Mendel or Molecules First: What is the Best Approach for Teaching General Genetics?

CHARLES E. DEUTCH

Abstract

A key question in teaching a General Genetics course is whether to present the major concepts of Mendelian genetics first, or to start with the essential ideas of molecular genetics. A comparison of two sequential courses at Creighton University with similar groups of students indicated that there were no statistically significant differences in exam scores or final grades with the two approaches. It thus may be better to focus on the questions of how best to present the material in each area to contemporary students and how better to prepare them to take exams that involve different types of questions requiring analytical, numerical, and writing skills. These issues are discussed in the context of the modern biology curriculum.

Key Words: *Mendelian genetics; molecular genetics; undergraduate curriculum.*

○ Introduction

A course in General Genetics is an important component of most undergraduate biology curricula (Cheesman et al., 2007). General Genetics is often taken after two semesters of General Biology and two semesters of General Chemistry. The course is usually designed to cover several topics that are considered essential for any biology major, including the storage and expression of biological information, the role of gene products in determining specific structures and their functions, the origin and consequences of genetic variation, the role of natural selection in the process of evolution, and the analysis of genomes and the reconstruction of phylogenies (Brownell et al., 2014; GSA, 2015; Smith & Wood, 2016). These topics fit into several of the five core concepts and six core competencies of the *Vision and Change in Undergraduate Biology Education* proposal made by the American Association for the Advancement of Science (AAAS, 2011). Although there is little debate about the importance of these topics, there is less agreement about how best to teach them and how to assess student learning. Some have advocated the use of more active modes of teaching that go beyond lectures and forms of evaluation that are more complex than multiple-choice tests (Lee & Jabot, 2011; Smith & Wood, 2016). However, there are difficulties in implementing these changes and some ambiguity about their success (Andrews et al., 2011; Waldrop, 2015).

A key question in teaching General Genetics is whether to teach the basic concepts of Mendelian genetics first, then follow with a discussion of molecular genetics, or vice versa. Although there has been some research on this question as it applies to middle- and high-school students (Duncan et al., 2016), there have been no systematic studies about this issue as it applies to college- or university-level students. Several textbooks are currently available for use in a General Genetics course at this level (Hartl & Ruvolo, 2012; Griffiths et al., 2015; Hartwell et al., 2015; Klug et al., 2015; Sanders & Bowman, 2015; Pierce, 2016; Snustad & Simmons, 2016; Brooker, 2017). These books vary somewhat in difficulty and content but cover the same essential topics. They are now published in both digital and print versions, and have online resources for students in addition to the written text. These textbooks all use some version of the "Mendel first" approach and include chapters on (1) the basic patterns of inheritance in eukaryotic organisms as seen in monohybrid and dihybrid crosses; (2) mitosis, meiosis, and chromosome distribution; (3) extensions of Mendelian patterns including variations in dominance relationships, lethal alleles, and sex linkage; (4) chromosome mapping in eukaryotes and chromosome structure; (5) genetic analysis of prokaryotic organisms and viruses; and (6) extranuclear or organellar inheritance. These chapters are followed by ones dealing with (7) DNA structure; (8) DNA replication and recombination; (9) transcription and RNA processing; (10) translation and protein synthesis; (11) gene regulation in prokaryotes and eukaryotes; and (12) mutation and DNA repair. Later chapters in the textbooks are more variable but commonly focus on topics such as developmental genetics, cancer, genomics, DNA technology, population genetics, and evolution. Some textbook authors do suggest ways in which the chapters could be re-ordered to cover molecular genetics before Mendelian genetics (Sanders & Bowman, 2015; Brooker, 2017). Two versions of a genetics textbook have sometimes been published in the past (for example, Russell, 2005, 2009), but this is not common now.

The American Biology Teacher, Vol. 80, No 4, pages. 264–269, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2018.80.4.264.

During the Fall semesters of the academic years 2014–2015 and 2015–2016, I taught the General Genetics lecture course (BIO 317) at Creighton University in Omaha, Nebraska, as a sabbatical replacement for the two regular geneticists who were on sequential leaves. Although they had taken somewhat different approaches to the course, they both used *Introduction to Genetic Analysis* by Griffiths et al. (2015) as the primary textbook, and this book had been ordered before I arrived. I used the tenth edition in 2014–2015 and the eleventh edition in 2015–2016. The course at Creighton has two semesters of General Biology and two semesters of General Chemistry as prerequisites. Although the class is positioned as a second-level course, many students defer taking it until their senior year because it is believed to be one of the hardest classes in the biology program there. As a result, some students take courses in Cell Structure and Function or Biochemistry before General Genetics, but others do not. There is a separate Genetics Laboratory course (BIO 318) that is taken by some students either concurrently or after the Genetics lecture course. In 2014, I followed the general organization of the textbook by Griffiths et al. and used the "Mendel first" approach. In 2015, I revised the organization and used a "molecules first" approach with the same book. This thus constituted a kind of natural experiment in which to explore the advantages and disadvantages of the two different approaches with similar groups of students.

○ Course Organization

The General Genetics class was offered each year as two separate but parallel sections with about 30 students each and met for 50 minutes three times a week. Each class was based on a PowerPoint presentation, but often included examples of relevant data or sample problems. Creighton uses an in-class video recording system so all the PowerPoint presentations and the class audio were digitally saved for later review. A written handout was provided for each class with a summary of the lecture material, a list of specific terms to define and know, and problems from the textbook to be answered. There were no graduate assistants or separate recitation sections, but undergraduate assistants offered tutoring sessions, and I held extensive office hours/problem sessions each week. The initial enrollments were similar over the two years. In the Fall semester of 2014, there were a total of 52 students, which included no sophomores, 27 juniors, and 25 seniors. In the Fall semester of 2015, the initial enrollment was again 52 students, but included 12 sophomores, 18 juniors, and 22 seniors. This reflected a difference in the advising process in which some Biology majors were encouraged to take the class sooner. The sequences of topics for the two versions of the course are shown in Table 1.

Some topics were covered in a single class period, but others took a period and half or two periods. The schedule was adjusted during the semester, and some topics that were initially included, such as Developmental Genetics, were dropped as I learned more about the department's curriculum.

The courses were similar in that each had four or five in-class exams consisting of two parts. Part I was a set of 30 multiple-choice questions worth 2 points each for a total of 60 points. These questions were a combination of relatively simple genetic problems and those that tested student comprehension of the basic genetic facts or concepts. Part II consisted of four genetic problems or short-answer questions worth 10 points each for a total of 40 points. The genetic problems were more complex than those in the multiple-choice section and often involved multistep calculations. The short-answer questions were usually introduced with a figure similar to one used in the textbook or in the PowerPoint presentations given in class

Table 1. Course sequences in General Genetics (BIO 317) at Creighton University.

Fall 2014—"Mendel first"	Fall 2015—"molecules first"
The genetic system	The genetic system and genetic analysis
Inheritance of single genes in eukaryotes	DNA structure and organization into chromosomes
Variations in single gene inheritance	DNA replication and transmission in prokaryotes
Inheritance of independently assorting genes	DNA replication and transmission in eukaryotes
Inheritance of organelle genes	Transcription in prokaryotes
Gene interactions	Transcription and RNA processing in eukaryotes
Inheritance of linked genes and recombination	Protein synthesis
Mapping genes on eukaryotic chromosomes	Cloning and sequencing of DNA
Mapping genes in bacteria	Transcriptomes and proteomes
DNA structure and chromosome organization	Inheritance of single genes in eukaryotes
DNA replication	Sex linkage and human pedigree analysis
Transcription	Dihybrid crosses and independent assortment
RNA processing	Variations in Mendelian patterns
Protein synthesis	Polygenic traits and epistatic interactions
Regulation of gene expression in bacteria	Organelle genetics
Regulation of gene expression in eukaryotes	Inheritance of linked genes and recombination

(continued)

Table 1. Continued

Fall 2014—"Mendel first"	Fall 2015—"molecules first"
Transposable elements	Mapping genes on eukaryotic chromosomes
Mutation	Mapping genes in bacteria
DNA Repair	Molecular mechanisms of recombination
Recombination and recombinational repair	Regulation of gene expression in bacteria
Large-scale chromosomal changes	Regulation of gene expression in eukaryotes
Population genetics	Transposable elements
Inheritance of complex traits	Large-scale chromosomal changes

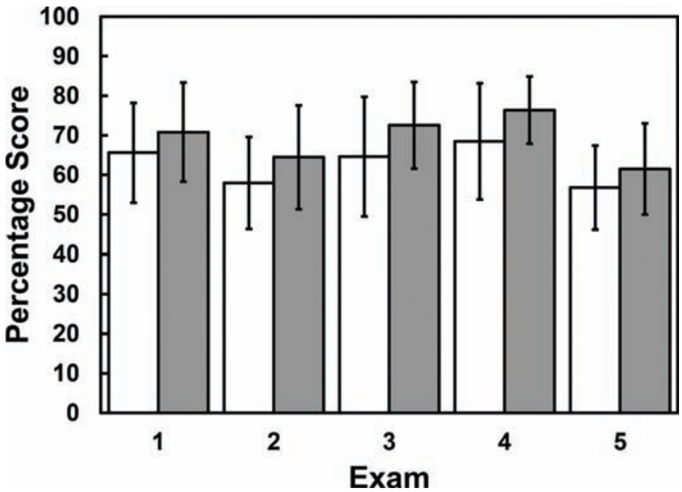

Figure 1. Mean percentage scores on the five exams in General Genetics (±1 SD) for the Fall semester of 2014. The open bars show the scores for students who had not taken Cell Structure and Function prior to enrolling in Genetics. The filled bars show the scores for students who had taken Cell Structure and Function prior to enrolling in Genetics. An ANOVA analysis of the data was done with an online program (Vasavada, 2016), and post-test analysis indicated that the only significant differences were between the scores on Exam 4 and Exam 5 for each group.

and involved several subparts. In addition to the exams, there were eight to ten homework assignments each year that could be completed individually or in small groups. Again, depending on the material, the homework assignments consisted of genetic problems of different types or short-answer questions. I also had the students in the Fall 2014 class write a term paper on a topic of their own choosing about genetics, but I dropped this assignment for the Fall 2015 class.

There were several reasons for changing the approach from "Mendel first" to "molecules first" in the second year. First, I found that students who had Cell Structure and Function before taking General Genetics appeared to do better on each of the five exams in 2014 (Figure 1). Exams 1 and 2 focused on Mendelian genetics, Exams 3 and 4 focused on molecular genetics, and Exam 5 covered a mixture of topics. Although the standard deviations were relatively large, an ANOVA analysis of the data (Vasavada, 2016) indicated significant differences among all 10 of the exam scores (F-statistic = 6.23, p-value = 8.34×10^{-8}). A Tukey HSD (honestly significant difference) post-test analysis as well as Scheffé and Bonferroni and Holm comparisons indicated the most consistent significant differences were between the scores on Exam 4 and the scores on Exam 5. However, on any individual test, there were no significant differences between those students who had taken Cell Structure and Function and those who had not.

Second, I thought that some Mendelian concepts like dominance, epistasis, and variable penetrance would make more sense if students understood how genes worked and contributed to a phenotype. If a student does not know that genes direct the synthesis of proteins, and that gene products interact to produce observable phenotypes, these concepts are often obscure. In a similar way, genetic exchange and gene mapping in bacteria are better understood if a student knows how DNA replication and molecular recombination work. Third, I felt that because the material in molecular genetics is somewhat more descriptive, students might do better on the exams at the beginning of the course. They would thus develop enough confidence to cope better with the more difficult analytical material that is involved in the interpretation of crosses in Mendelian genetics.

○ Student Performance

Figure 2 summarizes the percentage scores on the exams for the two years I taught General Genetics at Creighton University. The data shown in Figure 1 were pooled to give the results for 2014, and as before, the standard deviations were relatively large. The exams were similar in difficulty, but because of the differences in the sequence of topics, they varied in the specific questions on each test. The average percentage score for all of the exams in the Fall 2014 class was 65.77 with a standard deviation of 12.79. The average percentage score for all of the exams in the Fall 2015 class was 65.02 with a standard deviation of 13.12. Qualitatively, the scores appeared to increase in 2014 (except for Exam 5) as we moved from Mendelian genetics to molecular genetics, and to decrease in Fall 2015 as we moved from molecular genetics to Mendelian genetics.

An ANOVA analysis of the data (Vasavada, 2016) indicated statistically significant differences among the exams. Across all nine exams, the F-statistic was 5.48 for a p-value of 3.87×10^{-7}. As a test of the hypothesis that presenting molecular genetics first might lead to better performance on the Mendelian analysis questions, I compared the scores on Exams 3 and 4 from 2015, which focused on

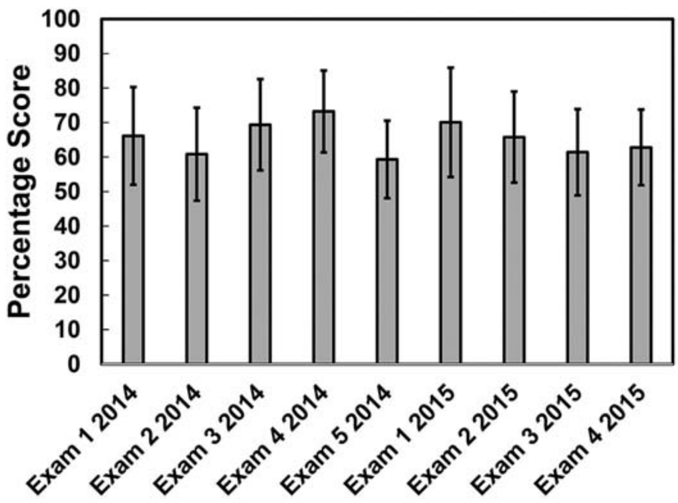

Figure 2. Mean percentage scores (±1 SD) for the five exams in the Fall semester of 2014 and for the four exams in Fall semester of 2015. An ANOVA analysis of the data was done with an online program (Vasavada, 2016), and post-test analysis indicated no significant differences based on the order of the topics.

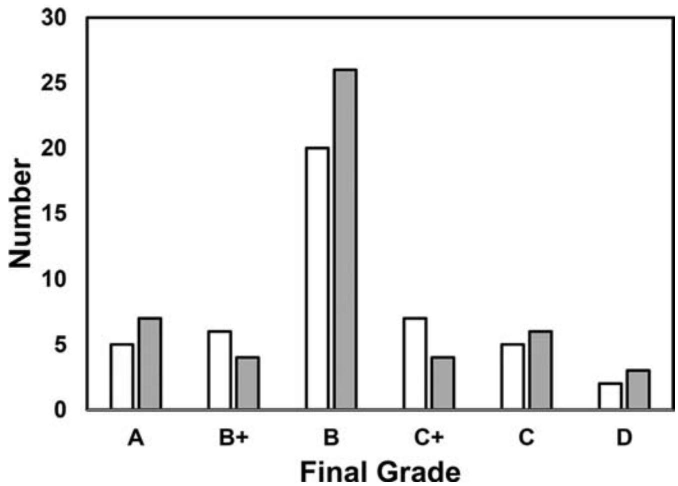

Figure 3. Distribution of final grades in General Genetics for the Fall semester of 2014 (open bars) and the Fall semester of 2015 (filled bars).

Mendelian genetics, with those of Exams 1 and 2 of 2014. The averages for 2015 were 61.41 ± 12.5 and 62.81 ± 10.96, respectively. The averages for 2014 were 66.14 ± 14.15 and 60.83 ± 13.47, so there was no apparent improvement. The post-test Tukey HSD analysis indicated no significant differences as a result of changing the sequence of topics. In a same way, the averages for Exams 3 and 4 in 2014, which covered molecular genetics (69.37 ± 14.15 and 73.21 ± 11.88), were similar to those for Exams 1 and 2 in 2015 (70.08 ± 15.83 and 65.8 ± 13.2). Again, the post-test Tukey HSD analysis indicated the differences were insignificant.

Figure 3 shows the final grade distributions for the two years. Creighton does not use minus grades, so only grades of A, B+, B, C+, C, and D are shown. About 10 percent of the students withdrew from the course each year before the end of the semester. Although the averages on the exams were consistently less than 70 percent, the students were able to raise their total points for the semester through the open-book, group homework assignments, a supplementary problem set, and a term paper in 2014, and a 5 percent grade inflator in 2015. I also adjusted the final percentage cut-offs slightly from the standard Creighton grading scale (A = 90–100%, B+ = 87–89.9%, B = 80–86.9%, etc.). I confirmed with the other instructors and the Department Chair that these grades were typical of past performance in the class.

○ Perspectives and Conclusions

This natural experiment indicates that in the General Genetics course at Creighton University, it makes little difference whether Mendelian genetics is presented before molecular genetics or vice versa. I found that in both 2014 and 2015, some students did better in the section on molecular genetics than they did in the section on Mendelian genetics. Other students did better in the section on Mendelian genetics than they did in the section on molecular genetics. With the addition of points from the homework assignments and other supplementary points, the scores balanced out so the final percentage scores and grade distributions were similar. In general, however, students had more difficulty with the Mendelian genetics section than they did with the molecular genetics section.

The student course evaluations did not differ with the approach and were decidedly mixed each year (average of about 3.5 out of 5 on the most general questions). For some students, I was one of the best instructors they had ever had, but for others I was one of the worst. For some, the workload and exams were reasonable, but for others the material was too difficult and the exams were too long and too hard. For some, there was a good correlation between the class presentations and the exams, but for others these were disconnected. Interestingly, none of the students commented on the sequence of topics in the semester that they took the class. The fact that the means on the exams were around 60–65 percent was a source of much anxiety. Many biology majors at Creighton have high aspirations and are focused on health-related careers. The possibility of not getting an A or B+ was a major concern. Other faculty in the department told me that is not unusual for this class and that my experience there was normal.

My general conclusion from this experiment is that "Mendel first" or "molecules first" is not the right question to ask about a General Genetics course. Better questions to ask are, what do the students find difficult about each of these aspects of genetics, and how can their performance on exams in each area be improved. In the case of Mendelian genetics, the major difficulties were related to data interpretation and analysis. For many students, this was an entirely new experience that required the ability to think through various possibilities and a level of numerical fluency they had not yet attained. Although I assigned many problems from the textbook and gave them extensive homework assignments, many students struggled with these types of questions. I gave them handouts with suggestions for how to do this, including references to specific books (Kowles, 2001; Elrod & Stansfield, 2010; Nickla, 2010), links to various web sites, and examples from other textbooks. I also spent many hours each week helping students with the homework problems. However, many of them never figured out how to solve genetic problems effectively. They often looked for quick short-cuts or formulas, and would not take the time needed to work through the possibilities. As the course moved along, they sometimes forgot about topics we had discussed before. The low scores on Exam 5 in 2014 were a clear example of this.

In the case of the molecular genetics section, the major difficulties were related to the complexity of some of the material that was not in the textbook, to the need to recall concepts at different times during the class, and to the students' abilities to deal with the short-answer questions on the exams. Although the textbook by Griffiths et al. is very good at presenting genetic analysis and contains extensive end-of-the-chapter problem sets, its discussion of molecular and microbial genetics is largely historical. I had to supplement the material on DNA replication, transcription, translation, and DNA repair with additional slides in the PowerPoint presentations. Likewise, I had to present many modern techniques like high-throughput DNA sequencing, genome analysis, and transcriptome and proteome analysis, which were not covered in the book at all. Although I had thought that the students might do better on the exams dealing with this material, that was not consistently the case. They often did not remember the basics of DNA structure and metabolism when the issues of DNA repair and recombination or transposition came up later in the course. Many students came into the class from large courses like General Biology where the exams were composed entirely of multiple-choice questions. They had difficulty in understanding what was expected to get full-credit on a short-answer question and in writing good answers during the exam itself. Although I included similar questions as part of the homework assignments, they often complained even when they were given partial credit on an exam question. To them, getting 7 out of 10 possible points looked like 70 percent and a C. Getting 5 or 6 points was even worse.

From this experiment, I believe each instructor needs to determine the best sequence for their students, based on the organization of their department's curriculum, his or her personal background and experience, and the choice of textbook. Most genetics textbooks are now very large (700–800 pages) and contain more material than can be reasonably covered in one semester. For a survey course that attempts to cover both Mendelian genetics and molecular genetics, I still think the "molecular first" approach may be the best, particularly if the students do not have to take a course like Cell Structure and Function first. My own background is in microbial genetics and molecular biology, so these are topics in which I have a particularly strong interest. Other instructors whose interests are in genomics, evolution, or human genetics may have other preferences. Because genetic analysis is so hard for many students today, it might be preferable to move most of the molecular material into a separate course in Molecular Genetics (Molecular Biology) or to include it in a course in Cell Structure and Function. By doing this, the General Genetics course could move at a slower pace and give students sufficient time to learn how to deal with the analytical problems. The ability of the students to deal with both genetic problems and short-answer questions seems to be related primarily to the amount of practice they get.

As noted in the Introduction, the AAAS proposal entitled *Vision and Change*, which suggests major revisions in undergraduate biology, refers to several topics that are included in a General Genetics course. Of the five core concept areas, General Genetics is most important for Evolution and for Information Flow, Exchange, and Storage. Of the six core competencies, General Genetics is critical to the Ability to Apply the Process of Science, the Ability to Use Quantitative Reasoning, the Ability to Use Modeling and Simulation, and the Ability to Understand the Relationship between Science and Society. Although the *Vision and Change* document is very useful in outlining these core concepts and competencies, it is less clear about the order in which specific courses might be taken and about how students might gradually develop their scientific and intellectual skill. Mead et al. (2017) found that teaching Genetics before Evolution to high school students in the United Kingdom helped student understanding but did not change their acceptance of the evolutionary process.

Some genetics instructors have suggested discarding the "canon" found in most textbooks and restructuring the General Genetics course completely (Redfield, 2012). However, to the extent that the course needs to prepare students to take standardized tests like the Graduate Record Exam (GRE) or Medical College Admissions Test (MCAT), I do not think the basic content of Mendelian genetics and molecular genetics can be eliminated completely. Nevertheless, there is a need to discuss how best to present this material to contemporary students. Several authors have looked recently at these issues (Pavlova & Kreher, 2013; McElhinny et al., 2014; Smith & Wood, 2016), and it is important for this conversation to continue. To assess how different curricula or teaching approaches affect student learning, some instructors may want to use a standardized concept assessment test for either Mendelian genetics (Smith et al., 2008) or molecular genetics (Couch et al., 2015). These tests might be used as either pre-tests or post-tests. Further explorations of the "Mendel first" or "molecules first" question in different institutions with varying student populations would be very helpful.

○ Acknowledgments

I thank Dr. Pamela A. Marshall of the West campus of Arizona State University for helpful discussions and for reading the manuscript. I also thank the faculty and staff in the Department of Biology at Creighton University for their hospitality while I was there.

References

American Association for the Advancement of Science (AAAS). (2011). *Vision and change in undergraduate biology education: A call to action*. Washington, DC.

Andrews, T. M., Leonard, M. J., Colgrove, C. A. & Kalinowski, S. T. (2011). Active learning *not* associated with student learning in a random sample of college biology courses. *CBE-Life Sciences Education*, *10*, 394–405.

Brooker, R. J. (2017). *Genetics: Analysis and principles* (6th ed.). New York: McGraw-Hill Education.

Brownell, S. E., Freeman, S., Wenderoth, M. P., & Crowe, A. J. (2014). BioCore Guide: A tool for interpreting the core concepts of vision and change for biology majors. *CBE-Life Sciences Education*, *13*, 200–211.

Cheesman, K., French, D., Cheesman, I., Swails, N., & Thomas, J. (2007). Is there any common curriculum for undergraduate biology majors in the 21st century? *BioScience*, *57*, 516–522.

Couch, B. A., Wood, W. B., & Knight, J. K. (2015). The molecular biology capstone assessment: A concept assessment for upper-division molecular biology students. *CBE-Life Sciences*, *14*, 1–11.

Duncan, R. G., Castro-Faix, M., & Choi, J. (2016). Informing a learning progression in genetics: Which should be taught first, Mendelian inheritance or the central dogma of molecular biology? *International Journal of Science and Mathematics Education*, *14*, 445–472.

Elrod, S. L., & Stansfield, W. D. (2010). *Schaum's Outline of Genetics* (5th ed.). New York: McGraw-Hill Education.

Genetics Society of America (GSA). (2015). Core concepts and competencies in genetics. Retrieved from http://www.genetics-gsa.org/education/GSAPREP_CoreConcepts_CoreCompetencies.shtml

Griffiths, A. J. F., Wessler, S. R., Carroll, S. B., & Doebley, J. (2015). *Introduction to Genetic Analysis* (11th ed.). New York: W. H. Freeman and Company (10th edition, 2012).

Hartl, D. L., & Ruvolo, M. (2012). *Genetics: Analysis of genes and genomes* (8th ed.). Burlington, MA: Jones and Bartlett Learning.

Hartwell, L. H., Goldberg, M. L., Fischer, J. A., Hood, L., & Aquadro, C. F. (2015). *Genetics: From genes to genomes* (5th ed.). New York: McGraw-Hill Education.

Klug, W. S., Cummings, M. R., Spencer, C. A., Palladino, M. A., & Killian, D. (2015). *Concepts of Genetics* (11th ed.). Boston: Pearson Education.

Kowles, R. (2001). *Solving Problems in Genetics*. New York: Springer-Verlag.

Lee, W. T., & Jabot, M. E. (2011) Incorporating active learning techniques into a genetics class. *Journal of College Science Teaching*, *40*, 94–100.

McElhinny, T. L., Dougherty, M. J., Bowling, B. V., & Libarkin, J. C. (2014). The status of genetics curriculum in higher education in the United States: Goals and assessment. *Science & Education*, *23*, 445–464.

Mead, R., Hejmadi, M., & Hurst, L. D. (2017) Teaching genetics prior to teaching evolution improves evolution understanding but not acceptance. *PLOS Biology*, *15*, e2002255.

Nickla, H. (2010). *How to Solve Genetics Problems*. San Francisco: Benjamin/Cummings Pearson Education.

Pavlova, I. V., & Kreher, S. A. (2013). Missing links in genes to traits: Towards teaching for an integrated framework of genetics. *American Biology Teacher*, *75*, 641–649.

Pierce, B. A. (2016). *Genetics: A conceptual approach* (6th ed.). New York: W. H. Freeman and Company.

Redfield, R. J. (2012). "Why do we have to learn this stuff?"—A new genetics for 21st century students. *PLoS Biology*, *10*(7), e1001356.

Russell, P. J. (2005). *iGenetics: A Mendelian approach* (1st ed.). Boston: Benjamin/Cummings Pearson Education.

Russell, P. J. (2009). *iGenetics: A molecular approach* (3rd ed.). Boston: Pearson Education.

Sanders, M. F., & Bowman, J. L. (2015). *Genetic analysis: An integrated approach* (2nd ed.). Boston: Pearson Education.

Smith, M. K., & Wood, W. B. (2016). Teaching genetics: Past, present, and future. *Genetics*, *204*, 5–10.

Smith, M. K., Wood, W. B., & Knight, J. K. (2008). The genetics concept assessment: A new concept inventory for gauging student understanding of genetics. *CBE-Life Sciences*, *7*, 422–430.

Snustad, D. P., & Simmons, M. J. (2016). *Principles of Genetics* (7th ed.). Hoboken, NJ: John Wiley & Sons.

Vasavada, N. (2016). One-way ANOVA (ANalysis Of VAriance) with post-hoc Tukey HSD (Honestly Significant Difference) Test Calculator for comparing multiple treatments. Available at http://astatsa.com/OneWay_Anova_with_TukeyHSD/

Waldrop, M. M. (2015). The science of teaching science. *Nature*, *523*, 272–274.

CHARLES E. DEUTCH is Professor Emeritus in the School of Mathematical and Natural Sciences at the West campus of Arizona State University, Phoenix, AZ 85069-7100; email: Charles.Deutch@asu.edu. This study was done while he was a Resident Professor in the Department of Biology at Creighton University in Omaha, NE 68178.