The process of designing an inquiry-driven science unit can be complicated. While there are several resources that aid in unit development, such as Wiggins and McTighe’s (2005) *Understanding by Design* and the 5E Instructional Model by Bybee (2009), there is no “one stop shop” for science teachers to research, plan, and design coherent units for their students. The National Science Teaching Association (NSTA) and the *Next Generation Science Standards* (NGSS) have attempted to make planning easier for teachers by creating a common resource bank, but there is no unit design process specifically created for science teachers in a project- and inquiry-based classroom. Other educational professionals have also attempted to create processes to help teachers plan instruction and create material that is aligned with the NGSS including Krajcik et al. (2014). Daisley (2016) asserted that there are several challenges to the implementation of the NGSS, including lack of resources and training.
With this in mind, the primary goal of this endeavor was to synthesize a set of design principles for other teachers to follow when building their own units. Once these principles were identified, a planning guide was created and used to develop an NGSS-aligned unit focused on genetics to explicitly show the benefits of these principles in action. What follows is a brief synopsis of the guiding principles of unit development, the planning guide that was created using these principles, and how the principles and planning guide supported the development of a new inquiry-driven unit.

Guiding principles

The guiding principles summarized in Figure 1 and expanded upon below were either found through research or developed based on firsthand experience creating inquiry-driven science units for a high school audience. These guiding principles can serve as a foundation to designing a cohesive unit. The first principle came directly from a handbook that was created through a collaboration between inquiryHub (n.d.) and Next Generation Science Storylines (n.d.). According to the Storylines Teacher Handbook, the students “figure out scientific ideas ... figure out where [they] are going at each step... [and] figure out how to put ideas together over time” (p. 4). Student voice and choice, therefore, should serve as guiding principles when designing inquiry-driven units.

The second guiding principle was based upon prior experience designing several other units for use in the inquiry-based science classroom. It is no secret that teachers can be extremely busy. When teachers become overwhelmed, daily reflection can fall by the wayside. To best facilitate learning in a student-centered unit, it is imperative to build opportunities for teachers to reflect on a daily basis. Teachers can take this time to summarize that day’s learning and subsequently figure out where students need to go next. This will allow teachers to be flexible and responsive to student needs, despite the up-front work in developing the unit. Without daily reflection on what was learned and where to go next, it would be easy for both students and teachers to get lost. Differentiation for an individual student’s needs can be addressed easily if teachers can put aside time to reflect. Therefore, the second principle that was used to develop this unit was a clear focus on teacher reflection.

The remaining guiding principles, which can be broken down into five ideas, were developed by Penuel and Reiser (2018). In their paper, they explain seven ideas that are central to any NGSS-aligned unit. For the purpose of the development of these guiding principles, we simplified the components that they developed. The guiding principles from Penuel and Reiser that can fundamentally improve the unit design process include three-dimensional learning, phenomena/design challenges, incremental sense making, coherence from the learner’s perspective, and multiple opportunities for teachers to elicit and interpret student thinking. A brief syn-

<table>
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<tr>
<th>Guiding Principle</th>
<th>Explanation</th>
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<tr>
<td>Student voice and choice</td>
<td>To engage students, teachers can give them an opportunity to share their thoughts and choose what to explore.</td>
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<tr>
<td>Teacher reflection</td>
<td>To be responsive to student needs and differentiate accordingly, teachers must reflect on what was accomplished each day.</td>
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<tr>
<td>3-dimensional learning</td>
<td>The NGSS science and engineering practices, crosscutting concepts, and disciplinary core ideas are central to any inquiry-based unit.</td>
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<tr>
<td>Phenomena/design challenges</td>
<td>Putting phenomena or design challenges at the forefront of each unit and each lesson keeps students engaged and makes learning relevant.</td>
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<tr>
<td>Incremental sense making</td>
<td>In a traditional classroom, content is sometimes front-loaded without context. By ensuring students incrementally make sense of new information, teachers allow them to form new ideas and discover information on their own.</td>
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<tr>
<td>Coherence from the learner’s perspective</td>
<td>By using student input to guide the direction of the unit, teachers can ensure that the content being learned and the skills being practiced by the learner are both coherent and relevant. Students should be able to answer, “Why are we learning this?”</td>
</tr>
<tr>
<td>Opportunities for teachers to elicit and interpret student thinking</td>
<td>Units and lessons should give students multiple opportunities to share what they have learned so that teachers can adjust the pace or the sequence of the unit accordingly.</td>
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opinions of each of these ideas can be seen in the planning guide that was created as well as the newly developed genetics unit created using this guide (see Online Connections for both).

Two other principles that Penuel and Reiser (2018) referenced are support for equitable participation and support for teacher learning. Equitable participation should be inherently addressed in a unit as long as teachers focus on developing a unit that is student-centered, is coherent from the learner’s perspective, and includes multiple opportunities to elicit and interpret student thinking. By differentiating at various points in the unit for students’ varying needs (e.g., reading level, oral proficiency, math proficiency, or special learning needs), teachers can ensure equitable participation for all students. Similarly, support for teacher learning is an extremely large undertaking and therefore could not be a focus in the development of this particular unit. Support for teacher learning is less relevant for individual teachers and more applicable for curriculum developers and professional development providers, and so is not included here.

**Planning guide**

*Understanding by Design* (UbD), created by Wiggins and McTighe (2005), was central to the development of the planning guide. One of the central ideas of UbD is that unit developers start with the end in mind and work backwards to figure out the best way to teach. There are three stages in backwards design: Stage 1 (identifying desired results), Stage 2 (evidence), and Stage 3 (learning plan). The same general approach was used for this new process. Nonetheless, there were several aspects of UbD that had to be changed to be more in line with the new guiding principles.

The first divergence from UbD came in Stage 1. Wiggins and McTighe believe that one of the most important aspects of planning and teaching is transfer. In other words, students should know the importance of the knowledge or skills that they learn and how they can apply them to the outside world. While the end result is the same, the NGSS process is different. Rather than focusing on how knowledge and skills can transfer to the world outside of school, the NGSS promotes using actual phenomena or design challenges that students can use as motivation and ground them in the concepts and skills that they are practicing. Since this unit is meant to be fully aligned with the NGSS, a large portion of the adapted Stage 1 has a space dedicated to providing an overview of the driving question, phenomena, or design challenge of the unit.

Another substantive change that was made to Stage 1 allows the units that are developed to be more student centered. Instead of using teacher-generated Essential Questions, student-generated driving questions are elicited and used. These driving questions help organize the unit and define the activities/explorations that will ultimately answer those questions.

In the new planning guide, an additional Driving Question section is included. The importance of this section is described below (see “Reflections on Planning”).

The last fundamental change came in Stage 2. According to UbD, Stage 2 of planning should focus on evidence and be broken down into only assessments and other evidence. Stage 2 of the new planning document replaces the idea of “evidence” with “artifacts and assessments.” Essentially, artifacts are notes, graphs, and figures that show what students have figured out and how their ideas lead to an understanding of the driving phenomenon or question. According to Penuel and Reiser (2018), artifacts are “important because a key aspect of making scientific practices central is establishing accountability to others in the classroom and to disciplinary norms for knowledge building” (p. 15). Stage 3, the learning plan, remained relatively unchanged aside from some formatting changes that made it more user friendly.

**Reflections on planning**

After developing the guiding principles and the planning guide, an entirely new unit was created to put these tools into action. The new unit is geared for 10th-grade students who are learning biochemistry. Specifically, this unit focuses on genetics and uses a two-minute video about sickle cell disease as the anchoring phenomenon. Throughout the unit, students ask questions and learn new information with the goal of coming up with a robust explanation of sickle cell. The culminating activity asks students to put themselves in the shoes of a genetic counselor and create an infographic or pamphlet that answers several questions for parents whose children might be affected by sickle cell. Students then are asked to create a second infographic or pamphlet about a new genetic disorder of their choosing. Ultimately, students will share their newfound knowledge with their peers through a gallery walk. With the guiding principles serving as a foundation that could consistently be referred back to, we noticed several important changes to the planning process that would ultimately benefit students’ learning, engagement, and practice.
On Day 1 of the unit, students watch a two-minute clip about two siblings, Devon and Sky Cooper, who live with sickle cell anemia. This video serves as the anchoring phenomena for the unit. While watching the video, students ask questions about sickle cell that they will research to fully understand this genetic disorder. After students generate questions as individuals, they gather in small groups to further organize and synthesize their questions. Finally, the entire class discusses the five to six questions that will be used to shape the unit. These questions will be included on the Driving Question Board, an excellent tool rooted in inquiry instruction, which will remain posted in the classroom for the duration of the unit. In an ideal world, teachers would use this newly created Driving Question Board to develop a roadmap for learning in real time.

The reality of teaching is that this approach isn’t feasible for most of us. To solve this conundrum, questions were developed by stepping into the mind of a student and considering questions that they would ask. These questions were then synthesized and condensed into four driving questions that would shape the unit. The driving questions were then associated with relevant NGSS Performance Expectations. The Driving Questions and the Performance Expectations were used as organizing factors in the creation of lessons and lesson sets. By using students’ questions in this way, the hope is that learning will be both coherent and relevant from the perspective of the students.

Two guiding principles helped ensure that this new unit would be coherent from the student perspective while simultaneously avoiding front-loading new information at the beginning of each lesson. Using a single anchoring phenomena to drive the unit (Devon and Sky’s sickle cell) and smaller phenomena to introduce later lessons helps students make sense of new information incrementally. For example, the first driving phenomenon that will be used on Day 2 is a short movie that shows the development of a salamander from a single-cell zygote to a fully developed multicellular organism. While students are watching the video, they create a Notice, Wonder, What If Chart about what they are seeing. Using the video as a foundation to anchor their understanding, the chart as a way of organizing their inquiry process, and subsequent discussion to flesh out their ideas, students are incrementally making sense of mitosis. The teacher provides new information and vocabulary at the appropriate time so that students can see how the process of mitosis is related to the effects of sickle cell. This is contradictory to the way that many teachers approach the introduction of new information.

If coherence from the learner’s perspective and incremental sensemaking were not two of the guiding principles, the lesson

<table>
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<th>FIGURE 2</th>
<th>Synthesized driving questions.</th>
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<tr>
<td>Driving Question &amp; Performance Expectation</td>
<td>Initial Questions</td>
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<tr>
<td><strong>What are the effects of sickle cell?</strong>&lt;br&gt;HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.</td>
<td>• Are all cells in the body the same?&lt;br&gt;• Do all cells do the same thing?&lt;br&gt;• Why are red blood cells different?&lt;br&gt;• Why are only red blood cells affected?</td>
</tr>
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<td><strong>What genes are associated with sickle cell?</strong>&lt;br&gt;HS-LS1-1: Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins which carry out the essential functions of life through systems of specialized cells.</td>
<td>• What is a gene?&lt;br&gt;• Where do proteins come from?&lt;br&gt;• What is a character?</td>
</tr>
<tr>
<td><strong>Why/how does sickle cell occur?</strong>&lt;br&gt;HS-LS3-2: Make and defend a claim based on evidence that inheritable genetic variations may result from: (1) viable errors occurring during replication, and/or (2) mutations caused by environmental factors.</td>
<td>• Why is sickle cell more common in people with African descent?&lt;br&gt;• How do all genetic diseases occur?</td>
</tr>
<tr>
<td><strong>How are genes inherited?</strong>&lt;br&gt;HS-LS3-1: Ask questions to clarify the relationship about the role of DNA and chromosomes in coding the instructions for characteristic traits passed from parents to offspring.</td>
<td>• Why do Devon and Sky have sickle cell while the parents don’t?</td>
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</tbody>
</table>
would be structured completely differently. First, the teacher would give a brief introduction on the cell cycle and mitosis. Students would then learn about prophase, metaphase, anaphase, and telophase. Finally, students would get to watch the salamander video to watch mitosis in action. It would take an entire class for students to begin to understand why the information that they are learning is relevant or important. By using phenomenon and providing information incrementally, students make sense of new information in their own way.

According to the Storylines Teacher Handbook, students should figure out how to put together ideas over time. Throughout this unit, students explore different phenomena to answer a set of Driving Questions. Once students are able to answer the four different driving questions, they are presented with a final challenge that asks them to synthesize all of the information that they learned. A core part of the NGSS is an emphasis on science and engineering practices, specifically on developing and using models. This culminating project was created for students to put together all of their new ideas and practice developing models. With this project and the sickle cell phenomenon as a foundation that students can refer back to, they will be motivated to learn, grow, and explore in a way that would be very challenging without this student-centered approach to unit design.

Summary
There is a scarcity of resources that help science teachers develop NGSS-aligned units. Without a common set of guiding principles of unit design, the ability for science teachers to create NGSS-aligned units on their own is a very daunting endeavor. Any new methodology should be scrutinized, picked apart, and ultimately improved as a result of this scrutiny. With the current lack of resources available, it is our hope that other science teachers can use the guiding principles, the planning guide, and these reflections on the development of a new unit to inform their own unit design process.

ONLINE CONNECTIONS
Folder with Planning Guide & Genetics Unit: https://drive.google.com/drive/folders/1-CDz5SBluQrtIzo888WqrDlxvZWzKt
inquiryHub: https://www.colorado.edu/program/inquiryhub/
Next Generation Storylines: https://www.nextgenstorylines.org
NGSS Design Badge: https://www.nextgenscience.org/badge
Storylines Teacher Handbook: https://docs.google.com/document/d/1Ryo2OGa_V20t51xMnZ-SyJ67T1xu9L_DSTLocCBtY/edit
Sickle Cell Anchoring Phenomena Video: https://youtu.be/Zsbhvl2nWNE

REFERENCES
NGSS Lead States. n.d. NGSS design badge. https://www.nextgenscience.org/badge

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