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Genetics in the 21st Century: The Benefits & Challenges of Incorporating a Project-Based Genetics Unit in Biology Classrooms

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Abstract

How can science instruction help students and teachers engage in relevant genetics content that stimulates learning and heightens curiosity? Project-based science can enhance learning and thinking in science classrooms. We describe how we use project-based science features as a framework for a genetics unit, discuss some of the challenges encountered, and provide suggestions for enactment. This serves as an example of how project-based approaches can be integrated into high school science classrooms.

Key Words: *Project-based science; genetics; real-world connections; enhancing student learning; high school classrooms; models; explanations.*

An understanding of genetics can help students participate in conversations about issues in science and technology. However, genetics content is not only complex but also abstract and difficult to connect to the everyday lives and interests of students, which can subtract from the excitement of learning about it. Haga (2006) argued that although there is a high level of support for research and testing in genetics, there is very little conceptual understanding of it. As a result, teaching genetics in the high school classroom can be challenging for both teachers and students. How, then, can science instruction help students and teachers engage in relevant genetics content that stimulates student learning and heightens curiosity?

According to the National Research Council (NRC, 2000), achieving scientific literacy will require changes in how teachers approach science teaching. The NRC (2000) emphasizes a new way of teaching and learning about science that reflects the science discipline and implies changes in what and how students are taught and in how students are assessed. Project-based science is one approach that deviates from traditional transmission methods of learning and promotes the building of knowledge. This approach has the potential to enhance students' subject-matter knowledge and thinking in science classrooms (NRC, 2000; Krajcik & Blumenfeld, 2006).

Project-based science engages students in real and meaningful problems that are potentially important to the learners and that are similar to what scientists do in the field (Krajcik & Blumenfeld, 2006). In project-based learning environments, students encounter five essential features (Krajcik et al., 2000; Krajcik & Blumenfeld, 2006): (1) a driving question, or a central question, that guides instruction and that learners find meaningful and important; (2) situated inquiry, in which students investigate specific questions and problems that are central to the unit; (3) collaborations, in which students' learning opportunities are extended beyond the individual to include other members of the learning environment; (4) technology, which serves as a cognitive tool to enhance learning (Krajcik et al., 2000); and (5) creation of artifacts, whereby students create an external representation of their understanding.

Teachers can establish a learning environment that fosters student construction of knowledge in different age groups, achievement levels, and content areas, such as genetics. Here, we describe how we use project-based science features as a framework for the design and enactment of a genetics unit and discuss some of the challenges encountered.

The unit was developed for 9th- or 10th-grade introductory biology students and aims to help students understand the connections between genes, proteins, and physical characteristics, as well as more current ideas in genomics. Many of the learning goals for the unit are consistent with national science standards (see Table 1 for an overview of the unit). Students begin learning about genetics by exploring similarities and differences at the phenotypic level. As they progress through the curriculum, they explore different biological levels.

Students begin learning about genetics by exploring similarities and differences at the phenotypic level.

○ Project-based Features of the Unit

Driving Question

The "driving question" organizes principles and concepts and drives many of the activities throughout the unit (Krajcik et al., 1994; Krajcik & Blumenfeld, 2006). According to Krajcik and Blumenfeld (2006, p. 655), the driving question "provides a context in which students can use and explore learning goals and scientific practices, and provides continuity and coherence to the full range of project activities." Students design and perform investigations to answer the question, which should be relevant to national and district science standards, contextualized in real-world examples and problems, meaningful and exciting to the learners, and ethical (Krajcik & Blumenfeld, 2006).

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Table 1. Alignment of unit with state and national standards.

Lesson	Investigation	Artifacts	Phenomena	Learning Goals
How similar and different are we from each other?	• Examine pictures of skin cells	• List of similarities and differences	• Skin color	• Nature and function of proteins (AAAS, pg. 114, 5C: 9–12 #3)
What is going on inside us to make our traits?	• Protein in all parts of the chicken? • How do lactose intolerance pills work? • Building models of proteins	• Toober model • Comic strips of protein activity	• Skin color • Lactose intolerance	• Nature and function of proteins (AAAS, pg. 114, 5C: 9–12 #3) • Biochemical basis of traits
How do genes work?	• Building DNA models • How are genes decoded? • What effect do mutations have?	• DNA model • Explanation of mutation effect on a cholesterol receptor	• Cholesterol receptors	• Biochemical basis of traits • Nature and function of DNA (NRC, pg. 185, 9–12: C2 #1) • Genes and information for building proteins (AAAS, pg. 114, 5C: 9–12 #4) • Molecular nature of genes and mutations (AAAS, pg. 109; 5B: 9–12 #4)
How does my environment affect my genes?	• Are genes always on? • Are some of our similarities and differences caused by the environment?	• Explanation of lactose intolerance	• Lactose intolerance • Erythropoietin	• Biochemical basis of traits • Different cells use different genes (AAAS, pg. 109; 5B: 9–12 #6) • Environment and genes
What is a genome and how does it work?	• Gene scavenger hunt • Calculating the amount of similarities and differences between different organisms	• Description of genetic differences between organisms	• Genomes	• Constituents of a genome
How do genes cause diseases?	• How does the sickle cell mutation affect hemoglobin?	• Research project on specific trait or career	• Sickle cell and hemoglobin	• Biochemical basis of traits • Nature and function of DNA (NRC, pg. 185, 9–12: C2 #1) • Genes and information for building proteins (AAAS, pg. 114, 5C: 9–12 #4) • Molecular nature of genes and mutations (AAAS, pg. 109; 5B: 9–12 #4)

The project-based unit described here uses the driving question "How similar or different are we from each other?" The question initially prompts students to consider physical similarities and differences, such as eye color, skin color, and health. The students are then encouraged to ask questions and investigate the similarities and differences at sequentially deeper levels: cells, proteins, genes and genomes (see Table 1). Eventually, students learn that although many of their physical characteristics, such as hair type, seem different, they are in fact genetically 99.9% similar. Through the investigations, students cover national standards related to proteins, genes, and the biochemical basis of traits. The driving question serves its purpose by both situating the content in a real-world context that interests students – the similarities and differences among people – and addressing many learning goals that align with national standards.

Situated Inquiry

In project-based classrooms, students use what they learn as a foundation for the investigation of problems. They use various scientific practices that are common in the scientific community as they devise and carry out investigations that test their ideas and come to understand what makes such investigations effective. Additionally, students learn how to write evidence-based explanations that use their observations and scientific principles to explain their results (see Figure 1). The use of situated inquiry in project-based learning environments helps students value the tasks and activities they perform in science and generalize their knowledge to a wider range of situations (Krajcik et al., 2000).

To explore the similarities and differences between people more deeply, the students investigate various phenomena, including skin color and lactose intolerance, at multiple biological levels, including cells, proteins, and genes. In the first investigation, the students examine pictures of cells from different colors of skin and consider what is similar and different about the cells (see Figure 2). From this activity, students learn that although skin cells are similar among different kinds of people, the amount of melanin produced is different and results in the variety of human skin colors. The teacher can assess students' prior knowledge and understanding of cells throughout the body and encourage them to further investigate the driving question.

> Use evidence from your chart to explain why you think you have these differences and similarities. Use complete sentences.
>
> What is your claim?
>
> What are two pieces of evidence?
>
> How can you tie your evidence to scientific principles?

Figure 1. Students write evidence-based explanations for observed similarities and differences.

Similarly, when learning about proteins, students use flexible models of proteins called "toobers" (see Figure 3) to explore properties of protein functions. The flexible toober represents the backbone of a protein, and the thumbtacks represent properties of amino acids. Students learn how different amino acids interact with each other to create different protein shapes that correspond with their functions. The toobers allow students to build models of proteins, construct their understanding of how amino acids and their properties interact to determine the shape of proteins, and explore how protein shape and function are intertwined.

For example, students learn how similarities and differences in a protein, lactase, might affect the ability of the protein to break down lactose. The curriculum described here provides the students with a DNA sequence. The students work in groups to translate the DNA sequence into a chain of amino acids. Once the students have generated an amino acid sequence, they insert thumbtacks that represent appropriate amino acid properties. Once all thumbtacks have been inserted into the toober, the students bend the toober according to the amino acid properties and construct a three-dimensional model of a protein (see Figure 3).

The teacher can conclude the activity by having the students write evidence-based explanations that describe how changing different thumbtacks (amino acids) can change (or not change) the shape and function of the protein. The teacher can also use this model to encourage students to make predictions about protein shape by changing different parts of the model. Furthermore, the teacher can engage the students in a discussion that connects the content in the activity with the real-world issues, such as how changes in protein function can result in differences in bodily functions.

Situating student learning in this activity not only provides students with a hands-on activity that stimulates thinking and learning, but provides the teacher with an assessment tool. As students focus on genes and mutations, they investigate DNA sequences to determine how similarities and differences at the genetic level affect cholesterol trafficking.

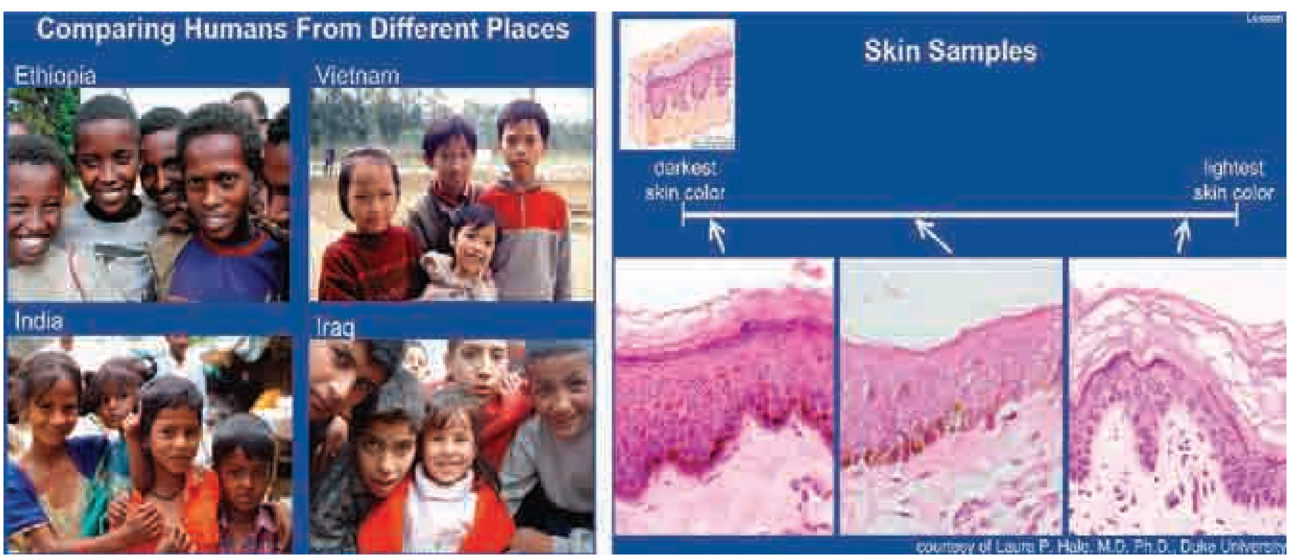

Figure 2. The cellular level. Students look at a variety of skin colors and learn how skin color is affected by the production of melanin.

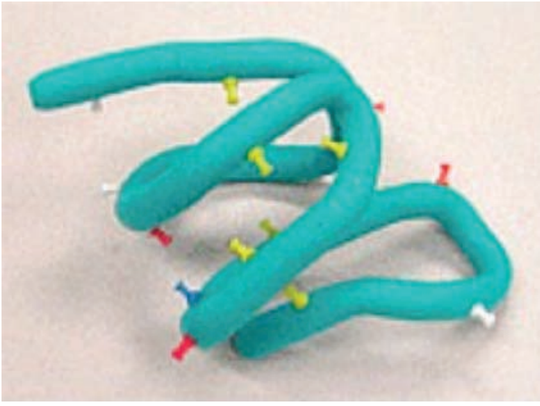

Figure 3. The protein level. "Toober" model of part of a protein. Thumb tacks represent amino acid properties.

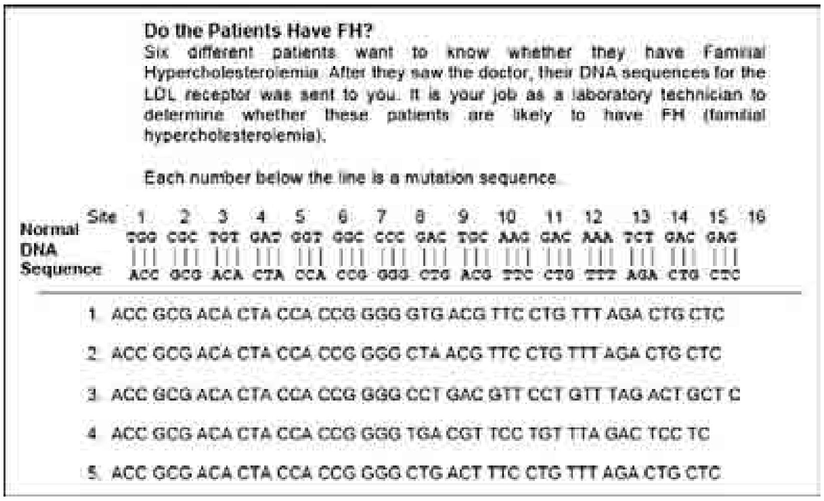

Figure 4. The DNA level. Student investigation using DNA data.

For example, students figure out whether a person is likely to have the disease familial hypercholesterolemia by determining the amino acid sequence of a protein after a mutation has taken place at the DNA level (see Figure 4). In this activity, students use several skills beyond recalling facts and information; they carry out the steps of transcription and translation, analyze data, make comparisons between data sources, and write scientific explanations using evidence to support their conclusions.

This series of investigations leads students through an exploration of the driving question at several different biological levels. Using the framing provided by the driving question, the investigations provide students with tools for considering each biological level and how the levels connect to each other and give them opportunities to ask questions, analyze data, and form conclusions.

Collaboration

When students engage in discussions with other students, they construct a shared meaning of concepts and experiences, draw on others' experiences, appropriate the knowledge of others, reflect on their own thoughts, and internalize the ways of speaking that are prevalent in the science discipline (Blumenfeld et al., 1997; Polman, 2004). Through collaboration in project-based classrooms, students not only build a shared understanding of scientific ideas and of the nature of the discipline (Krajcik & Blumenfeld, 2006) but also become participants in the science community by engaging in scientific discourse (Lemke, 1990; Lave & Wenger, 1991; Polman, 2004).

Throughout the unit, there are many opportunities for students to collaborate with each other. In one investigation described above, students collaborate to make sense of the lactase protein using toober models. Initially, students work in small groups to negotiate how to build the model. Then student groups must collect and analyze data and report their results to decide how a variety of changes will affect their model. Finally, students and teacher collaborate to make sense of proteins and their properties and determine how proteins play a role in similarities and differences. In this collaboration, students are encouraged to engage in discussions that promote a classroom culture of active listening and explanation of ideas. From a discussion of toobers, the teacher and students discuss how the model represents the lactase protein and how the amino acid properties determine the proteins' shape and function. They also begin to explore how this activity takes them closer to answering the driving question. Additional opportunities for students to collaborate are incorporated into many of the investigations and activities and supported with guiding questions and strategies in the teacher materials.

Creation of Artifacts

Because the use of multiple representations in genetics is argued to enhance student understanding (Cartier & Stewart, 2000), this project-based unit encourages students to construct multiple representations in order to process information in different ways (Krajcik et al., 1994). Students are encouraged to demonstrate and extend their knowledge and skills through completion of a variety of artifacts that mirror representations of products constructed by the scientific community. The artifacts created in the classroom are generally related to the other features of project-based science and can be used as an assessment tool to gauge students' understanding of content, process, and the driving question (Singer et al., 2000).

Students are provided ways to synthesize and demonstrate their knowledge by several activities involving the creation of artifacts. In the toober activity described above, students generate a model of the protein lactase. The model serves as an artifact, and when students are asked to explain their model either to the class or to the teacher, the artifact aids in the assessment of students' understanding of proteins and the role they play in similarities and differences. Another artifact used in the unit is student-designed comic strips explaining the molecular tasks of proteins and what happens when the task is not completed (see Figure 5A–C). For example, in Figure 5C, the student represented the liver as a city. This student related his knowledge of how cities function socially to explain how the liver functions. In his comic strip, he showed that when a person has familial hypercholesterolemia, liver cells struggle to rid themselves of cholesterol by depicting cholesterol (yellow globs) being illegally trafficked into the city. Because of the illegal trafficking, the city is in ruin. Over time, the liver is cleaned, which is represented by police confiscating the cholesterol.

Like the protein model, the comic strip and the student's explanation of it serve as an important opportunity to assess understanding. Not only were students able to demonstrate their understanding of scientific concepts, they were also able to showcase their artistic skills. Many students took pride in their artifacts and were motivated and eager to present and describe them to their peers. Throughout the unit, artifacts allow the teacher to assess students' understanding of connections between genes and traits and the ways in which the students are connecting these ideas to the driving question.

○ Challenges & Suggestions for Enacting Project-based Science in the High School Classroom

Although project-based science materials come with successes, they also raise new challenges as classrooms and teachers transition to new

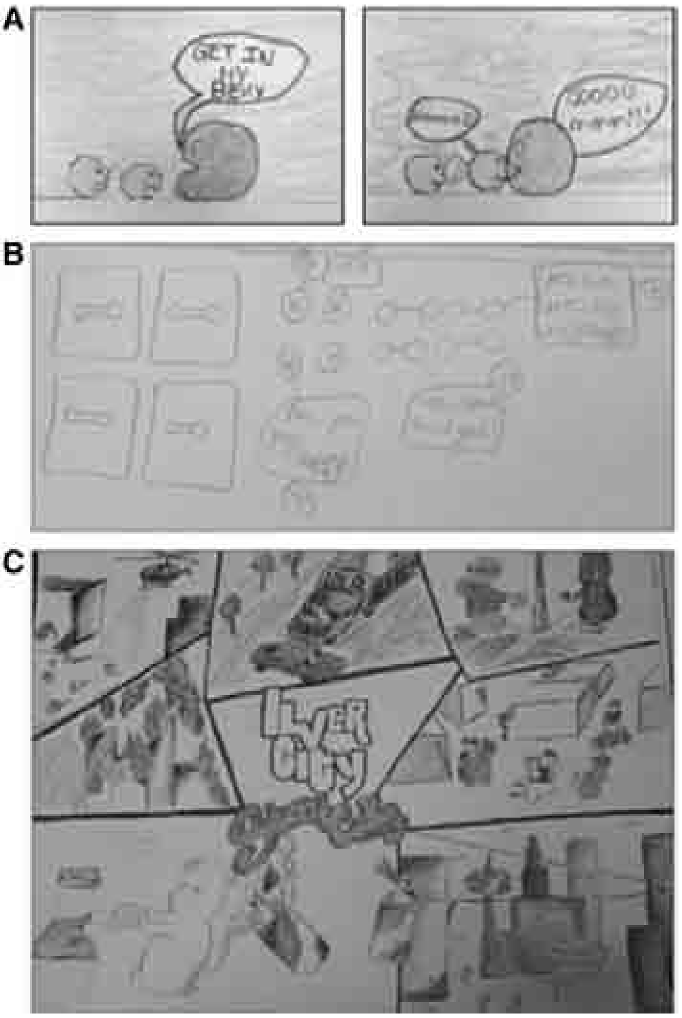

Figure 5. Student artifacts. Comic strips of proteins doing work in the body.

methods. We present challenges encountered and some suggestions for the enactment of the project-based science unit described here:

1. *Challenge*: Artifacts are more difficult to assess than standard pen-and-paper tests, yet they are rich in detail about student understanding.
   Suggestions: Formative assessments are useful in place of traditional pen-and-paper methods. As students work in groups, the teacher can walk around the classroom and ask questions. This will allow the teacher, through appropriate questions prepared in advance, to utilize classroom time for student group work and for assessing student understanding. Additionally, teachers can use gallery walks or student presentations as a way for students to explain their work. During gallery walks and presentations, students as well as the teacher can participate in asking questions, thus encouraging higher-level demonstrations of knowledge.
2. *Challenge*: Students are not generally conditioned to methods of inquiry, open-ended scientific discussions (Alozie et al., 2009), and collaboration. As a result, teachers need to employ strategies to help change the classroom norms.
   Suggestions: Help students participate in collaboration activities by assigning cognitive roles (Herrenkohl & Guerra, 1998; Herrenkhol et al., 1999). In these roles, students are required to master a thinking task, like interpreting the toober model, rather than physical tasks, like drawing the toober model. When students are engaged cognitively, they are more likely to stay on task and have some understanding of the activity. To promote discussions, encourage students to address each other when responding, use evidence to support their responses, and elaborate their answers. As the facilitator of the discussion, the teacher can ask follow-up questions to keep the discussion moving forward.
3. *Challenge*: The time required to effectively enact project-based materials is greater than with traditional learning methods, but students retain more knowledge and are able to apply it to new situations.
   Suggestions: The materials described here have been carefully aligned to national and state standards in content and skills. Plan to teach students the skills that are related to the standards during the beginning stages of enactment, and student familiarity will increase over time. Eventually, less time will be spent on repeating old skills and more on enhancing and transferring skills.

Although well-designed materials and professional development can help teachers address some challenges, we are still learning how to help teachers and students transition to this new learning environment.

○ Conclusions

Modern genetics is challenging, and, when using traditional materials, many students struggle to understand the fundamentals and connect their new knowledge with the real world. Although enactment of project-based science materials is challenging, it will help students learn modern genetics and make important and relevant connections to the real world. The approaches we have used to develop the features of project-based learning – a driving question, situated inquiry, collaboration, and artifacts – serve as examples of how project-based approaches can be integrated into high-school science classrooms.

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