GENOMIC LITERACY, EDUCATION, AND ENGAGEMENT (GLEE) INITIATIVE
2017 STRATEGIC VISIONING MEETING

K-16 Working Group

Introduction

The K-16 Working Group is focused on considering needs and opportunities to provide enrichment for science/biology educators in kindergarten through higher education in the fields of genetics and genomics. By supporting educators at multiple levels, this Working Group's goal is to increase the prevalence and quality of genetics and genomics education in our schools and to enhance genomic literacy and excitement among K-16 students and teachers. This white paper outlines the landscape of current activities, the expressed needs of educators, and a set of proposed actions to address these issues over the next five years.

The ever-increasing prevalence of genetics and genomics in everyday life and in the media calls for educating students in these fields (Kung, 2012; Hurle, 2013; Dressler, 2014; Desouza, 2017). Educators emphasize that a thorough knowledge of genomics is an essential component of science, health, and media literacy required for students to become informed citizens, consumers, and professionals. Concurrently, they report that current educational resources and curricula fail to adequately address this need. Similarly, career opportunities for students trained in genetics and genomics are growing in fields such as genetic counseling and bioinformatics, and recruiting and retaining talent in genomics is important for U.S. economic growth (USBL, 2017; Levine, 2014; Genomics Market, 2017).

The focus and practice of K-16 science education have undergone significant changes in recent years. Tension exists between the amount of factual knowledge students are expected to memorize/retain and conceptual understanding embedded within scientific practices. At the K-12 level, teachers have experienced an increased emphasis on standardized testing and reduced opportunities for teacher professional development (PD). In contrast, the 2012 Framework for K-12 Science Education (and the accompanying Next Generation Science Standards or NGSS) promote a three-dimensional learning approach focused on core ideas intertwined with science and engineering practices and crosscutting concepts such as “structure and function” (NGSS, 2017). Similarly, the AP Biology curriculum has been redesigned to incorporate inquiry-driven scientific practices into the core concepts (AP Biology, 2017). At the 2- and 4-year college level, biology education has also evolved under the influence of the AAAS Report “Vision and Change in Undergraduate Biology Education.” This report emphasizes teaching core concepts and science practices, evidence-based teaching methods and assessments, and increasing student participation in research (Vision, 2017). These changes in educational systems and practices provide an exciting opportunity to embed more genomics in K-16 classrooms due to both the interdisciplinary nature of the science and applications of genomics in real-world problem-solving (e.g., genomic causes of disease, suitability of a specific pharmacologic treatment, and genetic engineering).

Therefore, the K-16 Education Working Group proposes three main goals for the GLEE Initiative:

1. Become a central source of guidance for genomics educational content and standards to inform decision-makers at the national, state, and local levels in addition to non-governmental curriculum development organizations.
2. Promote the role of genomics education in workforce development by informing students, educators, and other relevant personnel how genomics integrates into future jobs and careers, including and beyond research and medical careers.
3. Support educators with the information they need to increase genomic literacy in their students

With these goals in mind, we hope to promote the following outcomes:

1. Trained genomic workforce
2. Equip students with sufficient background in genomics to be able to make informed healthcare decisions regarding genomic medicine for themselves, family members, and future offspring.
3. Encourage and equip students, as future citizens, with sufficient knowledge to participate in civic engagement relative to genomics (which may include issues such as genetically engineered foods, genomic privacy regulations, etc.).

State of the Field: Inventory of Existing Resources/Programs

There is extensive activity in genetics and genomics education at the K-16 level, both in a growing body of biology education research and in curriculum and resource development, including student-centered classroom activities, validated assessment instruments, simulations, and videos (Smith, 2016). Historically, genetics education parallels the evolution of the field, moving from Mendel to molecular genetics; thus, many resources that are currently available for K-16 educators focus on traditional Mendelian genetics concepts and DNA basics. Few resources are available to address the newer, nuanced understanding of genome structure and function and emerging genomic technologies, such as genome sequencing and genome editing. Growing interest in bioinformatics education at the K-12 and college level provides an additional entry point for genomics embedded in computer science and mathematics education.

The Working Group designed a survey for K-16 educators to investigate their current teaching practices, the resources utilized, and their anticipated needs (see **Appendix A**). After distribution through a variety of life science educator listservs, we received over 1600 responses, of which 1471 were from the US, with at least one from each state. Around 65% of respondents were high school teachers, with 25% teaching at the collegiate/graduate level. Most respondents taught life science courses (see **Appendix B** for data summaries and figures), indicating the respondents reflect an audience for whom genetics and genomics is highly relevant for their teaching.

Respondents typically teach the following topics: inheritance/transmission and variation; molecular genetics; biotechnology; genetically modified organisms (GMOs); population genetics; genome structure/function (e.g., non-coding DNA); and phylogenomics. Fewer educators reported teaching newer topics in genomics, including genomic medicine, epigenomics, next-generation DNA sequencing, or genome editing. Many educators reported a desire to teach these topics, but they felt they lacked expertise or needed additional teaching resources and professional development opportunities. The greatest barrier to implementing new material was that teachers felt it was not included in the curriculum standards. Other barriers included lack of time in the crowded curriculum, outdated textbooks, and lack of budgets/equipment. These data support the need to develop up-to-date, high-quality, low/no-cost resources AND to address curriculum standards or education policy for the GLEE Initiative at the K-16 level to achieve its goals.

The two most commonly referenced resources were Howard Hughes Medical Institute's (HHMI) BioInteractive website and the University of Utah's Genetic Science Learning Center (GSLC, learn.genetics and teach.genetics), followed by textbooks (see **Appendix C** for a full list of resources identified). Most respondents found HHMI and GSLC "very helpful," indicating that these organizations have established audience loyalty, and teachers are likely to return to these sources to find new resources and materials. In particular, teachers viewed videos and animations as filling a critical instructional need across education levels. For resources rated as "not helpful," respondents described the content as too challenging for their students, or that the site was not user-friendly to navigate; thus any newly-developed repository or clearinghouse should take user experience design/testing into consideration. Many educators also report writing their own activities, lesson plans, and wet/dry lab experiences, indicating an opportunity to share teacher-developed resources after vetting and review.

Hands-on, inquiry-based science experiences (including those investigating authentic datasets) are also growing in popularity, as are several course-based research experiences, and education research shows these techniques result in substantial learning gains (NGSS, 2017; Auchincloss, 2014). Consistent with this, respondents preferred teaching methods for genomics that are: hands-on activities, wet labs, virtual labs, and case studies. Lectures (although not TED talks or webinars) continue to be a popular teaching method, indicating that there is still a need for accessible, high-quality, and up-to-date reference material on which lectures could be based. Reliance on lecture also points to a need to support PD on active learning and other evidence-based teaching and assessment methods (Freeman, 2014).

Gap Analysis

The heavy focus on Mendelian genetics may contribute to persistent student conceptual difficulties, including genetic determinism (one gene, one trait; lack of emphasis on environmental influences or polygenic traits) and confusion about the nature of genetic material and the genetic basis of disease (Bowling, 2008; Shaw, 2008; Smith, 2008). Other persistent misconceptions include lack of understanding of the limitations of genomic technologies (e.g., genetic association vs. causation), and insufficient numeracy and statistical knowledge. Because of these challenges, there have been calls for a change in the structure and style of genetics and genomics education to emphasize real-world applications and complex trait genetics first (Dougherty, 2009; Redfield, 2012). These conceptual difficulties present a significant barrier to the successful implementation of genomic medicine, and any curriculum or policy efforts should take these issues into consideration.

Drawing on the survey data, it is clear that there are few resources available for teaching 'modern' genomics topics (such as genomic medicine, epigenomics, genome sequencing, genome editing), and many teachers would be interested in PD (especially during the summer months) to learn this new content and to be able to create and share resources. Of the respondents, 71% expressed interest in PD and 80% did not know of any available PD in genomics. Among the broad range of institutions offering PD (often universities or research institutes), teachers specifically mentioned

HHMI and Cold Spring Harbor Labs/DNA Learning Center (CSHL/DNALC) as go-to sources. Access to local, high-quality, affordable PD is a critical gap that could be addressed by developing an inventory of opportunities and assessing geographic distribution, costs, grade-level appropriateness, and other factors that may influence their success.

While many digital resources are free, there may still be some significant limitations for teachers and students in low-resource communities - particularly in communities where internet access may be unreliable, technology/computers may be unavailable, or opportunities for enrichment (e.g., field trips and scientist-in-the-classroom visits) are unavailable. Funding available to purchase equipment for hands-on and lab-based experiences also needs to be addressed for any major initiative to be truly equitable. It may be necessary to expand the survey and conduct targeted outreach or focus groups to make sure we capture the needs and constraints of educators in diverse settings.

A persistent theme regarding barriers to implementation was that many modern genomics concepts are not included in the state-mandated curriculum, and are peripherally mentioned in the NGSS and AP Biology curricula (Lontok, 2015; Wefer, 2008). Due to the nature of education policy and recent Department of Education administration changes, it will likely be necessary to monitor changes and trends in public and private education that may impact genomics teaching. At the college level, CourseSource provides an excellent conceptual framework and learning objectives for both genetics and bioinformatics that could be informative for the GLEE Initiative (CourseSource, 2017).

Finally, many teachers highlighted a need for workforce development and training. Respondents expressed a desire to connect course content with real-world applications, including career exploration for their students. Many students are unaware of the range of industry sectors and career possibilities in which genomics is becoming increasingly relevant, such as agriculture, energy, and biomanufacturing.

Proposed Action Plan

There are many directions that the GLEE Initiative could take with respect to K-16 education in genetics and genomics. The following K-16 Education Working Group recommendations address the critical needs identified above (education policy; genomics careers; and support for resources); and specific actions are grouped by implementation timelines of six months, one year, and two to five years.

In 6 Months

Resource Dissemination	● Evaluate existing resources: cost, features, target grades, accessibility, genetics vs. genomics-focused, etc. ● Identify useful features of various websites ● Distribute resources by e-mail to survey respondents ● Develop plan for resource clearinghouse (see below)
Professional Development Resource Dissemination	● Evaluate resources: cost, type, geographic region, etc. ● Assess most popular type of PD from large organizations ● Distribute resources by e-mail to survey respondents ● Develop plan for PD clearinghouse (see below)

Address Audience Gaps in Survey Data	• Targeted outreach to low-resources communities, including focus groups; could reveal important gaps in our understanding of the state of the field • Targeted outreach to K-5 educators: relevance, needs, opportunities

By the End of Year 1

Genomics Education Resource Clearinghouse/Dissemination	• Develop resource clearinghouse listing partner websites • Develop functionality matrix (includes grade levels, types of resources, content, standards alignments, learning outcomes if applicable, etc.) with teachers • Develop submission system for new resources • Provide resources/staff to maintain regularly • Develop dissemination plan through partners and social media
Annual Meeting Opportunities	Establish annual meeting(s) for K-16 educators + public/community engagement to collaborate/share resources, programs, best practices, research, evaluation metrics and instruments
Basic Genomic Literacy	Establish framework for what constitutes ‘basic genomic literacy’ • Develop the 4x8 Notecard of Genomics Advice - “When I go to the doctor, what should I know about my genome?” • Expand CourseSource to K-12 (connect NGSS, AP Biology) • Align learning progressions: all students → professionals
Write Position Paper to Inform Policy-Makers	• Confirm a list of core concepts/learning objectives (see above) • Recommend specific content updates for textbooks • Develop plans for further conversations with decision-makers to influence curriculum changes → 2-5 years to influence change
Further Survey Data Analysis	Many further questions that could be investigated using this data Questions can be discussed at the GLEE Strategic Visioning Meeting Need to establish whether this is IRB-exempt; how to best share data if possible
Explore Genomics Education Embedded in Settings Not Addressed Here	Address informal science education (out-of-school time and museums/science centers) and non-scientific subjects (e.g., history, literature, psychology, health, mathematics and computer science, speech and debate teams) as avenues for genomics education dissemination Media literacy may also be an important avenue for genomics education

Years 2-5
Continue the above programs and initiate/implement the following:

Revisit Survey	Repeat 'White Paper' survey @ 5 years to determine what (if any) changes have occurred with respect to genomics education practice, resources, professional development, etc.
Evaluate GLEE K-16 for Outcome Measures	• Develop methodology for assessing outcomes • Measure outcomes
Address Low-Resource Community Needs	• Explore methods for resource dissemination in low-resource areas • Identify opportunities for low/no cost resources: e.g., equipment lending, mobile lab experiences, paper-based and DVD-based learning materials (not reliant on internet access) • Provide funding for educators in low-income, high-need districts to attend national conferences and professional development opportunities
Develop Genomics Careers Resource (or revise if appropriate)	• Identify existing models of career resource tools • Evaluate what is effective, user interest/needs • Develop resource (or revise existing if appropriate) • Disseminate resource using established channels above
Support Authentic Training Experiences with Genomics	• Identify existing genomics-focused research experiences (e.g., Course-based Undergraduate Research Experiences or Citizen Science Projects) for K-16 students • Identify and support new opportunities for K-16 student internships/career development in genomic healthcare • Disseminate opportunities using established channels above • NIH/SEPA to support the development of new projects? ○ Research/evaluation of best practices/success?
Develop Materials to Teach 'Advanced' Genomics Topics	• Define content areas of high interest and with limited available resources: e.g., genome editing (CRISPR), bioinformatics • Organize team(s) of educators/staff to develop new resources: may include fact sheets or powerpoint slides for lectures; animations/videos; case studies; and hands-on activities/labs • Contribute to peer-reviewed educational publications • Disseminate new resources using established channels • NIH/SEPA to support development of these types of projects?
Invest in Genomics Education Personnel Capacity Building	Address gaps in PD for STEM Teachers in genomics • Leverage teacher leaders (train-the-trainer) • Identify successful PD, provide support to expand what is working to new locations Fund STEM Teacher research fellowship opportunities in education research: Pre-service teachers could perform education research (e.g., state standards analyses), contribute data for program/product developers Fund STEM Teacher research fellowship opportunities in genomics science

	Create or scale up Genomics Ambassador Programs: genomics professionals interested in K-12 education/outreach or public engagement, etc. ● National DNA Day as organizing opportunity ● Identify successful programs, provide support to expand what is working to new locations (including training for volunteers)
Support Genomics-Focused Mass Media	Engage media that enhances awareness of genomics: e.g., National DNA Day, films, television programs, popular press
Partnerships for Genomics Competitions	Establish Genomics Competition(s) with partner organizations: e.g., HOSA Competitions or Science Olympiad; support existing contests

Summary

In this white paper, we summarize data and information provided by experts and practitioners in the field of K-16 genomics education and recommend specific steps that we, as a community, could take to enhance genomic literacy of this group. We believe that NHGRI, as a trusted source of scientific information, should play a central organizational and catalytic role in supporting ongoing genomics education efforts aimed at K-16 educators via curricular and professional development resources that will be developed, collated, vetted, and disseminated. These activities should always be done in partnership with educators to ensure that resources are appropriate and useful for their practice. The effort could not only result in a better trained workforce and more informed citizens, but also serve to build a community of educators, scientists, and organizations committed to genomic literacy.

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Appendices:

Appendix A: Survey Questions & Distributions
Appendix B: Survey Data & Summaries
Appendix C: K-16 Genetics/Genomics Education Resource List

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Appendix A. Survey Questions & Distribution

Survey Distribution Listservs:

National Association of Biology Teachers (NABT)
National Science Teachers Association (NSTA)
Howard Hughes Medical Institute (HHMI) Biointeractive
AP Biology Teachers Listserv
NHGRI's Genome: Unlocking Life's Code
American Society of Human Genetics (ASHG)
American Society of Microbiology (ASM)
Society for the Advancement of Biology Education Research (SABER)
Community College Undergraduate Research Initiative (CCURI)
Bio-Link Center of Excellence for Biotechnology and Life Sciences
Health Occupations Student Association (HOSA)

Survey Questions

See attached pdf *K-16 Appendix A SurveyMonkey*

Appendix B. Select Survey Data & Summaries

The following figures reflect a few analyses that the Working Group determined would be helpful in interpreting the recommendations provided in the White Paper. The resulting data from the educator survey is rich and will require further analysis to fully interpret the needs and opportunities for the GLEE Initiative in the K-16 space. We have done our best first-pass analysis, and some data have been further broken down by teaching level (e.g. high school vs. community college vs. other higher education) and are available upon request. For access to further quantitative and qualitative (summary statistics for open-ended responses) data, please contact Beth Tuck (elizabeth.tuck@nih.gov).

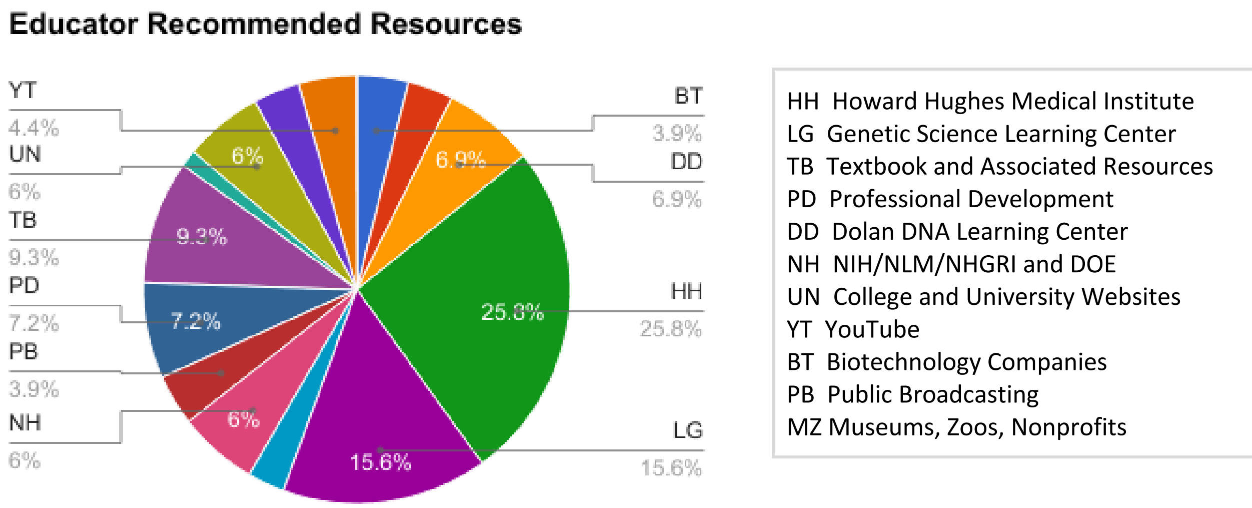

Figure 1. K-16 Educator Survey Q11 "*Please name three resources that have helped you teach genomics and provide website/organization information if possible.*" Number of respondents: 1594. Number of coded responses: 2629. Number of Countries: 92.

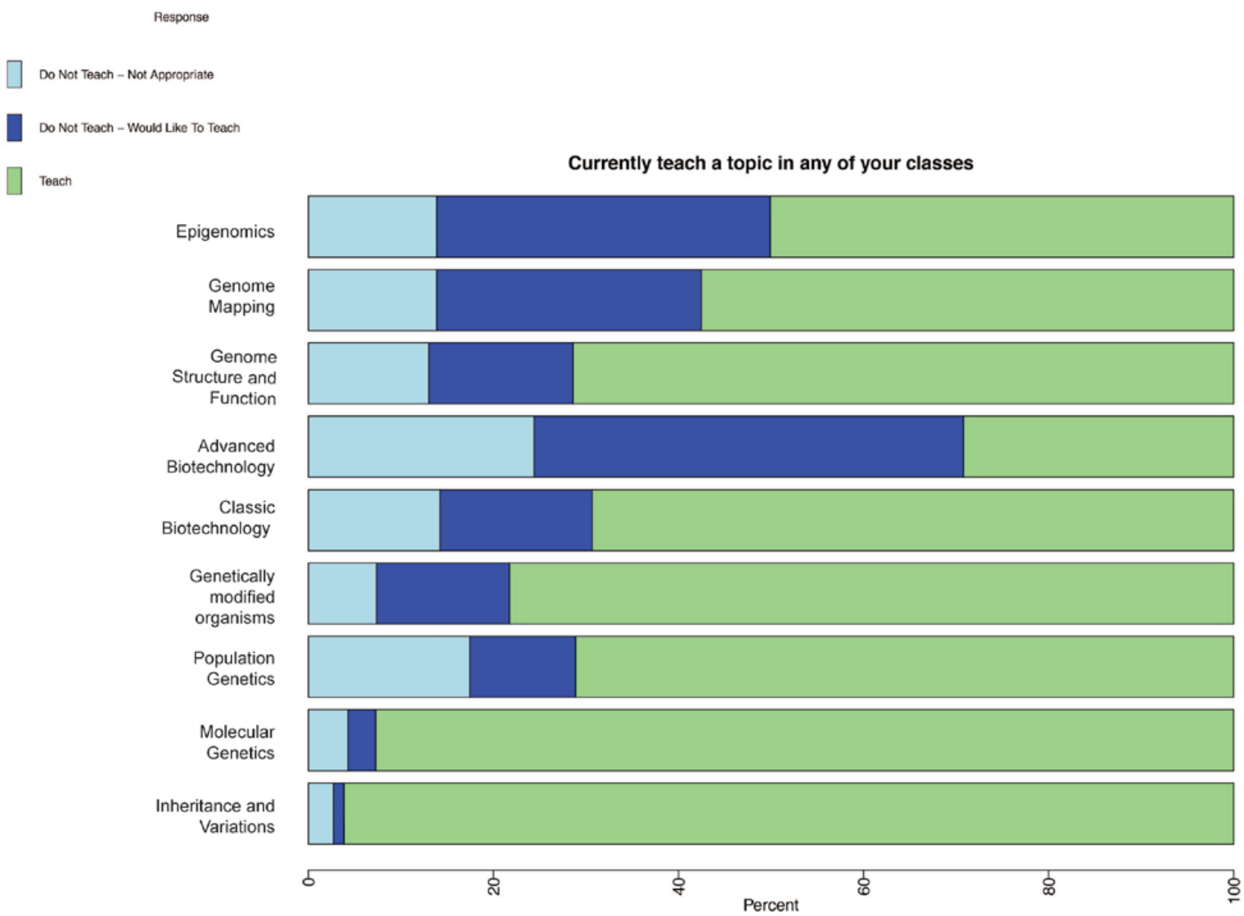

Figure 2. Stacked plot of all responses (elementary to doctoral university) for Question 6: "Please indicate whether or not you currently teach a topic in any of your classes. If you teach it in one and not the other, please respond affirmatively."

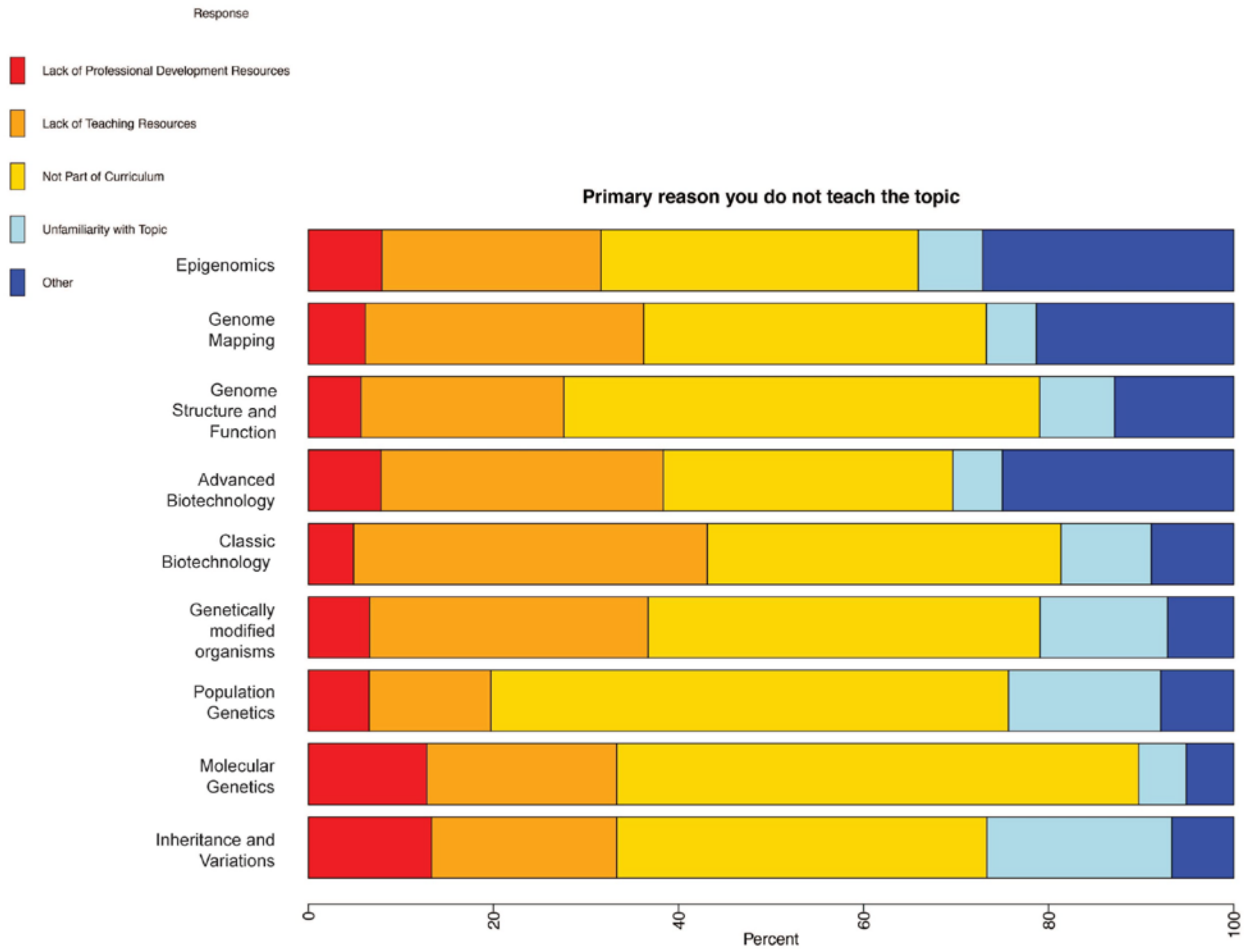

Figure 3. Stacked plot of all responses (elementary to doctoral university) for Question 7 "In the previous question, you indicated that you do not, but would like to teach the items listed below."

Appendix C. K-16 Genetics/Genomics Education Resource List

Note: Many of these resources are targeted for general biology educators, including both genetics- and genomics-focused resources; however, they skew heavily toward genetics (e.g., Mendelian traits and inheritance patterns, molecular genetics and 'classic' biotechnology). There is a need to differentiate between resources for genetics vs. genomics to fully identify specific gaps that could be addressed by developing new materials. These resources also do not focus very specifically on the application of genomics to decision-making.

Biotechnology Companies	**Websites**
23andMe	https://www.23andme.com/gen101/
Bio-Rad	http://www.explorer.bio-rad.com
Carolina Biological Supply	http://www.carolina.com/
Carolina/Twig	https://www.twigcarolina.com
Digital World Biology	http://digitalworldbiology.com/tags/molecule-world
Fisher Scientific	https://www.fishersci.com/us/en/products/I9C8KFT2/biology-classroom-kits.html
Flinn Scientific	https://www.flinnsci.com
Frey Scientific	http://www.freyscientific.com/stem-curriculum/ineosci/ineo-sci-overview
MiniPCR	http://www.minipcr.com
Science Takeout	http://www.sciencetakeout.com
The Jackson Laboratory	https://www.jax.org/education-and-learning/high-school-students-and-undergraduates/teaching-the-genome-generation
Ward's Science	https://www.wardsci.com/store/
Case Studies	
Life Sciences Learning Center, University of Rochester	https://www.urmc.rochester.edu/MediaLibraries/URMCMedia/life-sciences-learning-center/documents/LSLC_TEACHER_Genetic_TestingHD9-14-10.pdf
National Center for Case Study Teaching in Science, University at Buffalo	http://sciencecases.lib.buffalo.edu/cs/
New York Times	https://www.nytimes.com/2015/09/07/us/flicker-of-hope-for-children-with-rare-and-devastating-disease.html?_r=0
University of Illinois	https://neuron.illinois.edu/search/node/GENETICS%20CASE%20STUDY
Citizen Science/Games	
Foldit	https://fold.it/portal/
Eterna	http://www.eternagame.org/web/
Phylo	http://phylo.cs.mcgill.ca/
Colleges and Universities	
Baylor College of Medicine	http://www.bioedonline.org/lessons-and-more/resource-collections/gene-u-genetics-and-inheritance/
Berkeley University	http://evolution.berkeley.edu/evolibrary/home.php
Bryn Mawr College	http://serendip.brynmawr.edu/exchange/waldron/genetics
California State University	http://www.sciencecourseware.org/vcise/
Carleton College	http://serc.carleton.edu/genomics/activities.html
City University of New York	https://www.ccny.cuny.edu/education/unifying_life_site
City University of New York, Brooklyn	http://www.brooklyn.cuny.edu/bc/ahp/MGInv/MGI.Inv.html
Harvard University, Personal Genetics Education Project	https://pged.org/mission/
Indiana University	http://www.indiana.edu/~ensiweb/lessons/chromcom.html
Iowa State University	http://www.biotech.iastate.edu/for-k-14-educators/
Iowa State University	http://www.biotech.iastate.edu/laboratory-protocols/
Johns Hopkins University	https://www.omim.org
Kansas State University	https://www.k-state.edu/biology/pob/genetics/intro.htm
Massachusetts Institute of Technology	http://education.mit.edu/portfolio_page/ubiquitous-biology/
Massachusetts Institute of Technology	http://jura.wi.mit.edu/bio/education/
Massachusetts Institute of Technology	http://star.mit.edu/genetics/
Michigan State University	http://datanuggets.org

Milwaukee School of Engineering	http://cbm.msoe.edu
North Dakota State University	http://vcell.ndsu.nodak.edu/animations/
Oregon Health and Science University	http://www.letsgethealthy.org
San Diego Supercomputer Center	http://seqtool.sdsc.edu/CGI/BW.cgi
Santa Clara County Biotechnology Education Partnership	http://teachbiotech.org/programs/sccbep/
Stanford at the Tech: Museum of Innovation	http://genetics.thetech.org
Stanford University	http://www.yeastgenome.org/about
Stanford University	http://www.candidagenome.org
University of Arizona	http://www.biology.arizona.edu
University of British Columbia	http://www.bioteach.ubc.ca/outreach/
University of California, Davis	http://ceprap.ucdavis.edu
University of California, Santa Cruz	https://genome.ucsc.edu
University of Colorado	https://phet.colorado.edu/en/simulations
University of Florida	https://www.cpet.ufl.edu/wp-content/uploads/2012/10/The-Pompe-Predicament-by-Julie-Bokor.pdf
University of Illinois	https://neuron.illinois.edu
University of Nebraska, Lincoln	http://agbiosafety.unl.edu/education.shtml
University of Pennsylvania Discovering the Genome	https://discoveringthegenome.org
University of Utah Genetic Science Learning Center	http://learn.genetics.utah.edu
University of Utah Genetic Science Learning Center	http://teach.genetics.utah.edu
University of Washington	https://www.my46.org/learning-center
University of Wisconsin, Madison	www.cgslab.com/drosophila/
Virginia Commonwealth University	http://www.sosq.vcu.edu
Washington University in St. Louis	https://schoolpartnership.wustl.edu/instructional-materials/modern-genetics/
Web based Inquiry in Science (Berkeley)	https://wise.berkeley.edu
Weizmann Institute of Science	http://www.genecards.org
Museums, Nonprofit Websites, and Zoos	
American Society for Cell Biology	http://www.lifescied.org
American Society for Microbiology	http://www.asm.org/index.php/in-the-classroom#k12
American Society of Human Genetics	http://www.ashg.org/education/K12.shtml
Amgen Foundation	https://www.amgenbiotechexperience.com/about
Arabidopsis Information Portal	https://www.araport.org
Bio-alive	http://www.bio-alive.com
Bio-Community	http://www.bio-community.org/about/
Bionews, Progress Educational Trust, UK	http://www.bionews.org.uk/home
Concord Consortium	https://concord.org
CourseSource	http://www.coursesource.org/about
Dolan DNA Center (Cold Spring Harbor Laboratories)	https://www.dnalc.org/resources/
Dolan DNA Center (Cold Spring Harbor Laboratories)	http://www.dnai.org
Dolan DNA Center (Cold Spring Harbor Laboratories)	http://www.dnaftb.org
Education Development Center	http://www2.edc.org/weblabs/
European Learning Laboratory for Life Sciences	http://emblog.embl.de/ells/
Exploratorium	https://www.exploratorium.edu
Galaxy (Data and Tools for genomic research)	https://usegalaxy.org
Gene Technology Access Centre	http://www.gtac.edu.au
Genetic Alliance	http://genesinlife.org/about
Genome News Network	http://www.genomenewsnetwork.org
Genome Solver	http://genomesolver.org

Hastings Center	http://www.thehastingscenter.org/who-we-are/our-mission/
Health and Science Pipeline Initiative	http://www.haspi.org
Howard Hughes Medical Institute	http://www.hhmi.org
Howard Hughes Medical Institute	http://www.hhmi.org/biointeractive
Howard Hughes Medical Institute - SEA-PHAGES	http://phagesdb.org
iBiology	https://www.ibiology.org
International Society for Computational Biology	https://www.iscb.org/bioinformatics-resources-for-high-schools/lesson-plans-for-bioinformatics-curriculum
Massachusetts Biotechnology Education Foundation	https://www.massbioed.org/educators/bioteach
MD Bio Foundation	http://www.mdbiofoundation.org
National Center for Science Education	https://ncse.com
National Organization for Rare Disorders	https://rarediseases.org/about/
North Carolina Biotechnology Center	http://www.ncbiotech.org/educational-resources
Northwest Association for Biomedical Research	https://www.nwabr.org
Personal Genetics Education Project	https://pged.org/mission/
Project Lead the Way Biomedical Science	https://www.pltw.org/our-programs/pltw-biomedical-science-curriculum
San Diego Zoo	http://institute.sandiegozoo.org/#
Science in Motion & Advancing Science in Pennsylvania	http://www.science-in-motion.org
Science in the Classroom	http://www.scienceintheclassroom.org
Scitable by Nature Education	http://www.nature.com/scitable
Smithsonian National Museum of Natural History	https://naturalhistory.si.edu
The Science Spot	http://sciencespot.net
National Institutes of Health and other federal resources (US, Canada, UK, Australia)	
BLAST, NCBI, NLM	https://www.ncbi.nlm.nih.gov/blast/
Cell Biology and Cancer, National Cancer Institute	https://science.education.nih.gov/supplements/nih1/Cancer/guide/guide_toc.html
Gene Bank, National Center for Biotechnology Information (NCBI), NLM	https://www.ncbi.nlm.nih.gov/genbank/
Gene Ed, NLM, National Human Genome Research Institute (NHGRI)	https://geneed.nlm.nih.gov/
Genetics Home Reference, NLM	https://ghr.nlm.nih.gov/
Genome British Columbia (Canada)	http://www.genomebc.ca
Genome: Unlocking Life's Code	https://unlockinglifescode.org/learn/resources-teachers
Genomic Science Program, US Department of Energy	http://www.genomicscience.energy.gov/education/index.shtml
Genomics Education Program, UK	https://www.genomicseducation.hee.nhs.uk
Human Genome Resources, NCBI, NLM	https://www.ncbi.nlm.nih.gov/genome/guide/human/
Joint Genome Institute, Department of Energy and Lawrence Berkeley National Laboratory	http://jgi.doe.gov/
Mapviewer, NCBI, NLM	https://www.ncbi.nlm.nih.gov/mapview/
National Human Genome Research Institute (NHGRI)	https://www.genome.gov/
National Library of Medicine (NLM)	https://www.nlm.nih.gov
PlantEd Digital Library Botanical Society of America	http://planted.botany.org/index.php?P=Home
Rare Diseases and Genetic Information Center, National Center for Advancing Translational Sciences and NHGRI, NIH	https://rarediseases.info.nih.gov
Visible Proofs, NLM	https://www.nlm.nih.gov/visibleproofs/
Your Genome (Wellcome Genome Campus, United Kingdom)	http://www.yourgenome.org
Public Broadcasting	

Nova	http://www.pbs.org/wgbh/nova/
Public Broadcasting Service	http://www.pbs.org
Science Friday	http://www.sciencefriday.com/
Textbook, accompanying websites, for profit educational resources	
Activate Learning IQWST	http://www.activatelearning.com/iqwst/
BrainPOP	https://www.brainpop.com
CK-12 Foundation	http://www.ck12.org
Coursera	https://www.coursera.org
Elsevier Scopus	https://www.scopus.com/home.uri
eScience Labs	http://www.esciencelabs.com
Explore Learning Gizmos	https://www.explorelearning.com
Genetics Society of America	http://www.genetics-gsa.org
Genomics Help, Dr. Brown, New York University	http://genomicshelp.com
Github (Tools for genomic research)	https://github.com/BD2KGenomics
Kesler Science	http://www.keslerscience.com
Learn 360	https://learn360.infobase.com
Newsela	https://newsela.com
Open Stax Free Textbooks	https://openstax.org/details/biology
Pearson Mastering Biology	http://www.pearsonmylabandmastering.com/northamerica/masteringbiology/
Science Channel	http://www.sciencechannel.com
Science Music Videos	http://www.sciencemusicvideos.com
Teachers Pay Teachers	https://www.teacherspayteachers.com
Web Resources	
Biology Corner (Shannan Muskopf's Site)	https://www.biologycorner.com
Biology Junction (Cheryl Massengale's Site)	http://www.biologyjunction.com
Bioman Bio	https://www.biomanbio.com/index.html
Explore Biology (Kim Foglia's Site)	http://www.explorebiology.com/regentsbiology/
Webinars, TED Talks, Youtube	
Ambry Genetics	http://patients.ambrygen.com/general-genetics/resources-for-you/educational-videos
Amoeba Sisters	https://www.youtube.com/user/AmoebaSisters
Barry Schuler TED 2008: Genomics 101	https://www.ted.com/talks/barry_schuler_genomics_101
Bill Gahl TEDx 2011: Medical Mysteries and Rare Diseases	https://youtu.be/aMMBmc_pQVA
Bioethics, Michigan State University	http://bioethics.msu.edu/homepage/about
Biolink, National Advanced Technological Education Center of Excellence for Biotechnology and Life Sciences	http://www.bio-link.org/home2/
Bozeman Science	http://www.bozemanscience.com
Crash Course	https://www.youtube.com/watch?v=QnQe0xW_JY4&list=PL3EED4C1D684D3ADF
Global Genes, Allies in rare diseases	https://globalgenes.org/rare-documentaries-and-films/
How to Sequence a Genome (TED-Ed)	https://youtu.be/MvuYATh7Y74
Khan Academy	https://www.khanacademy.org
MIT Blossoms Videos	https://blossoms.mit.edu/videos
TED Talks	https://www.ted.com/talks
Whole Genome Sequencing & You	https://youtu.be/IXamRS85hXU
Yourekascience	http://yourekascience.org