Promoting Student Scientific Literacy of Molecular Genetics and Genomics

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ABSTRACT

As the fields of molecular genetics and genomics have boomed and become increasingly important in the lives of the general public, traditional education methods have struggled to address the challenges in developing modern genetics literacy. To increase the understanding of the efficacy of tools designed to help students better understand fundamental concepts in modern genetics, we report on the initial enactment of a unit focused on these concepts. The unit differs from traditional materials by focusing on proteins and genes as well as the relationship between them. Through the use of classroom video, student pre- and post-tests, examination of student work in class, student surveys, and teacher meetings we collected data on student achievement focused on specific learning goals, teacher enactment of suggested discussions, and student engagement and motivation within the contexts used in the unit. Although we did not target the collection of specific data relating to language use as it relates to the unit, some of our data suggests that there were notable challenges in this area. While the gains that students made were modest, we have gleaned several important lessons about helping students learn modern genetics. We present here some of the challenges we faced as well as some of the lessons learned from the enactment of these materials. These insights have informed the revision of our curriculum materials and teacher professional development around the materials.

INTRODUCTION

When compared to other scientific subjects that U.S. high school students are exposed to, the content covered by molecular genetics and genomics is likely to have the most immediate and direct relevance to their lives in this new century. Research findings in genetics are already having an impact on people's lives; parents are making decisions concerning their unborn children and cancer patients are making decisions about which therapies to pursue based on genetic results presented at the doctor's office. Moreover, the newest branch of genetics research, genomics, has the potential to impact society exponentially. Genetics research is progressing rapidly, stimulated by the Human Genome Project, resulting in a flood of new genetic tests (Gollust, Wilfoend, & Hull, 2003; Hull & Prasad, 2001).

Unfortunately, traditional instructional methods do an inadequate job of motivating and educating students in molecular genetics and genomics. Few textbooks deal with genomics, and like the vast majority of science taught in the U.S., molecular genetics instruction relies heavily on textbooks (Tyson, 1997; Weiss, Pasley, Smith, Banilower, & Heck, 2003). With specific reference to molecular genetics, Project 2061 of the American Association for the Advancement of Science (AAAS) found that most current textbooks address the structure of DNA to excessive detail and yet fail to address fundamental understandings about DNA and genes (Project 2061, 2004). As a consequence of such traditional curriculum and instruction, students develop naive conceptions and inaccurate conceptual models about genetics (Lewis & Wood-Robinson, 2000; Pashley, 1994; Stewart, 1982). For example, students often fail to connect genes to proteins and phenotypes, and as a consequence fail to recognize the importance of proteins in this process, (Lewis and Wood-Robinson, 2000; Marbach-Ad and Stavy, 2000), thus in some cases students incorrectly assume that genes are particles that directly express traits in organisms (Lewis and Kattman, 2004). Unfortunately, not only is textbook-based instruction flawed in the material it presents concerning genetics, but it also is flawed in the manner that

this information is presented. Some traditional instructional methods rely on textbooks, lecture, and presenting information in a de-contextualized manner and this can lead to a lack of motivation and interest to learn science on the part of students (Blumenfeld, Kempler, and Krajcik, 2006). Thus, traditional teaching methods do an inadequate job of preparing students to become scientifically literate in modern genetics. While a few attempts have been made to develop new materials for modern genetics (e.g. BSCS Biology, 2006; Rotbain, Marbach-Ad, and Stavy, 2006; Duncan and Reiser, 2007), we still lack information on what instructional strategies and features of materials lead to deeper understanding of modern genetics. Hence, an urgent need exists to develop and study more materials and strategies that can help students develop a deeper understanding of modern genetics so that they can go on become genetically literate citizens in a time when genetics is taking a prominent role in society.

To help address this need to understand how to best help students learn genetics, we developed and studied the use of a high school unit that covers content in molecular genetics and genomics. Due to the difficult nature of the concepts and students tendency to struggle with key concepts, developing effective molecular genetics materials is a challenging task. To address this challenge, this unit uses a non-traditional scope and sequence: it gives deep attention to both proteins and genes. The unit includes several features that science educators and education psychologists believe are likely to lead to deeper learning, such as contextualization of content, inclusion of engaging and personally relevant phenomena, multiple representations, inquiry-based student activities, and educative features for teachers (Blumenfeld, Krajcik, Marx, & Soloway, 1994, S Kesidou & J.E. Roseman, 2002).

Through the use of classroom video, student pre- and post-tests, examination of student work in class, student surveys, and teacher meetings we collected data on student achievement focused on specific learning goals, teacher enactment of suggested discussions, and student engagement and motivation within the contexts used in the unit. Although we did not target the collection of specific data relating to language use as it relates to the unit, some of our data suggests that there were notable challenges in this area as well. While the gains that students made were modest, we have gleaned several important lessons about helping students learn modern genetics. We present here some of the challenges we faced as well as some of the lessons learned from the enactment of these materials. These insights have informed the revision of our curriculum materials and teacher professional development around the materials.

DESIGN AND METHODS

Curriculum design

We have designed a high school curriculum unit for $9^{th}/10^{th}$ graders designed to support students' understanding of molecular genetics and genomics. This curriculum is project-based and integrates content on proteins and genes. A brief description of the materials is presented below.

Features overview

The unit contained many features designed to 1) help motivate and improve students' learning of modern genetics and 2) enable the teachers to more effectively enact these non-traditional materials. Below is a description of some of the these features.

Learning goals The development of the materials was designed around specified enduring ideas that we feel students must understand in order to develop deep understanding of genetics and have identified the following big ideas: 1) genes are instructions for assembling proteins, 2) it is the proteins that carry out the work of a cell, and 3) an organism's traits reflect the actions (and inactions) of its proteins. Our goal is for students to be able to provide an explanation for a given trait (such as sickle cell disease or dark skin color) at many levels, including genes, proteins, cells and whole organism. We also identified several National Benchmarks and Standards that that align with our identified core ideas in genetics (see Appendix A; AAAS, 1993; NRC, 1996). These benchmarks and ideas comprise the learning goals for this unit. We hope students who develop understanding of these ideas might be then be able to connect changes in genes to changes in protein function, cell function and organism phenotype. In contrast to ideas covering the nature of genes and DNA, there are no Benchmarks that cover genomics, in part because genomics grew as a field in only the last decade and these documents were developed more than ten years ago. Thus, we inquired with experts in the field to identify the big ideas that students should know about genomics and developed a learning goal devoted to describing what a genome is. This leaning goals of genomics focus on the finding that there are tens of thousand of genes and billions of DNA base pairs that include both protein coding and non-coding regions (see Appendix A). We have used these big ideas and benchmarks in molecular genetics and genomics to design the scope and sequence, context, and assessments for our curriculum materials. Thus the materials are entirely focused around these identified learning goals.

Driving question - It is believed that placing content in a relevant context is important to engaging and motivating students to learn content (Sherwood, Kinzer, Bransford, & Franks, 1987; Blumenfeld et al., 1991; Edelson, 1997). This avoids the content from being seen as a collection of facts, which reformers in science education would like to avoid (AAAS, 1993; NRC, 1996). We believe, that over-riding questions embedded in the materials will enable students to integrate and relate content being taught into a more cohesive picture. Such a question is referred to as a "driving question" (Krajcik et al., 2000; Rivet and Krajcik, 2004). We try to make this question personally meaningful and relevant, as well as engaging and motivating. Thus we sought to identify a driving question for this unit. We chose "How similar or different are we?" This question asks students to make two comparisons: compare themselves to other humans and compare themselves to other organisms. Students are then told that in this unit, they will learn what contributes to making us different or similar and will be developing their answers to this question. This context is broader than other curriculum units that have been developed around similar learning goals. For example, some materials with a context or driving question have focused exclusively on one disease. The driving question here allows our materials to cover a number of different disease traits as well as non-disease related traits such as skin color or eye color. Indeed, we have incorporated a number of examples from which students can relate the ideas of genes and proteins to their own experiences and knowledge. These examples are discussed in the next section.

Phenomena - We have identified phenomena to incorporate into the materials that illustrate the science concepts we are trying to help students learn. We made attempts to identify phenomena that are relevant to students so that it will be engaging and motivating. Given the importance of talking about genes and proteins in relationship to traits, we identified phenomenological examples that are 1) based in a biological context that were relatively easy for student at this

high school level to understand, 2) understood by scientists enabling instruction at both the DNA and protein levels, 3) provide traits that are familiar to the students. Given these criteria we identified a number of phenomenological examples that demonstrate the learning goals of the unit. Genetic traits included sickle cell disease, Phenylketonuria (PKU), eye color in flies, skin color in humans, and muscle mass in mammals.

Multiple Representations - The materials also provide students with multiple representations to give students multiple opportunities to make sense of the concepts of protein, DNA and the relationship between the two. For example, students use 2-D representations as well as physical models based on foam tubes and thumbtacks to represent the folded proteins. Additionally, students are provided with 2-D cartoon images, electron micrograph images of DNA, and physical 3-D models of DNA. Students are provided with a cartoon animation of the process of using the instructions in a gene to make a protein and are asked to build a 3-D protein model from a DNA sequence posted in class. In addition, students are asked to write text descriptions and produce drawings of the process of moving from gene to proteins.

Inquiry-based instruction - Science educators advocate that students actively engage with the science in classrooms, as apposed to listening to a teacher lecture, and that students engage in the practices of scientific inquiry to build their understanding of science (NRC, 2000). It is advocated that student ask questions, make predictions, analyze data, construct explanations and use models to understand the science content (NRC, 2000). These students in these units are asked to make prediction about genes and proteins, analyze DNA and protein data, construct explanations for observable phenotypes, and use models to understand protein and DNA structure.

Educative Features - In addition to the student supports addressed above, we provide teacher supports intended to educate teachers in effective enactment of the unit concepts (Davis & Krajcik, 2005). Since the genetics curriculum is a non-traditional approach to teaching genetics, it is important that teacher receive adequate supports that will promote teacher learning (Schneider & Krajcik, 2002). We established consistent contact with the teachers that use these curriculum materials to help inform us of what is of value to their practice and beneficial for teacher and student learning (Ball & Cohen, 1996). Our educative curriculum materials are meant to promote teacher learning, in addition to student learning, by providing not only appropriate activities that the students find relevant, but also the rationale behind the recommended activities and ways that the teacher can adapt the activities for different situations (Davis & Krajcik, 2005). We provide rationale and purpose for lessons and activities, student misconceptions, instructional strategies, teacher content background, and checkpoints for teacher along with expected correct students answers for checkpoints. These supports are included in the written teacher version of the materials.

Lessons overview

The learning goals identified necessitated that we integrate content about proteins and genes in the same unit. Rather than just talk about a made-up polypeptide that a gene sequence encodes (as many textbooks do), the unit goes into detail about what proteins are, how they function, and what happens if they cannot function. In contrast to traditional, the unit starts with proteins first and then covers DNA and genes. We hope that this non-traditional sequence will

enable students to understand why proteins are important to the function of an organism and why it would be important to have genes provide instructions for assembling proteins. Ultimately we hope this approach will allow students to make connections between genes, proteins, and traits. To avoid superficial coverage of proteins our genetics unit devotes two entire lessons to proteins. In addition both the genes and the protein products are presented when specific examples are addressed. For example, when the unit covers sickle cell disease, it addresses both the hemoglobin gene and the hemoglobin protein product. A scan of current material suggest that when they do address proteins in the same context as genes, often they do so only at a superficial level without reference to a particular cellular function. Moreover traditional materials that do address protein and genes substantially often do so in entirely separate sections of the text book or to excessive detail which obscures the fundamental connection between genes and proteins (Kesidou and Roseman, 2002; Koppal and Caldwell, 2004). The unit, expected to take 4 – 6 weeks to complete, is divided into 7 lessons:

1. *Similarities and differences* – The students begin to explore the driving question of the unit: How similar or different are we? Students experience skin color difference at a cellular level.
2. *Understanding proteins* – Students begin to explore proteins as the workers in cells and begin to understand the differences between different proteins using flexible protein models.
3. *Exploring the world of proteins* – Students explore different types of proteins and how they function.
4. *Genes and their relation to proteins* – Students learn what genes are and how cells "decode" them to generate proteins.
5. *The molecular basis of genetic diseases* – The lesson extends students' understanding of how different forms of proteins can lead to disease by exploring sickle cell disease.
6. *Exploring biochemical pathways* – Students explore fruit fly eye-color and further explore skin color to learn how proteins work together to generate a product. Lesson 5 explores the ethics of altering genes to change muscle mass.
7. *Genomes* – After learning some specifics about genes in previous lessons students explore how genes are related to chromosomes and genomes.

Subjects and school context

The curriculum was enacted by two teachers from two urban high schools in a large city in the Midwest during the 2005-2006 school year. Students were representative of the schools' populations each of which are over 97% African-American. Of the 177 students who participated in the curriculum, 78 students and their parents agreed to participate in the program by allowing us to videotape them in class and review their class work and tests. Sixty-five students completed both the pre- and posttest. Results from statewide, standardized science tests rank the schools below the statewide average.

Data collected

During the course of the enactment of this unit, we collected several types of data. Data and analyses include:

- *Pre and posttests* – Pre and posttests were collected from a total of 65 students who completed both tests. The test contained multiple choice and open-ended items aligned with

the unit. The open-ended items are scored using a rubric designed to evaluate depth of content understanding. Generally, the lowest indicated no answer or an answer that exhibited no comprehension, the middle scored answers exhibited some comprehension, but used vocabulary incorrectly or were not completely accurate and the highly scored answers demonstrated an increasingly deeper understanding of the material and correct vocabulary use. Each scorer was compared to the master and determined to have a reliability of greater than 90% for each item. Student gains were analyzed using a paired T-test for students who completed both a pre- and posttest. Significance was determined for differences with a P-value of less than 0.05.

- *Student work* – Student guides designed to aid and assess knowledge and understanding in the unit and containing a few readings for students as well as student activity sheets were collected. The student guides are reviewed to determine the students' level of understanding and ability to communicate effectively about genetics.
- *Video Analysis* – Videos of each classroom were taken during key lessons. The videos are analyzed to assess teacher use of materials and educative features and student engagement.
- *Student surveys* - The students completed surveys at the end of the unit, reporting on the lessons and activities they found most and least interesting as well as their perception of the importance of what they learned.
- *Teacher meetings* – Over the course of two meetings occurring after the completion of the enactment of unit, the teachers reported their perception of the most and least engaging and useful activities and responded to the effectiveness of the various representations.

RESULTS AND DISCUSSION

Student achievement by topic

Analysis of the pretests, posttest, student surveys, teacher interviews, student guides and video, indicates that students made some gains in understanding aspects of the more challenging concepts encountered in the molecular genetics materials. We report student progress on four key topic areas covered by the unit: proteins, genes, connection between genes and proteins, and genomes (Table 1).

There are several potential reasons that the modest gains seen in Table 1 might not reflect the extent to which the students gained knowledge and understanding:

- Students did not receive a grade on the posttest
- The test addressed content that teachers did not have time to cover during the time allotted to the unit
- Some of the test items were ineffective for measuring student learning.

Here we focus on four aspects of the unit enactment for which we believe there are lessons to be learned and that have informed the redesign of our materials: 1) student progress towards an important learning goal, 2) classroom discussions that support inquiry, 3) contextualization of the materials, and 4) use of scientific language specific to modern genetics.

Table 1 - Analysis of pre/posttest

Area of Emphasis	Gain†	p-value†	Effect Size†
Proteins	12.0%	0	0.76
Genes	9.1%	0.004	1.15
Connections between genes and proteins	14.5%	0.042	1.51
Genomes	22.5%	0.065	1.48
Total	11.9%	0.001	1.48
Adjusted total*	13.7%	0.001	1.52

Proteins refers to content covering the structure and function of proteins, *genes* refers to content covering the function and molecular nature of genes, *Connection between genes and protein*s refers to content reflecting the relationship between genes and proteins, and *genomes* refers to content covering the composition of genomes and information provided by comparative studies of genomics.

*Reflects gains upon omitting 3 items that we know were not covered or were ineffective.

† See Appendix C for statistical methods.

Progress towards an understanding of the relationship between genes and traits

Intention of Materials

Although the unit addressed many learning goals, as outlined above, here we address the progress made and lessons learned from one of the primary learning goals of the unit: students should understand the connection between genes and traits (AAAS, 1993; NRC, 1996). Previous research and pretest results indicated that students relate genes to traits, but are unable to explain how genes play a role in traits (Marbach-Ad and Stavy, 2000). To help students make connections between genes, proteins, and traits our materials do the following: 1) introduce proteins and their importance in biological functions before introducing genes, 2) present educative features to inform teachers about the difficulties students have making these connections, and 3) include scaffolds that prompt students to write explanations of a trait at the levels of gene, protein, cell, tissue, and organism. The scaffold design was borrowed from RG Duncan, (see Appendix B; personal communication).

Student Response

Based on analysis of the pretest and posttest results, students have made some initial progress in understanding the connections between genes and proteins, but many students failed to connect genes to traits through proteins. Two questions designed to assess student understanding of the connection between genes and proteins were questions 6 and 21 (Table 2). Student answers to these questions suggest that many students strongly connect changes in DNA sequence to changes in protein function as indicated by their answers in both question 6 and question 21. Although the correct answer to question 6 is false, 76% of the students answered true on the posttest, compared to 52% answering true on the pretest. Similarly, in the first part of question 21 of the posttest, 74% of students incorrectly indicated that it is not "possible to change a DNA sequence and not change the function of a protein." Of the students who offered an explanation for their negative response, 50% provided an explanation about how changing a DNA sequence changes a protein function.

Table 2

Question:	% of students answering correctly on pretest	% of students answering correctly on posttest
6. State if the following statement is **TRUE OR FALSE**: Mutations in DNA always affect the function of a protein.	47	24
21a. Is it possible to change a DNA sequence and not change the function of a protein?	15	26
21b. Explain your reasoning.	n.a.	n.a.

n.a. – not applicable, this question was scored on multiple aspects

Examples of student explanations for question 21.

> Because if you change the DNA sequence that means your amino acids change so it makes your proteins function different.
>
> If you change the DNA sequence the protein shape and function would also change

While most students are unable to explain situations in which a change to a DNA sequence does not change the protein sequence, many students have made a strong connection between DNA sequence and protein function that was not indicated on the pretest. While students do not have a complete understanding of the connection between genes and proteins, their answers to these questions indicate that they have made some progress in understanding the connection.

Table 3

Question:	% of students answering correctly on pretest	% of students answering correctly on posttest
16. The sugar called glucose provides a source of energy to the cells of our body. In order for cells to get glucose, cells must take up glucose from the blood. In order for glucose to be taken up by cells it must be passed through the cell membrane. Type I Diabetes is a disease that results when cells, such as fat and muscle cells, do not properly take up sugar from the blood. There are many symptoms of diabetes; however, one common symptom is a large increase of glucose levels in the blood, called hyperglycemia, because glucose cannot enter the other cells of the body. Hyperglycemia can cause blurred vision and can make one feel extremely hungry and very tired. In extreme cases it can	10	21

cause loss of consciousness. Type I diabetes is a genetic disease. Given the above information and what you know about genes and proteins, hypothesize a molecular explanation for how a mutation in a gene could cause this disease.		

n.a. – not applicable, this question was scored on multiple aspects

The completion of the connection from genes to traits remained challenging for most students. In question 16 of the posttest, students were generally unable to explain how a change in a gene could result in Type 1 diabetes (Table 3). Additionally, one of the teachers indicated that students struggled to complete an activity in the student guide requiring them make similar, but scaffolded explanations for other genetic diseases. The other teacher did not do this activity in class. Another potential indicator of students' incomplete connection is seen in their answers to the question "What is a gene?' on the posttest. While significant number of students indicated a connection between genes and proteins when specifically asked about it, most students only related genes to heredity when not prompted to consider proteins. The relation of genes to heredity was covered prior to this unit in both biology classes. Thus it appears that associations between genes and hereditary function remain the dominant idea in many students' conception of genes, despite our attempt to develop ideas that relate to the molecular functions of genes.

Obstacles

There are several potential reasons why students failed to make the connection between genes and traits. Although a few activities designed to help students make this connection were included in the materials, they did not occur until later in the unit. For the most part, these activities asked students to make the connection from gene to trait based only on a brief reading about the trait. Thus, timing frequency and types of student supports may not be optimal and teacher supports may not be adequate to promote enactment as intended.

In addition, another explanation for students' difficulties is that while the connection from gene to protein is essentially the same for each trait, the connection from protein to trait requires a new biological context for each new trait. Students have a limited understanding of the specific biological contexts at the cellular, tissue, and whole organism level that they need to effectively connect from protein to trait. For example, in order for students to make a complete explanation of cystic fibrosis, students need to understand the function of the lung, as well as how the Cystic Fibrosis Transmembrane Conductance Regulator (CFTR) gene contain the instructions for the CFTR protein. While understanding how genes function as instructions will help the student when they consider a new trait, understanding lung function will not. Thus, there is a balance that is needed between general knowledge about genetics and specific knowledge about cells and tissues that is needed to make sense of new traits that are explored.

Informing materials-design

We have addressed this challenge of helping students make connections between genes, proteins, and traits, in a subsequent version of the unit with the following strategies: 1) adding more activities addressing the relationship between genes, proteins and traits, including an activity in which the students compare and contrast the similarities of the connections for several different traits; 2) including a greater variety of activities relating genes to traits throughout the

unit; and 3) using genetic traits with simple or familiar biological contexts, and 4) narrowing down the number of new traits and contexts for students to explore. In addition, student difficulties with this learning goal were addressed more explicitly in the teacher materials and in many of the professional development activities. The reformed materials will provide students with a variety of ways to build the connection from genes to traits and provide further opportunities to assess student understanding of these connections.

Classroom Discussions

Intention of Materials

One of the more important and yet more difficult aspects of teaching inquiry-based materials is enacting effective classroom discussions. Effective discussions allow students to synthesize deeper understanding of activities and readings, connect ideas across concepts, and make sense of their experiences. Discussions also provide the teacher with formative assessment opportunities. Several discussions were suggested throughout the teacher materials with support consisting of a brief description of what to discuss, some example questions and in some cases goals for student progress during the discussion. In the following example of a discussion prompt, the teacher is asked to help students relate what they have learned about genes to a term they might or might not have heard, "genetic disease".

> Through class discussion about the meaning of "genetic disease" introduce the idea that DNA is the material that is passed from one generation to another and in doing so can pass on mutations. Ask students if they have ever heard of the word "genetic" or have they every heard a disease be called genetic. Ask students what they think that means? Based on their understanding of genes what do they think that means. Focus on root of word "gene" in "genetic" and encourage students to consider what they have thus far learned about genes.

Teacher response

Analysis of video of classroom discussions indicates that teachers are in many cases holding discussions where they are indicated but not enacting them in a way that supports inquiry. For the most part, teachers tended to revert to initiation-reply-evaluation (IRE) recitation patterns. An example of a typical classroom exchange:

> Teacher: The next question is, what causes there to be a different protein? What is it that determines what the protein is going to be?
>
> Student 1: DNA?
>
> Teacher: The DNA. So, what should we write at the DNA level?
>
> Student 1: A change.
>
> Teacher: A change. What kind of change is it? You told me-
>
> Student 2: -A substitution.
>
> Teacher: Yep, you told me what kind of substitution. You said it was a mutation and that it was a substitution mutation. So, folks what you can write for the last one, gene or DNA level, you can say the gene has changed. That there is one letter that's different. It's a substitution mutation. And

that's what causes the protein to be different. Don't forget that genes are the instructions for how to make a protein.

In this example the teacher is questioning the students about what might cause the protein, hemoglobin, to change in sickle cell disease. While the teacher initiates with questions that could prompt a longer explanation, he accepts the one-word answers. Without much further questioning, the teacher moves on to elaborate the students' responses and finally offers the answer for the students to write down. Although the discussion covers the questions and content recommended in the teacher materials, the students have had minimal participation, all interactions have been teacher-student, not student-student, and the answer was ultimately constructed by the teacher.

Obstacles

As indicated by our experiences here, the minimal support included in the teachers' materials relating to enacting discussion did not effectively support classroom discussions. Although the materials aided in starting a discussion by providing some appropriate questions, they did not help the teacher envision how discussions that support student inquiry should proceed. Discussions that support inquiry are more difficult than most IRE type discussion hence they require more extensive support in the teacher materials and in professional development activities.

Informing materials-design

Although we intend to include more extensive support in future versions of the unit, a recent revision of the materials strives to help support classroom discussions by explicitly categorizing each discussion and stating a goal for each discussion. Additionally, an activity devoted to more effective discussions was included in professional development activities. Future revisions will include educative feature designed to further aid teachers in promoting effective discussions in an inquiry setting (Alozie, 2007).

Contextualization of the materials

Intention of materials

One of the challenges of any material focusing on content happening at the molecular level is to make it relevant to the experiences of students. A goal of molecular genetics materials is to help students contextualize DNA molecules, genes and proteins within their prior knowledge about human traits and prior experiences with cells and parts of the cell. The materials strive to help put the content of the unit into the context of the students' lives through the choice of driving question and the phenomena used to explore genes and proteins. The driving question, "How similar or different are we?" was designed to push the students to relate the similarities and differences they can see to the ones that they cannot see, but learn are there. We chose skin color and sickle cell disease as phenomena to explore on the molecular level because we believed they were phenomena in which students had familiarity and interest on the organism level.

Student response

Based on our video analysis and teacher interviews, teachers did not use activities intended to help students contextualize content using the driving question. Analysis of the

student surveys indicated that students had varied reactions to the driving question: "How similar or different are we?" When asked, "To what extent were you interested in discovering the answer to How similar are we?", 53% of students responded that it was relevant or very relevant. However, many students reported that an activity involving exploring similarities and differences was one of the most interesting activities of the unit. Perhaps many of the students who believed the driving question was minimally relevant believed so because they had few opportunities to make the connection between what they had learned and the question.

Analysis of the student surveys as well as responses from the teachers indicated that the phenomena of sickle-cell disease and skin color were of particular interest to the students. Students had some understanding of these traits based on their prior experiences and many students reported interest in learning about what was happening on the molecular level to affect these traits. Teachers' reports echoed these results. Some phenomena, such as the role of the protein lysozyme in fighting bacterial infection were less interesting to the students.

Obstacles

The under-use of activities relating to the driving question might reflect how the driving question was incorporated into the teacher materials. Most of the activities designed to specifically reflect on the driving question and its relation to the topic at hand were designed as discussions at the end of a lesson. The teachers did not receive enough support to effectively enact these discussions, as discussed above. So while the students showed interest in exploring similarities and differences, they received little opportunity to make connections between what they were learning and their prior knowledge about similarities and differences. Hence the driving question did not provide the context that it was intended to provide.

The driving question and some of the phenomena used in the unit were successful in engaging and motivating students. The contrast between the phenomena that were interesting to the students and those that were not are informative about phenomena that can help motivate students. Students reported that they were interested in learning about sickle cell and skin color based on their personal relevance. Although students are presumably aware that human bodies fight bacterial infections, they did not seem to find relevance in lysozyme. One explanation is that students had difficulty relating lysozyme to their lives because the biology of lysozyme and immune response is more complex than that of skin color or sickle-cell. Additionally students might relate more easily to traits with which they are familiar. Students see variations in skin color and many have met or know someone with sickle cell disease; few students are likely to know someone with a trait related to a defective lysozyme protein. Although predicting how students will respond to different phenomena might require some trial and error, these experiences might serve to help inform decisions about potentially successful context phenomena.

Informing materials-design

The relative interest in the driving question despite its under-use as a contextualizing tool indicates that with more attention to its use in the materials, the driving question could become more effectively used. To address its use as a contextualizing tool, future materials could, 1) spread activities throughout the lessons instead of concentrating them at the end of lessons, 2) include more variety of activities relating to the driving question including reading and writing activities, and 3) help support the teacher by providing better discussion frameworks and professional development focused on relating concepts to the driving question.

While several of the phenomena in the materials proved to be motivating for the students, the success of sickle cell disease and skin color as examples inspired us to consider the biological context and the associated trait for each of our examples.

Language use

Intention of materials

Scientific literacy requires not only and understanding of scientific concepts, but an ability to communicate about those understandings. With attention to this consideration, the teacher's materials discussed the use of language and made specific suggestions in many instances. For example, in the case of transcription and translation, the materials suggested that the words could be used but were not necessary. Attention was paid to terms that students confuse, such as proteins and amino acids, but specific vocabulary strategies were not suggested. For the most part, the materials emphasized a focus on the concept and not on the vocabulary associated with the concept.

Student response

In analyzing students' written responses on the posttest, there were several instances where it was unclear whether the student misunderstood the concept or misused the vocabulary associated with the concept.

Question:	% of students answering correctly on pretest	% of students answering correctly on posttest
Below are parts of a gene sequence from four individuals. Person A has the sequence found in most healthy people and the other people have mutations in the gene sequence. Person A: ATGTTCTAAACTACCGGAATT (healthy person) Person B: ATGTTCTAATCTACCGGAATT Person C: ATGTTCTAACTACCGGAATT Person D: ATGTTCTAAAACTACCGGAATT If the gene sequence in Person A is important for a proper functioning heart, which person (Person B, C or D) is **LEAST** likely to have heart problems?	35	55*
Explain your reasoning.	n.a.	n.a.

* p-value less than 0.05

n.a. – not applicable, this question was scored on multiple aspects

Student answers on question 7:

> Because there gene structure is almost the same as person a. There letters follow the same pattern and helps the body follow.
>
> Person B because it only has one mutation its TCT and its supposed to be ACT.
>
> Person B only has one different strand of DNA than Person A

Although the emphasis was on the students understanding what kind of changes at the DNA level were most likely to result in health problems, it was unclear from these responses what the students understood without using the words nucleotide, base, or DNA letter. The materials did not consistently use these terms or specifically ask the students to use them. In most cases, students failed to use them on the posttest. Potentially students understand why B is the best choice, but they are unable to correctly use vocabulary terms to express their understanding in a scientifically correct way. Other open-ended test items showed similar responses with students not using appropriate words or using words incorrectly.

Obstacles

Neither the student materials, nor the teacher materials give a clear indication of which new vocabulary terms will be necessary for students to express understanding of molecular genetics concepts. Students encountered a large number of new vocabulary terms to associate with the newly learned concepts. Some terms more general: gene, protein, mutation, and chromosome. Other terms were more context-dependent: hemoglobin, melanin, and lysozyme. Although some students might have noticed that certain terms were used throughout the materials and other were dependent on the example, the barrage of new words had the potential to be overwhelming for many of the students.

Another point to consider is that although there are several terms used in National Benchmarks as well as in popular press that we believe students should know, it is less clear if there are other terms that will help propagate student understanding. While using the terms transcription and translation might not be found in these benchmark materials, they might provide the students a useful way to understand and express their understanding about the process of using the instructions in genes to make proteins.

Informing materials-design

Fortunately, some of the solutions described above about helping students progress towards learning goals and contextualize materials, should also help address students' difficulties with language. Reducing the number of examples, choosing examples with relatively simple biological contexts and choosing example with contexts relevant to the students lives should reduce the number of new terms and increase the number of familiar terms the students must learn to contextualize the material. Additionally, adding activities to help the students connect the concepts with the terms will support further developments in students' communication abilities. The current materials help address the need for more activities relating to language use by adding significantly more and diverse readings as well as writings. Future versions could also include activities intended to address meanings of specific words like gene and protein and to help students differentiate between the words that are context specific and those that are generally used.

CONCLUSION

Developing materials that promote students' understanding of genetic concepts and support teachers' use of non-traditional materials is challenging. Some of the lessons learned echo through the aspects discussed here:

- Choosing appropriate examples has the potential to allow students to make the connections necessary to progress towards understanding how genes connect to traits, to place their new knowledge in a familiar and relevant context and to connect new terms with new concepts in a useful way.
- Supporting teachers' use of the materials is difficult but necessary in all aspects: addressing challenging learning goals, enacting discussions that effectively support inquiry, helping students make contextual connections, and addressing language and term use. Teacher professional development focusing on these aspects is also essential.

As we continue to revise the materials in the unit, we strive to incorporate the lessons learned and to support students' development as genetically literate citizens in a rapidly advancing world.

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APPENDECES

Appendix A – National benchmarks addressed by unit:

1. Nature and function of proteins: The work of the cell is carried out by the many different proteins. Proteins molecules are long, usually folded chains made from 20 different kinds of amino-acid molecules. The function of each protein molecules depends on the specific sequence of amino acids and the shape the chain takes is a consequence of attractions between the chain's parts. (AAAS, pg. 114, 5C:9-12#3)
2. Biochemical basis for traits. An organism's traits reflect the actions (and inactions) of its proteins. (no reference number yet-AAAS considering this but has not published it yet)
3. Nature and function of DNA: In all organisms, the instructions for specifying the characteristics of the organism are carried in DNA, a large polymer formed from subunits of four kids (A, G, C, and T). The chemical and structural properties of DNA explain how the genetic information that underlies heredity is both encoded in genes (as a string of molecular "letters) and replicated (by a templating mechanism). Each DNA molecule in a cell forms a single chromosome. (NRC, pg. 185, 9-12:C2#1)
4. Genes as information for building proteins: The genetic information in DNA molecules provide the instructions on assembling protein molecules. The code is virtually the same for all life forms. (AAAS, pg. 114, 5C:9-12#4)
5. Molecular nature of genes and mutations: Genes are segments of DNA molecules. Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it. The resulting features my help, harm, or have little or no effect on the offspring's success in its environment. (AAAS, pg. 109, 5B:9-12#4)
6. Heritable material: The information passed from parents to offspring is coded in DNA molecules (AAAS, pg 108, 5B:9-12#3)
7. Mutagens: Gene mutations can be caused by such things as radiation and chemicals. When they occur in sex cells, the mutations can be passed onto offspring; if they occur in other cells, they can be passed on to descendant cells only. (AAAS, pg 109, 5B:9-12#5)
8. Constituents of a genome: A genome consists of all of the DNA found inside a single cell or virus. The genome contains all the genes required to build, maintain and propagate the cell, or a multicellular organism. For humans the genome includes all the DNA within both 23 pairs of chromosomes within the nucleus and the DNA in the mitochondria. The human genome consists of about 3 billion base pairs and is estimated to have 25,000 genes. The smallest free living organism, a bacteria has about 500,000 base pairs and 5,000 genes. (I wrote this one with input from other experts). Most of the human genome is non-coding DNA, while only a small fraction is protein coding. The non-coding DNA includes some small parts that are highly variable DNA, which can be used to identify people. The genomes

of any two humans are highly similar (99.9% identical to be exact) (no reference number yet-AAAS considering this but has not published it yet).

9. Environment and genes: Most physical and behavioral characteristics that an individual possess are the combination of both genes and environment. (no reference number yet-AAAS considering this but has not published it yet)
10. Social risks and benefits of technologies: New technologies increase some risks and decrease others. Some of the same technologies that have improve the length and quality of life for may people have also brought new risks (AAAS, pg. 56)
11. Impact of genetics on human health: Knowledge of genetics is opening whole new fields of health care. In diagnosis, mapping of genetic instructions in cells makes it possible to detect defective genes that may lead to poor health. In treatment, substance from genetically engineered organisms may reduce the cost and side effects of replacing missing body chemicals. (AAAS, pg.207)
12. Controversy and biotechnology: Biotechnology has contributed to health improvement in many ways, but its costs and application have lead to a variety of controversial social and ethical issues. (AAAS, pg. 207)

Appendix B – Scaffold for molecular explanation of traits

Write a molecular explanation for how sickle cell disease arises from a mutation in the hemoglobin gene. *Your explanation should include a description of the disease at the trait, tissue, cellular, protein, and DNA levels.*

Trait/Symptom Level: These are physical defects that doctors and patients can easily observe or describe by examining their whole body or behaviors.

Tissue/Organ Level: These are defects that can be detected and described at the whole tissue level (such the heart, circulatory system or brain) that can cause the symptoms described at the trait level.

Cell Level: These are defects that can be detected or described at the cellular level that cause the defects at the tissue level.

Protein level: These are defects that can be described at the protein level that cause the defects at the cellular level. This should include what the protein is that is responsible for the cellular defects and how the protein structure and function are defective (type of amino acid change should be indicated).

Gene/DNA Level: These are defects that can be described at the gene level that cause the defects at the protein level. This should include what the gene is and what the mutation is that affects the protein (indicate the type of mutation— i.e. deletion, addition, substitution—and the specific nucleotide change).

Appendix C – Statistical methods

Gain = (mean posttest score – mean pretest score)/(total number of points in section)

p-Value – Determined using a paired T-test for each section and total score.

Effect-size = (mean posttest score – mean pretest score)/(standard deviation of pretest score)