3) Several times a week

12. Study with a formal study group with peer leader/mentor
   0) Never
   1) Once a month
   2) Once a week
   3) Several times a week

13. How much competition do you feel towards your classmates at this point in the semester?
   0) No competition
   1) A little competition relative to my other courses
   2) Moderate competition relative to my other courses
   3) A lot of competition relative to my other courses

Please rate the following activities as to the relative value or helpfulness in learning material in your University of Wisconsin-Madison science courses.

14. Reading before lecture
   0) Very helpful 1) Helpful 2) Not helpful 3) I do not read before lecture

15. Reading textbooks
   0) Very helpful 1) Helpful 2) Not helpful 3) I do not read the textbook

16. Doing chapter problems
   0) Very helpful 1) Helpful 2) Not helpful 3) I do not do chapter problems

17. Watching and reviewing online movies/podcasts

0) Very helpful 1) Helpful 2) Not helpful 3) I do not watch movies/podcasts

18. Taking and reviewing lecture notes

0) Very helpful 1) Helpful 2) Not helpful 3) I do not take lecture notes

19. Reviewing in-class worksheets or activities

0) Very helpful 1) Helpful 2) Not helpful 3) I do not review in-class worksheets

20. Rewriting or outlining notes

0) Very helpful 1) Helpful 2) Not helpful 3) I do not rewrite or outline notes

21. Making flashcards

0) Very helpful 1) Helpful 2) Not helpful 3) I do not make flashcards

22. Making diagrams

0) Very helpful 1) Helpful 2) Not helpful 3) I do not make diagrams

23. Reviewing and practicing old exams

0) Very helpful 1) Helpful 2) Not helpful 3) I do not review or practice old exams

24. Doing and reviewing assigned homework questions or problem sets

0) Very helpful 1) Helpful 2) Not helpful 3) I do not do homework questions or problem sets

25. Discussing material with others (TA's/students) in discussion sections

0) Very helpful 1) Helpful 2) Not helpful 3) I do not discuss materials with others in discussion sections

26. Studying alone

0) Very helpful 1) Helpful 2) Not helpful 3) I do not study alone

27. Studying with a classmate

0) Very helpful 1) Helpful 2) Not helpful l 3) I do not study with a classmate

28. Participating in an informal study group with classmates

0) Very helpful 1) Helpful 2) Not helpful 3) I do not participate in an informal study group

29. Participating in a formal study group with a peer leader/mentor

0) Very helpful 1) Helpful 2) Not helpful 3) I do not participate in a formal study group

Appendix C.

ABS version D. - given to Spring 2010 students in Biology 152, Biocore 303, Biocore 333 and Genetics 466 (Genetics 466 administered online in Qualtrics)

Q1

What is your student ID number? (This is for research purposes only. You will not be identified by name.)

The following questions are about the current course you are taking.

Q2

In the past month, how often did you study with one other student for this class?

- Never
- Once a Month
- Once a Week
- Several times a week
- Almost every day

Q3

In the past month, how often did you study alone for this class?

- Never
- Once a Month
- Once a Week
- Several times a week
- Almost every day

Q4

On average, how many hours per week did you spend studying for this class?

0-2 hours 3-4 hours 5-6 hours 7-8 hours 9-10 hours >10 hours

Q5

In this course, how much of your coursework emphasized the following mental activities?

Very much Quite a bit Some Very little

MEMORIZING facts, ideas, or methods from lectures and readings
ANALYZING the basic elements of an idea, experience or theory
SYNTHESIZING and organizing ideas and information to new, more complex interpretations and relationships
INTERPRETING and MAKING JUDGEMENTS about the value of information or data
APPLYING theories or concepts to practical problems or in new situations

Q6

In the past month, how often did you work in student groups with one or more classmates, in this class during class time?

- Never
- Once a month
- Once a week
- Almost every class period

Q7

When you worked in student groups during class time in this class, for about how long did you work?

- Less than 15 minutes
- 15 to 30 minutes
- More than 30 minutes
- I never work in student groups

Q8

A formal study group is a group made up of three or more students and also includes a peer leader or mentor. In the past month, how often did you study with a formal study group for this class?

- Never
- Once a Month
- Once a Week
- Several times a week
- Almost every day

Q9

An informal study group is a group made up of three or more students. In the past month, how often did you study with an informal study group for this class?

- Never
- Once a Month
- Once a Week
- Several times a week
- Almost every day

Q10

In this class relative to other biological science courses, how much competition do you feel towards your classmates at this point in the semester?

- No competition
- A little competition
- Moderate competition
- A lot of competition

Q11

For this class, how often did you attend discussion section?

nearly every week
occasionally
just before exams
not at all

Q12

Rate the following activities as to the relative helpfulness in learning material in Genetics 466 as well as your other biological science courses at UW-Madison?

	Very helpful	Helpful	Somewhat helpful	Not helpful	I do not do this activity
Reading text before lecture					
Taking and reviewing lecture notes					
Making flashcards					
Making diagrams					
Doing and reviewing homework questions					
Rewriting or outlining notes					
Discussing material with others (other students or TAs) in discussion sections					
Reading text after lecture but before exam					
Developing and answering anticipated exam questions					

The following questions are about courses other than this course.

Q13

How useful do you believe coursework in the following disciplines is to your learning of biological science?

	Not at all useful	A little useful	Somewhat useful	Very useful	Extremely useful
General and Organic Chemistry					
Physics					
Mathematics					
Statistics					

Q14

Which of the following introductory biology sequence are you taking or have you completed?

Zoology 101/102 and Botany 130
Biology 151/152
Biocore
Did not take any of these course sequences

Q15

How useful has your introductory to intermediate course sequence been to your learning in other biological science courses?

Extremely useful	Very useful	Somewhat useful	Not at all useful	Did not take this sequence

Zoology 101/102 and/or Botany 130
Biology 151/152 or 153
Biocore

Q16

To what extent has your introductory to intermediate biology course sequence work (in Biology 151/152 OR Biocore OR Zoology 101/102 and/or Botany 130) contributed to your knowledge, skills, and personal development in the following areas?

	Very much	Quite a bit	Some	Very little
Writing clearly and effectively				
Speaking clearly and effectively				
Thinking critically and analytically				
Analyzing quantitative problems				
Using computing and information technology				
Working effectively with others				

Q17

How would you evaluate your entire introductory to intermediate biology course experience at UW-Madison?

- Excellent
- Very Good
- Good
- Fair
- Poor

Q18

Since you have been a student at UW-Madison, have you ever formulated your own scientific research question with or without guidance from a mentor or instructor?

- Yes
- No

Q19

Since you have been a student at UW-Madison, have you ever conducted a scientific investigation with or without guidance from a mentor or instructor?

- Yes
- No

Q20

How confident are you in your ability to do the following activities on your own?

	Not at all confident	A little confident	Somewhat confident	Very confident	Extremely confident
formulate your own scientific research question					
conduct a scientific investigation					

Q21

How confident are you in your ability to write a scientific paper or research proposal?

- Not at all confident
- A little confident
- Somewhat confident
- Very confident
- Extremely confident

Q22

How much has learning to write in a scientific manner helped you in the following mental activities?

	Not at all helpful	A little helpful	Somewhat helpful	Very helpful	Extremely helpful
understand the process of science					
understand scientific concepts					

These last few questions are about your background.

Q23

What is your gender?

- Male
- Female

Q24

Are you 18 years of age or older?

- Yes
- No

Q25

Not including the current semester, how many semesters of coursework have you completed as an undergraduate?

0-1	2-3	4-5	6-7	8 or greater

Q26

In high school, did you complete Advanced Placement (AP) Biology or International Baccalaureate (IB) Biology coursework?

Yes
No

Q27

Not including laboratory courses, since you started college have you worked and/or done research in a research laboratory?

Yes
No