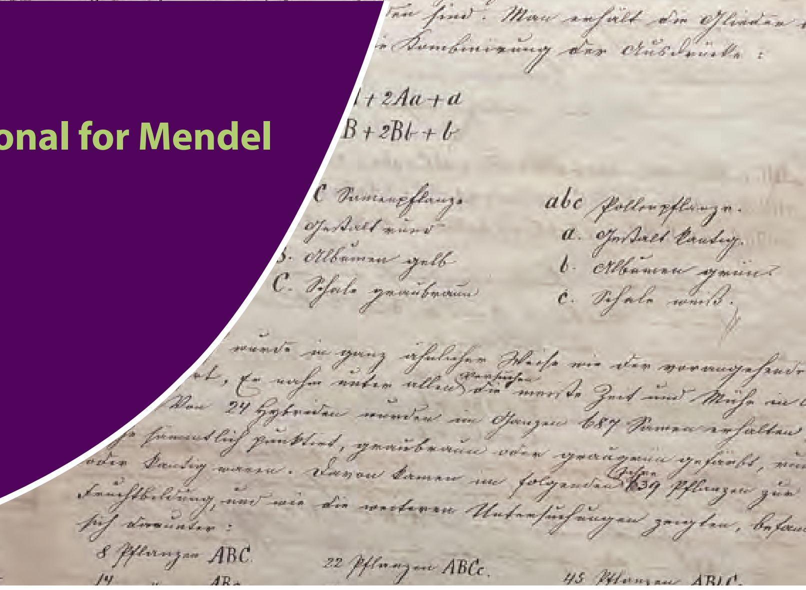
FEATURE ARTICLE

Genetics Gets Personal for Mendel



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Abstract

The sequencing of Gregor Mendel's genome in conjunction with the 200th anniversary of his birth marks a historical first; the scientist who founded a major discipline has had that very science applied to himself. The use of ancient DNA (aDNA) to investigate Mendel's health history provides students an opportunity to explore the related technology and to consider the ethical implications of probing the genomes of famous historical individuals. This article suggests a class exercise.

Key Words: *Gregor Mendel; ancient DNA; genome sequencing; bioethics; OMIM.*

○ Introduction

In an unprecedented quirk of history, an iconic natural scientist has been subjected to the application of his own work, using the most modern biotechnology 160 years after he founded his field—genetics. Gregor Mendel, who discovered the particulate nature of inheritance, now called genes, and set forth the fundamental rules of the process, has had his own genome sequenced. That event bookends the famed abbot's pioneering studies of inherited biological variation with the current ability to identify such variation at the level of individual DNA bases. Sequencing of Mendel's genome occurred as part of a year-long celebration of the bicentennial of his birth in 1822, with many of the related activities taking place during July in Brno, Czech Republic, where Mendel meticulously worked on the pea plant *Pisum sativum* (Evans, 2022; McInerney, 2022).

Definitive findings from the exhumation and the genomic sequencing of DNA have not yet been published in a peer-reviewed scientific journal. Still, the preliminary findings in a monograph written in Czech, German, and English (Drozdová et al., 2022) provide students with opportunities to investigate the capabilities and limitations of genomic data and associated bioethical issues. The application of genomic technology to virtually all areas of the life sciences raises numerous and diverse biological questions (Capps et al., 2025) that can be the source of productive investigation in the biology classroom. The sequencing of Mendel's genome provides one such opportunity, applied in this case to the scientist who birthed the entire discipline.

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○ The Genome of *Pisum sativum*

Modern biotechnology has finally elucidated the detailed nature of the genes associated with the seven pea traits Mendel investigated, as described in most biology textbooks that address genetics. Table 1, summarized and abbreviated from work published in *Nature* (Feng et al., 2025), can help guide students into more detailed investigations of relevant genes and gene products. One line of investigation, for example, might address the origin and evolutionary conservation of the genes across plant taxa, while another might explore genes whose manipulation could enhance traits such as plant yield and disease resistance. A third might investigate the biochemical pathway from gene to trait.

○ Mendel's Genome

Contemporary information from Mendel's life suggests long-standing kidney disease, in medical terms, "a somewhat rapid demise from chronic hypertension and glomerulonephritis with edema, uremia, and nephrotic syndrome" (Mulvihill & Grody, 2023). Exhumation of Mendel's remains, in 2021, had the approval of the Catholic Order of Saint Augustine and legal authorities in Brno. Additional clinical findings, summarized in the *Journal of the American Medical Association* (Mulvihill & Grody, 2023), include

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Table 1. The Gene Variants of Mendel's Seven Pea Traits

Trait	Variants (first is dominant)	Trait Abbreviation	Chromosome	Gene Product (Gene Abbreviation)
Seed shape	Round; winkled	R	3	Starch branching enzyme 1 (*PsSBE1*)
Stem length; plant height	Tall; dwarf	Le	5	Gibberellin 3-oxidase (*PsGAox1*)
Fasciation or flower position	Axial; terminal	Fa	4	CIK-like (co-) receptor kinase (*PsCIK2/3*)
Ripe pod shape (form)	Inflated; constricted	P*	1	Signaling small peptide (*PsCLE41*)
		V*	5	Transcription factor (*PsMYB26*)
Unripe pod color	Green; yellow	Gp	5	Chlorophyll synthase (*PsChiG*)
Flower color	Colored (purple); white	A	6	Basis helix-loop-helix (*PsbHLH-A*) transcription factor of chalcone synthesases
Seed coat and cotyledon color	Yellow; green	I	2	Mg-dechelatase (*PsSGR*), a STAY-GREEN enzyme

*Two loci affect cell-wall thickening in pods.

- "evidence of chronic periodontitis, obesity, a biological age of 65 years (versus a calendar age of 62 years), spina bifida of three sacral vertebrae;
- a variant in the gene *KCNJ2*, known to underlie the rare Anderson-Tavil cardiodysrhythmic periodic paralysis syndrome with dysmorphic facial and skeletal features (OMIM 170390 and 600281);
- variants in two genes associated with long-QT syndrome (a hereditary cardiac conduction arrythmia);
- one gene variant with hypertrophic cardiomyopathy;
- three variants with kidney failure; and
- one variant with hyperaldosteronism (possible hypertension and depression)."

The authors also caution, "of course, one should be careful not to overinterpret these variants as indicative of causality in the absence of known symptoms of these genetic disorders during life."

OMIM refers to Online Mendelian Inheritance in Man, "a continuously updated catalog of human genes and genetic disorders and traits." Housed at the Johns Hopkins University School of Medicine, OMIM is the online version of the classic reference *Mendelian Inheritance in Man*, first printed in 1966 by the pioneering medical geneticist Victor A. McKusick. OMIM is accessible free of charge at https://www.omim.org. Your students can consult this valuable resource using the OMIM numbers here (or just the clinical terms) to find information about the traits and genes in question, including disease features and the mode of inheritance.

Although Mendel was a priest, never married, and had no children, he did have two sisters, Veronika and Theresia, and they had living descendants, now said to reside in Germany and Austria. In 2010, family members and the Augustinian Order were embroiled in a dispute (Wade, 2010) over ownership of Mendel's original manuscript *Experiments in Plant Hybridization*, considered by historians of science to be one of the two most important scientific works of the 19th century, the other being Darwin's *On the Origin of Species by Means of Natural Selection*.

Could the laws of inheritance Mendel elaborated have implications now for his descendants six generations later, based on his newly sequenced genome? What is the likelihood that any of Mendel's distant relatives are at risk for any of the maladies genome sequencing has revealed? (Hint: each step between relatives, on average, means half the genes are passed on.)

○ Ethics & Ancient DNA (aDNA)

During the last several decades, techniques for isolating and analyzing aDNA have improved markedly (Dalen et al., 2023) and have probed topics ranging from very early human evolution and migrations (Reich, 2018) to the more recent peopling of the Americas (Raff, 2022), the presence of Neanderthal genes in our human genome (Li et al., 2024), the descendants of African American iron furnace workers in 19th-century Maryland (Curry, 2023; Harney et al., 2023), and even the evolution of plants as revealed by aDNA extracted from herbaria worldwide (Burbano & Gutaker, 2023).

Given the power of this technology, it is hardly surprising that attention would turn to the genomes of famous historic individuals. Recently, genomic data were published from hair samples of the legendary German composer Ludwig van Beethoven, who died in 1827 (Begg et al., 2023). He suffered from several chronic illnesses during his lifetime, "including progressive hearing loss, recurring gastrointestinal complaints, and liver disease." The most significant positive finding of the genomic analysis was a genetic predisposition to liver disease, likely aggravated by the composer's love of wine. The most significant negative finding was the absence of any of the known mutations that could explain his deafness.

The data on Beethoven's liver disease are a reminder of the multifactorial nature of most diseases (Tabery, 2023) and of the need to consider both genetic and environmental determinants for most diseases when teaching genetics (Dougherty, 2009; McInerney, 2022; Griswald, 2023).

Even though neither Beethoven nor Mendel had children, questions may arise about the privacy of the research results in the context of more distant surviving relatives. A more overarching question might address the perceived justification for doing these studies in the first place. Is there a compelling medical, scientific, or historical import to be gained? One can argue that genomic studies on Beethoven are valuable to musicologists because his deafness had tremendous impact on his life and work, and no cause for it has yet been demonstrated. In contrast, Mendel—to the best of our knowledge—suffered from no such major physical handicap during his life, and had no unusual medical problems beyond those that were very common among Europeans at the time; moreover, his age at death was well within the typical lifespan for the era. Given this knowledge, can Mendel's exhumation and comprehensive genetic probing be justified beyond mere academic interest, simple curiosity, or public awareness? The Czech team opined that Mendel "would have been enthusiastic about this endeavor" (Drozdová et al., 2022).

○ Addressing Bioethics in the Classroom

Although it is of value to address bioethical dilemmas in the classroom (Zhong, 2024), most biology teachers have little formal training in ethical analysis, and such sessions in the classroom easily can devolve into unfocused discussion and disagreement without a clear framework and rules. One well-tested structure employs goals, rights, and duties to compare the interests of parties involved in an ethical dilemma. The framework is based on an article by the philosopher Gerald Dworkin, from the magazine *Hard Choices*,

Table 2. Basic Questions Related to Goals, Rights, and Duties

Category	Questions
Goals	• What are the objectives or outcomes of the act in question? • What are the consequences, positive or negative, of the act in question?
Rights	• Is one entitled to a certain kind of treatment no matter the consequences? • Does the assertion of a given right impose an implicit duty on some other person or entity to fulfill that right?
Duties	• Is there an obligation to act in a certain way? • Will fulfillment of the duty achieve a worthy goal?

Note: Goals, rights, and duties often can be in conflict for interested parties, and there even can be conflicts within each category. For example, a patient's goal to die without the application of expensive life-saving technology can conflict with his or her physician's goal to preserve life at all cost.

Table 3. Framework for Considering Ethical Issues

INTERESTED PARTY	GOALS	RIGHTS	DUTIES
RESEARCH COMMUNITY	Investigate the genome of a famous, historic person	Have access to requisite biological materials	Conduct the genomic analysis using the best methods and techniques available
	Report the results publicly	Have fair access to appropriate review and publication mechanisms	Report the results fully and accurately
			Respond fully and accurately to questions from the research community, descendants, and the public
			Alert descendants to any potential harms inherent in the genomic data
DESCENDANTS	Protect the family's legacy	Veto any research that might cause harm to family members	Provide full and accurate information about all family members
	Prevent stigma and discrimination based on genetic findings	Discuss potential implications with researchers before and after genomic analysis	
		Have free access to consultation and health care for any family members found to be at risk because of the genomic analysis	

circa 1980. The Biological Sciences Curriculum Study (BSCS) used this approach to good effect in several of its classroom modules on human genetics and the human genome project. Before we undertake a discussion of the ethics of sequencing Mendel's genome, the categories need definition, as shown in Table 2, adapted from *Basic Genetics: A Human Approach* (BSCS, 1980).

Although many bioethical cases are rooted in clinical situations, students should realize that goals, rights, and duties apply to the analysis of many ethical questions in biology beyond medical issues. Examples arise in taxonomy, ecology, and evolution, for example, in the potential use of CRISPR-related gene editing to control and perhaps obliterate all species of *Anopheles* mosquitos that transmit the malarial parasite. Gene editing can render female *Anopheles* mosquitos infertile, and that trait can spread rapidly through an entire population, causing markedly reduced reproduction, and even, some ecologists fear, the elimination of the entire genus.

Is this procedure ethically defensible (Kaebnick et al., 2025)? Should we protect our own species from significant harm—approximately 500,000 children in Africa and Southeast Asia die annually from malaria—by destroying other species? A standard maxim of ecology is that you can never do just one thing in a complex ecosystem. What might be the unintended effects on the rest of the ecosystem that includes the mosquitos and their predators such as bats and dragonflies? We can use the goals, rights, and duties triad to investigate the interests of some of the parties in this challenge, such as affected populations, geneticists and entomologist who would conduct the gene editing, ecologists and evolutionary biologists who study the impact of extinction, and even advocates for the mosquitos.

You can conduct these discussions of ethics with the entire class at once or divide the class into smaller groups who then report their results to the whole class. It is helpful to record the students' views in a chart such as that shown in Table 3. Such a display makes clear where the conflicts or disagreements lie among the interested parties over the question of whether and how genomic sequencing of a famous historic person should occur. As in all ethical analyses, there often is no "correct" resolution, but careful, thoughtful analysis helps to distinguish well-reasoned from badly wrought resolutions.

Table 3 provides some potential goals, rights, and duties for only two interested parties: the research community and descendants of the historic person. You and your students might choose additional interested parties and likely will generate additional goals, rights, and duties. Other interested parties might include health-care providers for relatives, health-care payors for relatives, public-health professionals who track the aggregation of disease in populations, and even pharmaceutical entities that might use aDNA for commercial purposes. Students can elaborate the goals, rights, and duties for those and other parties.

○ Conclusion

The unique confluence of events and technology in connection with the Mendel birth bicentennial can provide a rich context for scientific and ethical exploration by students. To emphasize, Mendel entered the clergy and performed his momentous experiments with pea plants on the grounds of his monastery; but his initial ambition was to be a teacher—a goal dashed primarily by his lifelong performance anxiety, causing him repeatedly to fail the teaching certification exams (Evans, 2022; Hennig, 2000; Orel, 1984). How appropriate, then, that the conjunction of his fundamental laws of inheritance with the latest cutting-edge techniques in molecular biology should produce such a teachable moment on the occasion of his 200th birthday.

References

Begg, T. J. A., Schmidt, A., Kocher, A., Larmuseau, M. H. D., Runfeldt, G., Maier, P. A., Wilson, J. D., Barquera, R., Maj, C., Szolek, A., Sager, M., Clayton, S., Peltzer, A., Hui, R., Ronge, J., Reiter, E., Freund, C., Burri, M., Aron, F., Tiliakou, A., … & Krause, J. (2023). Genomic analyses of hair from Ludwig van Beethoven. *Current Biology* 33, 1431–1447.

Biological Sciences Curriculum Study. (1980). *Basic genetics: A human approach*.

Burbano, H. A. & Gutaker, R. M. (2023). Ancient DNA genomics and the renaissance of herbaria. *Science*, *382*(6666), 59–63. https://doi.org/10.1126/science.adi1180.

Capps, B., Chadwick, R., Joly, Y., Lajaunie, C., Hauptmannova, I., Mackenzie, S., Mulvihill, J.J., Mumford, E., Rasmussen, S. A., Sanghavi, K., Thaldar, D. W., Yeates, J., Quinzin, M. C., & Lederman, Z. (2025). The ecological genome project and the promises of ecogenomics for society: Realising a shared vision as One Health. *Bioethics*, *39*(9), 788–795. https://doi.org/10.1111/bioe.70020

Curry, A. (2023). Forging connections. *Science*, *381*(6657), 472–477.

Dalen, L., Heintzman, P.D., Kapp, J.D., Shapiro, B. (2023). Deep-time paleogenomics and the limits of DNA survival. *Science*, 382(6666), 48-53.

Dougherty, M. J. (2009). Closing the gap: Inverting the genetics curriculum to ensure an informed public. *American Journal of Human Genetics*, *85*, 1–7.

Drozdová, E., Doubek, M., & Pospíšilová, S. (2022). *Gregor Johann Mendel: Ways to the genome of the founder of genetics*. Masaryk University Press. https://doi.org/10.5817/CZ.MUNI.M280-0081-2022

Evans, J. P. (2022). Still learning from Gregor Mendel after 200 years. *The American Biology Teacher*, *84*(1), 8–13.

Feng, C., Chen, B., Hofer, J., Jiang, M., Song, B., Cheng, H., Lu, L., Wang, L., Howard, A., Bendahmane, A., Fouchal, A., Moreau, C., Sawada, C., LeSignor, C., Zhang, C., Vikeli, E., Tsanakas, G., Zhao, H., Cheema, J., … & Cheng, S. (2025). Genomic and genetic insights into Mendel's pea genes. *Nature*, *642*, 980–989.

Griswald, J. C. (2023). Moving from Mendel to multifactorialism in genetics instruction. *The American Biology Teacher*, *85*(7), 367–368.

Harney, E., Michletti, S., Bruwelheide, K. S., Freyman, W. A., Bryc, K., Akbari, A., Jewett, E., Comer, E., Gates, H. L., Jr., Heywood, L., Thornton, J., Curry, R., Ancona Esselmann, S., Barca, K. G., Sedig, J., Sirak, K., Olalde, I., Adamski, N., Bernardos, R., Broomandkhoshbacht, N., … & Reich, D. (2023). The genetic legacy of African Americans from Catoctin Furnace. *Science, 381*(6657), 500. https://doi.org/10.1126/science.eade4995.

Henig, R. M. (2000). *The monk in the garden*. Houghton Mifflin.

Kaebnick, G. E., Collins, J. P., Jayaram, A., Tiernan, R. G., Barnhill, K., Carter, L., Chemhuru, M., Fresia, P., Jennings, B., Meine, C., Ndebele, P., Palmer, C., Preston, C., Redford, K. H., Rohwer, Y., Sandler, R., Scott, M. J., Taitingfong, R., & Zoloth, L. (2025). Deliberate extinction by genome modification: An ethical challenge. *Science 388*(6748), 707–709.

Li, L., Comi, T.J., Bierman, R. F., & Akey, J. M. (2024). Recurrent gene flow between Neanderthals and modern humans over the past 200,000 years. *Science*, *385*(6705), 158. https://doi.org/10.1126/science.adi786.

McInerney, J. D. (2022). Honoring Gregor Mendel. *The American Biology Teacher*, *84*(1), 7.

Mulvihill, J. J. & Grody, W. W. (2023). The Gregor Mendel bicentennial tribute—Enduring mementos of the founder of genetics. *Journal of the American Medical Association*, *330*(4), 297–298.

Orel, V. (1984). *Mendel*. Oxford University Press.

Raff, J. (2022). *Origin: A genetic history of the Americas*. Twelve.

Reich, D. (2018). *Who we are and how we got here: Ancient DNA and The new science of the human past.* Pantheon Books.

Tabery, J. (2023). *Tyranny of the gene: Personalized medicine and its threat to public health*. Alfred A. Knopf.

Wade, N. (2010). *A family feud over Mendel's Manuscript on the laws of heredity*. New York Times, May 31, 2010. https://www.nytimes.com/2010/06/01/science/01mendel.html

Zhong, L., Tang, P., Jin H., Li, M., Wang, Y., Shen, J. (2024). Introducing bioethics: The case of genome-edited children. *The American Biology Teacher*, *86*(1), 30–33.

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