Technology-Enhanced Formative Assessment

Question-Driven Instruction Using Student Response Systems in High School Life Science Classes

By:

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Abstract

The evaluation of student learning for the purpose of modifying teaching and learning activities to improve learning outcomes through formative assessment is widely considered to be a best practice for improving student learning. Effective secondary teaching includes measurable improvement of what students know and can do and student performance relies on opportunities to receive and apply feedback. Technology-enhanced formative assessment (TEFA) combines question-driven instruction with student response systems to create a discussion based classroom environment that invites continual feedback. Student-led discussions are the platform for learning with TEFA with the teacher facilitating TEFA also provides the flexibility to assess student learning and target instruction in real time during lesson relevant discussions. This project offers TEFA lessons aligned to the core ideas of the Next Generation Science Standards (NGSS) for high school life science that can be readily implemented in most classrooms with existing technology.

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Chapter 1: Introduction

Rationale

According to the National Research Council in *A Framework for K-12 Science Education*, secondary science education, including life science education, should provide students with "sufficient knowledge of the practices, crosscutting concepts, and core ideas of science and engineering to engage in public discussions on science-related issues, to be critical consumers of scientific information related to their everyday lives, and to continue to learn about science throughout their lives" (Schweingruber, Keller, & Quinn, 2012, p. 9). While learning the concepts and practices of science is the desired educational outcome of all secondary science courses, measuring learning can only be done by students demonstrating what they know and can do. As a result, our current educational standards and policies center on the measurement, while what ultimately impacts learning, the *process* of teaching and learning in the classroom, is not receiving the attention it deserves (Black & William, 1998).

With the emphasis in secondary teaching on measurable improvement of what students know and can do, teachers often focus on summative assessment of student learning. However, the purpose of secondary science education is for students to gain conceptual understanding and develop scientific thinking, not to achieve specific score distributions, therefore efforts in the classroom need to promote student learning. Formative assessment is widely considered to be a best practice for improving student learning, but is often underutilized in classroom teaching (Frey & Schmitt, 2010). Formative assessment is evaluation of student learning for the purpose of modifying teaching and learning activities to improve learning outcomes. In order to be

considered formative, reoccurring assessment must occur *during* classroom activities and appropriate adjustments to teaching must follow.

One challenge for effectively using formative assessment in secondary science classes is collecting and aggregating data on 20-30 students within the time constraints of a class period (Shirley & Irving, 2015). To overcome this challenge, teachers can incorporate technology into classroom lessons. Student response systems are technological tools that integrate instantaneous collection and aggregation of student responses into classroom lessons.

Student response systems, also called classroom communication systems, classroom response systems, audience response systems or "clickers," consist of hardware and software systems that allow students to answer digitally displayed questions through the use of a hand-held device or personal electronic device. This technology is currently used in most universities and thousands of k-12 schools in the U.S. (Beatty, 2004). Responses are collected and summarized instantaneously and results are displayed graphically, providing feedback to both students and teachers. Student responses are displayed anonymously, but teachers have access to individual student data through each handset's identification.

Student response systems are tools to collect and display student responses to posed questions which can be used for formative teaching practices. One practice is to follow up lectures or presentations with conceptual questions for the teacher to evaluate the efficacy of instruction. Students can also try to convince each other of their view of the correct response before the teacher indicates which answer is accurate, encouraging students to develop skills in forming and articulating arguments (Mazur, 1997). While these are both effective formative strategies, a question-driven instructional approach that involves initiating instruction with

challenging conceptual questions, leads to even greater learning gains (Beatty, Gerace, Leonard, & Dufresne, 2006).

In question-driven instruction, teachers utilize contextually challenging questions to initiate instruction, engage students and create context for learning (Beatty, Leonard, Gerace, & Dufresne, 2006). Questions and problems are not meant to provide information about what students have already learned, but to provide direction for the construction of new knowledge through their cooperative sense-making efforts. Questions are designed to encourage students to explore and connect new learning, to elaborate and challenge current understanding, determine misunderstandings or gaps and finally, to promote self-assessment (Beatty & Gerace, 2009).

Technology-enhanced formative assessment (TEFA) is a pedagogical approach to using student response system technology in combination with a question-driven instructional paradigm (Beatty & Gerace, 2009). With this approach, conceptual questions are presented at the outset of instruction and students use the aggregated responses to spark productive discussions about their ideas and understandings. The goal of TEFA is to create an environment of continual feedback for teachers to use to adapt instruction through two procedures: through student's answering of questions that are carefully created to expose thoughts, understandings, and cognitive skills rather than to evaluate performance, and through student-led and extensive dialogue (Dufresne, Gerace, Leonard, & Mestre, 2013). A cycle of question presentation, small group and whole group discussion is repeated multiple times within a class period to introduce and expand on main disciplinary topics.

In addition to the question-driven instruction, the effectiveness of TEFA hinges on extensive classroom discourse, formative assessment and development of meta-thinking (Beatty

& Gerace, 2009). Including all four aspects in the TEFA lesson structure allows students to achieve the best possible learning gains.

A key component to the TEFA question cycle is classroom discussion. Extensive classroom discourse includes whole-group, small-group or partner formats where perceptions can be articulated, explored, compared, challenged and resolved (Beatty & Gerace, 2009). An important aspect of discourse in TEFA is that discussions are student-led and dialogical in order for student experience, prior knowledge and ways of thinking to be integrated in new learning (Edwards & Mercer, 1987; Wertsch, 1997). Existing knowledge has the potential to enhance and support new learning, as well as create obstacles to learning. Pre-existing alternative conceptions can prevent students from fully grasping new concepts, resulting in rote memorization for the purposes of a class while students maintain misconceptions (Donovan & Bransford, 2005). Teacher-directed discussions are often focused on having students generate correct answers and do not provide the formative information about students' underlying conceptions and idea construction (Wertsch, 1997).

The student responses and the extensive discussions that result from TEFA provide teachers with immediate information on student beliefs, knowledge and process skills allowing adapted instruction. This aspect of TEFA is largely dependent on the teacher's skill in evaluating and recognizing student conceptions based on their comments, as well as the teacher's ability to guide discussions toward discovery of accurate conceptions (Feldman & Capobianco, 2008; Fosnot, 1995; Harris, Phillips, & Penuel, 2012). In order to develop and support these skills, teachers can utilize learning progressions that have been developed for particular subject areas such as those available in the *Next Generation Science Standards* (Furtak, Thompson, Braaten, & Windschitl, 2012; National Research Council (U.S.), 2013).

The development of meta-thinking stresses the importance of discourse beyond science content. TEFA encourages students to consider how learning occurs, how mindset impacts learning, and why scientific thinking is important by introducing and scaffolding these questions into discussions (Beatty & Gerace, 2009). Through participation in class discussions, students can also be prompted to reflect on rules and strategies for effective communication.

The potential benefits of TEFA for both student learning and targeted instruction make it a useful pedagogical approach for life science teaching. While formative assessment is well documented as a best teaching practice, implementation in the classroom may be limited due to a lack of clear usage guidance for teachers to follow. The explicit nature of the lesson structure, along with the guiding principles of TEFA, provides this guidance to simplify and encourage classroom use.

Significance of Project:

Although formative assessment is widely accepted to provide learning benefits to students, technology-enhanced formative assessment (TEFA) has previously only been applied to physics instruction. As student response system technology becomes more widespread, all disciplines will benefit from explicit examples of integrating TEFA into lesson planning. This project will detail lesson structures for high school life science units using TEFA.

TEFA is appropriate as an alternative for lecture-based or teacher-led discussion formats used to introduce and establish key disciplinary concepts. For this reason, selection of lesson topics for this project will be based on Next Generation Science Standards (NGSS) disciplinary core ideas (Schweingruber et al., 2012). The core ideas will provide focus for the areas of disciplinary proficiency students should attain. Another advantage to using NGSS core ideas as

instructional guidance is the availability of corresponding progressions of student learning that occur over time. These progressions provide information to guide expectations of initial conceptions and desired endpoints.

Alternative conceptions are common in introductory biology courses at the college level indicating a need to provide better conceptual understanding at the high school level (Anderson, Fisher, & Norman, 2002). The formative information provided through the use of TEFA gives teachers a way to evaluate the conceptual understanding of students as topics are covered, allowing teachers to provide adequate support for optimal learning.

Definition of Terms:

Technology Enhanced Formative Assessment: a pedagogical approach for embedding formative assessment into instruction using student response system technology with a question-driven instructional paradigm.

Question Driven Instruction: An instructional design that consists of posing, answering, and discussing of conceptually challenging questions as the mechanism for student learning.

Student Response Systems: Hardware and software systems that allow students to answer digitally displayed questions through the use of a hand-held device or personal electronic device. Aggregated class responses can be instantaneously displayed and often individual student data can be collected.

Student-led discussion: Classroom discourse that is initiated and maintained by student discussion that includes descriptions, comparisons, inferences, evaluations, explanations,

speculations and justifications. Teachers act as discussion facilitators rather than givers of knowledge.

Alternative conceptions: Inaccurate or incomplete conceptual knowledge that can impede new knowledge construction.

Metacognitive knowledge: The understanding of what one knows and does not know as well as reflective thinking about how learning occurs.

Chapter 2: Literature Review

Historical background

Formative assessment is a research-based best practice that is advocated by U.S. national policy statements (Duschl, Schweingruber, & Shouse, 2007; Schweingruber et al., 2012). Formative assessment improves student learning by providing feedback to students about their current understanding and skill as well as informing teachers of students' progress and difficulties (Black & William, 1998). Collecting and responding to formative data can be challenging given the time constraints of the classroom. Student response systems provide a useful tool for teachers to incorporate formative assessment into teaching and have instant access to student responses. In order for the tool to be useful, there needs to be an instructional framework that provides useful formative data.

One early approach to using student response systems for formative assessment in science classrooms is Eric Mazur's Peer Instruction (Mazur, 1997). Peer Instruction involves having students read material before class and dividing class time into short presentation-question cycles. In each cycle the teacher presents information on one main topic from the reading followed by a multiple choice conceptual question. Students have a brief time to think and answer the question individually using a student response system. A histogram of student responses is displayed and students are given a few minutes to discuss and convince their neighbors of their answers. After the discussions, students are directed to answer the question again and are shown the new distribution of responses. The teacher then explains the correct answer and begins a new cycle.

Peer Instruction was developed to enhance and guide a traditional instructional paradigm where a teacher provides students with information. The student discussions were inserted to benefit students through collaborative learning and increased engagement as well as to benefit teachers with feedback about student understandings. Researchers at the Scientific Reasoning Research Institute have found that inverting this design resulted in improvements to teaching and learning (Beatty, Gerace, et al., 2006). Rather than beginning lessons with teacher-led presentation, questions are posed first and learning occurs through the pondering answering and discussing that follows.

The UMass Physics Education Research Group (UMPERG) developed the approach of technology-enhanced formative assessment (TEFA) as a research based instructional framework for using student response systems (Beatty & Gerace, 2009). TEFA grew out of a formative assessment approach using student response systems developed by Dufresne and Gerace called Assessing-to-Learn (Dufresne & Gerace, 2004). Rather than presenting students with questions within a traditional instructional format, Assessing-to-Learn established the question cycle where students are presented with a question first, without initial instruction, and given time to discuss or think individually. Students then enter a response and view a histogram of class responses. Teachers facilitate a whole class discussion centered on student reasons and justifications for their responses, without revealing correct answers, encouraging all students to engage in debate. If needed, teacher explanations or presentations can provide lesson closure (Beatty, 2004; Dufresne & Gerace, 2004). This question cycle is at the heart of TEFA and is repeated several times during an instruction period. TEFA is best used for whole-class instruction of core topics and should be accompanied by other instructional approaches, such as group projects and hands-on laboratory activities(Beatty & Gerace, 2009).

According to the U.S. National Research Council in *How People Learn*, learning environments that are most effective are student-centered, knowledge-centered, assessment-centered and community centered (Bransford, Brown, & Cocking, 2000). TEFA has the ability to address each of these constructs by creating an environment where frequent formative assessment allows students to guide the direction of instruction while they engage socially with peers and teachers to construct knowledge that is relevant to their experiences (Beatty, Leonard, et al., 2006).

Theoretical background

The theoretical basis for the instructional framework in TEFA comes from the research on formative assessment, constructivist principles, and the established importance of student discourse in combatting misconceptions, promoting new learning and developing reasoning skills. Formative assessment, social learning and discussion facilitation are the hallmarks of TEFA that have theoretical and experimental support.

Formative assessment

Black and Williams have suggested that classrooms are often treated as a "black box" where students, teachers, standards, resources, assessments and rules are put in and there is an expectation that knowledgeable students will be the end product (Black & William, 1998). Recent educational policies reflect this view as learning standards and proficiency levels are the focus of reforms, rather than determination of effective methods that consistently produce increased learning. Lack of interest about what happens inside the box has led to a lack of guidance about what *should* happen inside, despite the fact that some teaching practices have clear evidence-based support.

Research has documented the efficacy of the classroom practice of formative assessment in producing significant learning gains (Black & William, 1998). Formative assessment is the process of gathering information about individual student's knowledge and skills to provide feedback to guide each student's further learning and inform the teacher's subsequent instruction. The key to accomplishing the potential learning gains is using the feedback to make adjustments to the instruction and the ways students' interact with information. TEFA provides streamlined access to information about student knowledge and skills with question-driven instruction and student response systems. Extensive student-led discussions allow students and teacher to use the feedback to adapt the direction and depth of information sharing, so the entire class can achieve understanding.

Formative feedback is also important for students' metacognitive knowledge. It is not sufficient to ask students to report their level of understanding of a concept because they often do not know what they have good conceptual understanding of and what they don't understand well (Caleon & Subramaniam, 2010). Glenberg and Epstein describe students as having an "illusion of knowing," where they report unwarranted confidence in their understanding (Glenberg & Epstein, 1985). In other words, students often say they understand something yet are unable to correctly answer questions on the topic. Feedback on both the students' claims for understanding and related question accuracy can help students become aware of discrepancies in their own conceptual confidence and proficiency.

Constructivist principles

Constructivist theory tells us that knowledge is constructed when we engage in new experiences and that information can be either be assimilated into existing cognitive constructs

or accommodated through realignment of constructs (Piaget, 1976). Students make sense of new material by expanding, confirming or changing their existing knowledge. Knowledge is not obtained passively; it is actively created and shaped through questioning, exploring, solving contradictions and reflecting (Fosnot, 1995). Simply seeing or hearing information does not ensure that students will gain understanding. The teacher's role is not to inform students, but to facilitate students in seeking and creating knowledge by questioning their thinking and strategies as well as repeated reflection on previous ideas as knowledge is expanded (Bruner, 1973). Question-driven instruction provides ongoing opportunities for students to construct knowledge through productive discussions that are led by students and facilitated by teachers.

The knowledge constructed through question-driven instruction is not simply a collection of facts, but conceptual understanding with well-developed scientific reasoning. When questions elicit discussions that include comparisons, inferences, evaluations, explanations, speculations and justifications, students construct their cognitive representations of ideas linked to the reasoning skills used (King, 1994). These representations are cognitive basis for the higher levels of thinking students need to demonstrate in science.

Student discourse

According to Vygotsky, social interaction is critical in cognitive development. The Zone of Proximal Development occurs when students interact socially through peer collaboration and teacher scaffolding (Vygotsky, 1978). Question-driven instruction allows teachers to position students in the Zone of Proximal Development by presenting conceptual questions and having students discuss their reasoning. The convergence of speech and activity provide optimal

intellectual development because of the concurrent activation of internal and external

representations (Vygotsky, 1978).

Posner and Gerzog describe the conceptual ecology as the interaction of beliefs and

knowledge that shape experiences with new information (Posner & Gertzog, 1982). In order for a

student's conceptual ecology to be evident, knowledge, beliefs and experiences need to be

verbalized. Student discussions prompted by questions on key science concepts provide exposure

of conceptual ecologies that can support new learning and those that need restructuring for new

learning to be optimized. For students to achieve deep and enduring understanding, prior

knowledge needs to be linked to new learning and a student's belief system needs to

accommodate new ideas. If a student's knowledge or beliefs are incompatible with new

information, students may not be able to achieve more that memorization of facts.

Incomplete conceptions and misconceptions are common in life science due to the

complex processes and interactions that are inherent in natural systems. Students often struggle

with complex biological concepts like cell division, photosynthesis, cellular respiration and

evolution due to inadequate understanding or misconceptions (Bahar, Johnstone, & Hansell,

1999; Brown, 1995; Lawson & Thompson, 1988). Scientific conceptions that are inappropriate

will persist if new problems can be solved without conflict (Posner & Gertzog, 1982). Allowing

students to explain and justify their thinking, as well as attempt to persuade others that don't

share their view, can result in cognitive conflict when disagreements expose preconceptions that

are incomplete or inaccurate. When a student becomes dissatisfied with their existing cognitive

construct conceptual change can occur (Posner & Gertzog, 1982). The required conditions for

reforming misconceptions and misunderstandings are awareness of one's own ideas and

exposure to alternatives that challenge existing constructs.

Just as an awareness of misconceptions and alternative conceptions is necessary for students to evaluate evidence to support or contradict the conceptions, students also need reasoning skills to appropriately evaluate conceptions. Reasoning skills allow students to generate possible scientific reasons for observed patterns or phenomena as well as determine consequences from theories or hypothesis. Concepts in secondary life science require students to move beyond concrete reasoning into more abstract reasoning (Karplus, 2003). To develop this scientific thinking, students need to learn and apply the language of their discipline (Newton, Driver, & Osborne, 1999). Although it seems obvious, it is sometimes overlooked in classroom settings that the practical application of disciplinary language is talking to one another. Discussions for instructional purposes in science classrooms are often referred to as dialogical arguments (Newton et al., 1999). The connection between reasoning and argument is suggested in Krummheuer's definition of argument "the intentional explication of the reasoning of a solution during its development or after it" (Krummheuer, 1995). Others have also suggested that reasoning skills are developed through exchanges in contradictory viewpoints (Lawson, 1988). Dialogical discourse in the science classroom not only allows teachers to appreciate students' reasoning underlying conceptions, but it promotes further development of desired reasoning skills.

Benefits

Student engagement

TEFA engages students in developing deeper understanding beyond recitation and recollection invoked by typical classroom instruction. Students are not able to be passive bystanders; they must participate in answering questions. Since all student responses are collected, not just the first to volunteer or the first called on, attending to the questions and

committing to an answer gain value for students (Abrahamson, 2007). Every student has a stake in the results and will be motivated to seek confirmation or clarification (Beatty, Leonard, et al., 2006). Student participation and attention are improved with the use of student response systems and students express a preference for hearing explanations for answers and ideas from their peers who share similar language structure (Kay & LeSage, 2009). Improvements in pre-class assignment completion also occurs due to increased student accountability with required participation in answering questions with student response systems (Caldwell, 2007).

Motivation, either intrinsic or extrinsic, is an important factor in what drives students to perform. Intrinsic motivation is the drive to do something because of the gratification derived from engaging in the activity itself and extrinsic motivation is the drive to engage in an activity to achieve a separate outcome. While both types of motivation can reinforce student behavior, it is desirable to utilize intrinsic motivation when possible because it leads to higher quality learning and because the rewarding properties of extrinsic motivators are often lost over time (Ryan & Deci, 2000). The student-led discussions that are a large part of TEFA allow students to control the direction and focus of their learning. Students who are given autonomy over their own learning develop feelings of competence and will therefore find that learning intrinsically motivating (Ryan & Deci, 2000).

Constructed knowledge

Knowledge construction is an active process that requires bringing existing constructs to consciousness, processing new information through the lens of prior knowledge and extending, altering or rejecting existing constructs to accommodate the information. Although knowledge is constructed internally, collaboration allows knowledge to be developed beyond rote

memorization (Johnson, Johnson, & Smith, 1991). Through displayed answers to questions and classroom discussions, preconceptions and background knowledge strengths and limitations are made obvious to students, allowing them to seek out clarification or correction. Students may be unaware of deficits in conceptual understanding and when simply asked if they understand, report affirmatively (Moss & Crowley, 2011). Having immediate feedback and discourse after incorrectly answering a question they thought they knew can provide students opportunity to address misconceptions. Verbalization of reasoning can also expose previously unknown logical flaws, gaps or contradictions that students have (Beatty, 2004).

The classroom discussions common to TEFA have been shown to lead to individual conceptual gains that would not occur if students simply went along with answers that other peers seem most confident of (Smith et al., 2009). This is in contrast to classrooms that engage in teacher-led discussions where students behave according to what they perceive are the teacher's expectations and do not seek to achieve conceptual understanding (Edwards & Mercer, 1987).

Contingent teaching

TEFA provides immediate feedback via student response systems regarding student preconceptions, knowledge acquisition, confusion and misconceptions. Feedback allows teachers to instantly modify instruction to address misconceptions or confusion, review misunderstood information or bypass topics students already display firm understanding of (Kennedy & Cutts, 2005). Rather than being limited to evaluating student work after and between lessons, adjustments to instruction can occur during lessons. Unlike raised hands where typically only students confident in answers will volunteer, all students submit responses to

displayed questions, providing teachers a better assessment of where the majority of the class and individuals stand in terms of conceptual understanding (Kay & LeSage, 2009).

In addition to student responses to displayed questions, their responses during discussions provide clarity both to the teacher and the students themselves as to who has grasped concepts and who hasn't. TEFA allows teachers the flexibility to continue discussions until students reach optimal conceptual understanding (Beatty & Gerace, 2009). Students can be prompted with guiding questions or comments to lead their discussions toward accurate and deep understanding of concepts. New information can be easily presented, as well as revisiting of previous topics, allowing students to connect knowledge. Teachers also have the opportunity to reflect on student learning by reviewing and analyzing stored student responses.

Language and communication

The language of science is not just about learning terminology, it is also about practicing science by communicating observations, explanations, comparisons, classifications, analysis, hypothesis, evaluations, conclusions and generalizations (Lemke, 1990). The discourse structure in many science classrooms is a teacher-centered cycle of presenting material, asking questions, selecting respondents, evaluating answers and elaborating on the material. When students do not get the opportunity to practice communicating through the language of science, it is unreasonable to assume that they will just pick up the skill (Lemke, 1990).

The challenge of appropriately using the language of a particular discipline is that it involves both a firm contextual understanding of the topic and familiarity with terminology (Zwiers, 2008). Students must practice using disciplinary language, learn to communicate ideas with clarity and develop effective listening skills. This practice occurs within each question cycle

in TEFA when students have opportunities to engage in meaningful small-group and whole-group discussions. The reason TEFA discussions have depth and meaning is due to the fact that students lead discussions and bear some of the responsibility for instructing their peers (Beatty, 2004; Brewer, 2004; Draper & Brown, 2004).

Reasoning skills

For a deep understanding of biology, students must progress from learning basic terms and structures to processes, interactions and systems. Reasoning skills that support scientific thinking need to be developed for this conceptual learning to occur. This requires secondary students to move away from concrete reasoning and toward abstract thinking and representation (Karplus, 2003). TEFA provides teachers' access to students' reasoning skills when students engage in explanations, justifications, comparisons and similar types of discourse. Equipped with this awareness, teachers can prompt students to develop higher level thinking. More advanced reasoning skills result in students who are better able to evaluate alternative conceptions and hold fewer biology misconceptions (Lawson, 1988).

Students can be encouraged to develop appropriate reasoning strategies through targeted question construction. Inductive reasoning skills are employed when students are asked to discover a pattern and generate plausible causes for it, while deductive questions would involve students deducing consequences of a hypothesis or construct (Lawson, 1988). Classroom discourse inherent in TEFA also helps students develop reasoning skills by providing multiple opportunities to engage in higher order skills such as supporting, justifying and evaluating.

Limitations

Question Development

Constructing useful questions for TEFA can be time consuming and difficult to accomplish. Questions that are conceptually challenging and stretch students' understanding becomes the instructional focus and this may be difficult to do while ensuring required curricular content coverage. Teachers must make a specific effort to target content and language demands with difficulty levels optimal for students to benefit from discussion, as well as include distractors that reflect common student misunderstandings (Feldman & Capobianco, 2008). Because students should be provoked and inspired into substantive discussions, questions that are typically used for exams or homework are not useful as TEFA questions (Beatty, Gerace, et al., 2006). The lack of resources for obtaining good questions for a particular topic makes question development the main obstacle for teachers to overcome (Beatty, Gerace, et al., 2006). Teachers also cite several other difficulties in creating questions such as: making questions interesting, designing questions that enhance understanding of the content, targeting higher-order thinking skills and creating questions that promote extensive discussion (Lee, Feldman, & Beatty, 2012).

Discussion Facilitation

Facilitating student discussion and learning by adapting instruction rapidly require teachers to develop new thinking and communication skills. Instead of telling students what they should know, teachers must steer discussions for students to come to consensus. To do this, teachers must allow students autonomy over the progression of their learning. This autonomy alters the structure and relationship between students and teachers from the traditional teacher-as-a –knowledge-giver, and may put teachers in a less familiar situation (Reeve, 2009).

Other factors may contribute to the difficulty in effectively facilitating, verses leading, classroom discussions. Teachers are often held accountable for student performance and as a consequence of feeling responsible for students meeting standards, feel pressured to structure lessons around content coverage (Reeve, 2009). Facilitating discussion, as opposed to direct presentation of material, is often more time consuming, which can also lead teachers to believe less content is being covered. Teachers may also believe that they may appear ineffective, or the class will appear chaotic, if they do not control discussions and lesson progression (Reeve, 2009).

Teachers may have difficulty using formative information effectively. The needed understanding of what students are thinking based on responses and discussions can be difficult for teachers to ascertain (Lee et al., 2012). As a result, teachers need a well-developed understanding of learning progressions and common misconceptions for the particular topic under discussion. Some teachers may also struggle with provoking and guiding discussion without explicitly indicating correct verses incorrect responses or giving answers (Lee et al., 2012). The availability of training and practice in inducing productive discussions may not be sufficient for some teachers.

Discussions may introduce difficulties from the students' perspectives as well. Competing ideas, arguments and explanations can cause confusion for students and prevent them from attending to or understanding key concepts (Kay & LeSage, 2009). As a result, students may be exposed to less content than the curriculum intends. It is also possible that a small number of students will actively engage in discussions and full class participation will only occur with student responses to presented questions (Nicol & Boyle, 2003).

Student Perceptions

Student perceptions of TEFA may impede effective implementation. Many students will come to TEFA classrooms with no prior experience with student response systems, question-driven instruction or student-led discussions. As a result, students may be reluctant to participate and may become frustrated trying to become accustomed to a new learning environment (Beatty, 2004; Boyle, 2006). Students also express the belief that content coverage that results from student-led discussion is less than what would occur from teacher-led framework (Allen & Tanner, 2005). Finally, some students may prefer a lecture based format where they can listen and take notes, or they may dislike collaborative learning paradigms that require active participation and increased effort (Trees & Jackson, 2007). Either situation would lead to diminished participation and disrupt the effectiveness of TEFA.

Implementation

Implementation of technology-enhanced formative assessment requires four elements: choosing and learning the hardware and software for a particular student response system, structuring the lesson around question-driven instruction, development of meaningful questions, and formative facilitation of student discussion. Choosing and learning to operate a student response system and structuring a question-driven lesson are the most straightforward and least difficult aspects to implement. Question development involves purposeful time and effort such that students are presented with questions that not only develop content knowledge, but cognitive process skills, metacognitive skills and discourse skills as well (Beatty, Gerace, et al., 2006). The teacher's role in facilitating deep, productive classroom discourse is unlike the often practiced three phase initiating question, student response and teacher evaluation form of communication (Coffey, Hammer, Levin, & Grant, 2011; Harris et al., 2012; Mehan, 1979). Content expertise, improvisational skills and establishment of a supportive classroom environment impact the

ability of teachers to interact with students in ways that extend thinking as opposed to acknowledging student responses and moving on (Harris et al., 2012).

Technology Choices

There is a good variety of student response system technology for teachers to choose from. In addition to hand held remote systems, or "clickers," there are many software options that allow computers, tablets or smartphones to act as student response systems. The choices are easily searched online and in some cases, such as Poll Everywhere (www.polleverywhere.com) and Socrative by Mastery Connect (www.socrative.com), the applications are free.

When choosing a system, the functionality as well as the interface should be considered. In many cases, questions can be created on PowerPoint slides and student responses can be multiple-choice, short answer or open response. Some systems, like Learning Catalytics™ from Pearson (www.learningcatalytics.com), allow students to make graphical or computational responses. The ability to review and store individual student responses is a feature of most systems, but not all. Another option that teachers may find desirable in some platforms is the ability to share questions with other teachers.

Lesson Structure

The typical lesson plan involves laying out the sequence of presentation of information and experiential events that supplement the information. Assessing whether students gained the desired learning occurs at some point after instruction. TEFA involves an inversion of the typical lesson plan such that instruction revolves around a question cycle that is repeated multiple times in a class (Beatty, 2004; Beatty & Gerace, 2009; Beatty, Leonard, et al., 2006; Lee et al., 2012; Moss & Crowley, 2011). The general structure of the cycle is:

1. Students consider a challenging question or problem at the beginning of the lesson.

2. Students think individually or in small groups and decide on a response.

3. Students respond to the question using SRS technology and aggregated class responses are displayed.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that addresses the ideas, assumptions and arguments brought up while helping them to form and expand understanding.

6. Based on what was learned about student thinking, summarize or present additional information, introduce meta-level comments or present a new question.

Optimally, no more than three or four question cycles should occur in a 50 minute class period to allow enough time for students to have productive, interactive discussions (Beatty & Gerace, 2009).

The instructional cycle begins with questions that are not assessments of previous instruction, nor are they assessments of the direction instruction should take; the initial questions provide context for students to make sense of instruction. According to *How People Learn* (Bransford et al., 2000), "Ideas are best introduced when students see a need or a reason for their use—this helps them see relevant uses of knowledge to make sense of what they are learning" (p.139). The question-driven instruction also brings students' prior knowledge into conscious awareness. Meaningful learning is built on prior knowledge and only memorization or rote learning results without it.

Just as learning is enhanced when accurate pre-existing knowledge can form a basis for new learning, incorrect assumptions will persist and disrupt learning if there is no explicit challenge to those ideas (Bransford et al., 2000). The responses to presented questions should expose gaps in understanding to the students themselves, so that the following discussions allow them to confirm, contradict, expand or restructure their own thinking.

The purpose of student-led discussion is for students to share their ideas and help each other confirm and expand accurate conceptions or refute and reconstruct inaccurate conceptions. The teacher's role is to facilitate discussion and guide students with prompts, not to point out errors or correct inaccuracies. If students are on the wrong track, the discussion should lead them to become dissatisfied with their current construct and seek new understanding. This type of discourse can help students make their own personal sense of science as well as expose them to the idea that science, by its nature is not certainty (Carlsen, 2007). Students can misunderstand the theoretical nature of science if instruction is presented as a collection of facts.

Question Development

When developing questions for TEFA, it is helpful to consider the content to be addressed, the cognitive process skills students should develop and the metacognitive skills students should practice as part of learning science (Beatty, Gerace, et al., 2006). Not all topics in a given subject area can be explored using TEFA because the time available to fully explore the material is not sufficient. Focusing on core ideas will benefit students by allowing deeper understanding and internalization of foundational concepts that will prepare them to access specialized concepts.

Focusing on core ideas provides guidance on *what* information students will need to access in order to answer the question, *how* they should demonstrate their understanding is what determines the process skills a question will require. One possible source for guidance on integrating core ideas and process skills in question development can be found in the Next Generation Science Standards performance expectations (National Research Council, 2013). An example of a high school life science performance expectation that could be used to guide construction of a meaningful question is "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" (National Research Council, 2013). Providing choices of possible explanations to the prompt of "DNA determines the structure of proteins by…" and having students justify and explain their thinking to each other could generate substantive discussion.

Beatty and colleagues have also provided guidelines for developing physics questions that could easily be extended to biology (Beatty, Gerace, et al., 2006). Suggestions include designing questions that ask for comparisons, ordering events or processes, imposing a constraint on a solution and presenting questions with multiple answers depending on the student's interpretation.

Formative Facilitation

Formative teaching is not a strategy, but an awareness and understanding of what students are thinking through interpretation of how they are communicating their thinking (Coffey et al., 2011). Among the challenges for effective use of formative data in the classroom is the ability of teachers to attend to student ideas and strategically adapt instruction to meet

those needs (Furtak et al., 2012). Teachers need to be able to identify and infer a student's thinking based on a response the student makes (Bennett, 2011). Since a teacher can not observe directly the thoughts and ideas of the student, linking student responses to appropriate or inappropriate conceptions is an important skill. Along with sufficient content knowledge, a teacher must have knowledge of the progression of student understanding and knowledge of frequent misconceptions and inaccuracies (Furtak et al., 2012). Tools to help teachers identify the stages of student thinking as they move from initial ideas to deeper conceptions are learning progressions.

Conclusion

TEFA is a research-based pedagogy that has the potential to enhance student learning in secondary life science. By focusing instruction of conceptually challenging questions and facilitating deep and rich discussions, students have the opportunity to form accurate conceptions that connect to their personal experiences. Student autonomy and self-awareness as a result of this approach provide incentive for learning leading to an engaged and productive classroom. Teachers benefit from having access to current information on student conceptions as well as the flexibility to guide discussions to the intersection of students' present understanding and instructional targets. The well-established benefits of formative assessment can be realized through the straightforward guidance of TEFA.

Chapter 3: Project Modules

Overview

Although formative assessment is widely accepted to provide learning benefits to students, technology-enhanced formative assessment (TEFA) has previously only been applied to physics instruction. As student response system technology becomes more widespread, all disciplines will benefit from explicit examples of integrating TEFA into lesson planning. This project will detail lesson structures for high school life science units using TEFA.

TEFA is appropriate as an alternative for lecture-based or teacher-led discussion formats used to introduce and establish key disciplinary concepts. The instructional cycle begins with questions that are not assessments of previous instruction, nor are they assessments of the direction instruction should take; the initial questions provide context and direction for students to make sense of instruction. The formative information provided through the use of TEFA gives teachers a way to evaluate the conceptual understanding of students as topics are covered, allowing teachers to provide adequate support for optimal learning.

The following modules consist of a series of Technology-Enhanced Formative Assessment (TEFA) lessons addressing ten subtopics within the four NGSS High School Life Science Disciplinary Core Ideas. Each lesson includes alignment to the New York State Living Environment Core Curriculum Standards and expectations for progression from middle school to high school. The TEFA lessons follow a question cycle that is repeated multiple times in a class. The general structure of the cycle begins with students considering a challenging question or problem at the outset of the lesson. A multiple choice question is displayed to the class through an electronic white board or other interface. Students think individually or confer in small groups and decide on a response, which is submitted individually using a student response system. Aggregated class responses are displayed as a histogram and, without revealing correct answers, students share reasoning and justifications for answers. The reasoning and justification should lead to productive discussions that address the ideas, assumptions and arguments brought up while the teacher targets input and feedback to help students comprehend key ideas and expand

understanding. Approximately three to four question cycles with productive discussion would be expected in a 60 minute class period.

Module Outline

Teacher Guidance for TEFA Lessons

Module 1: NGSS HS-LS-1: From Molecules to Organisms

> **Lesson 1: HS-LS1-A: Structure and Function**: Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level.

> **Lesson 2: HS-LS1-B Growth and development of organisms:** Cell division through mitosis allows multicellular organisms to grow and ensures that each daughter cell receives the identical genetic material of the parent cell.

> **Lesson 3: HS-LS-1C: Organization for matter and energy flow in organisms**: Matter is organized with carbon based molecules and energy is transferred from one system of interacting molecules to another through chemical reactions. Matter and energy flow through organisms by the processes of photosynthesis and cellular respiration.

Module 2: NGSS HS-LS2   Ecosystems: Interactions, Energy and Dynamics

> **Lesson 1: HS-LS2-A: Interdependent Relationships in Ecosystems**: Species population size is enhanced or limited by abiotic and biotic factors such as: availability of environmental resources, inter and intra-species competition, disease and predation.

> **Lesson 2: HS-LS2-B: Cycles of Matter and Energy Transfer in Ecosystems:** Energy for life enters the food web at the level of producers/autotrophs and moves upward providing heterotrophs at each successive level a fraction of the energy available at the lower level due to the utilization of energy within organisms to perform life functions and release of energy as heat.

Module 3: NGSS HS-LS3   Heredity: Inheritance and Variation of Traits

Lesson 1: HS-LS3-A: Inheritance of traits: Genes carry instructions for protein synthesis that drive expression of species characteristics through the sequence of DNA. Chromosomes consist of gene sequences and other DNA sequences that regulate gene expression. Cells within an organism contain the same genetic information (chromosomes), but express different gene sequences, which allows cells to have different structures and functions

Lesson 2: HS-LS3-B: Variation of traits: Genetic variation within species results from meiosis and crossing over; errors in DNA replication and environmental factors that cause mutations or influence gene expression.

Module 4: NGSS HS-LS4   Biological Evolution: Unity and Diversity

Lesson 1: HS-LS4-A: Evidence of Common Ancestry and Diversity: Genetic, molecular, anatomical and embryological similarities among species support common decent and species diversity results from evolutionary branches originating from common ancestors.

Lesson 2: HS-LS4-B: Natural Selection: Natural selection occurs only when there is both genetic variation in a population and variation in traits (the expression of genetic information) that leads to differences in performance among individuals.

Lesson 3: HS-LS4-C **Adaptation:** Individuals within a population that have traits that allow them to survive and reproduce will pass their traits on to the next generation and individuals whose traits do not provide a survival or reproductive advantage will not pass traits on to the next generation. The traits that lead to preferential survival and reproduction will increase in the population. Changes in environmental conditions can change the degree to which a trait provides an advantage or disadvantage and lead to changes in the distribution of traits in a population.

Teacher guidance for TEFA lessons

A lesson progression scenario is detailed below using the first lesson question in this sequence as an example. The sequence of the lesson follows this general outline:

- Students consider a challenging question or problem at the beginning of the lesson.
- Students think individually or in small groups and decide on a response.
- Students respond to the question using SRS technology and aggregated class responses are displayed.
- Without revealing correct answers, students share reasoning and justifications for answers.
- Teachers facilitate a student-led discussion that addresses the ideas, assumptions and arguments brought up while helping students to form and expand understanding.
- Based on what was learned about student thinking, summarize or present additional information, introduce meta-level comments or present a new question.

Introduce Lesson

Begin lesson with an introduction to the learning objectives. Objectives should be accessible to students, so that they can be referred to throughout the lesson.

Describe the procedure and use of student response system if students are unfamiliar with the process. Clearly explain to students that the questions are not intended to evaluate previous instruction, but are to provide context for students of the conceptual learning to follow.

Present Question

Project the first question on the electronic whiteboard or other chosen media and ask students to take one to two minutes to read and choose an answer to the question using a student response system. Teachers may also choose to have students work in pairs or small groups to discuss the question and then provide individual answers.
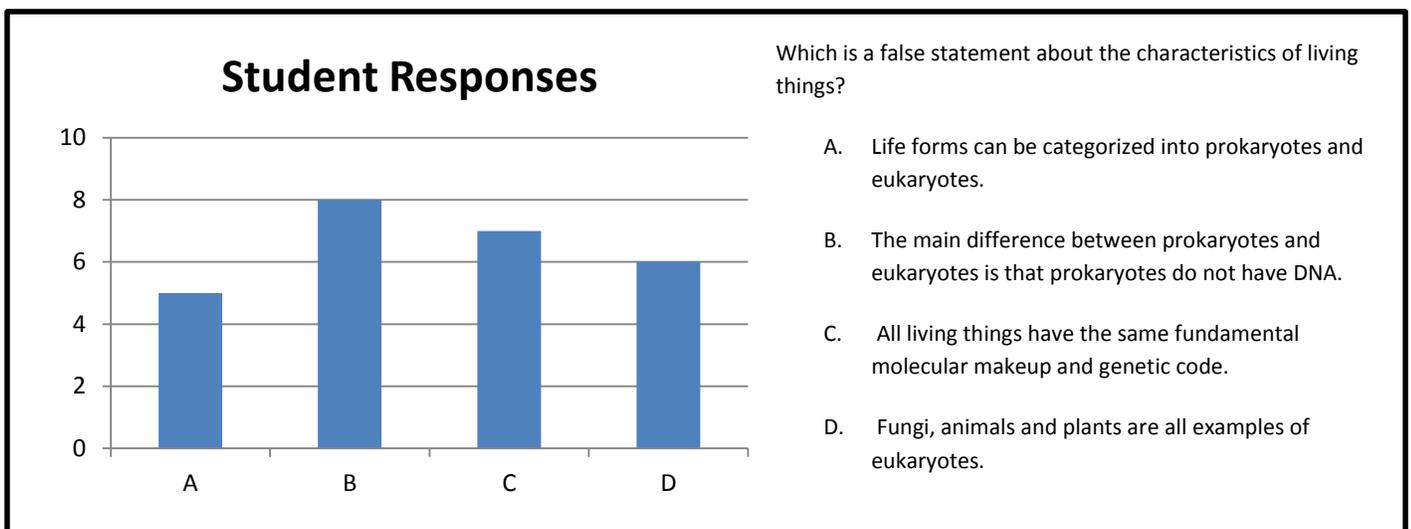
The first lesson question example is:

Which is a false statement about the characteristics of living things?

A. Life forms can be categorized into prokaryotes and eukaryotes.
B. The main difference between prokaryotes and eukaryotes is that prokaryotes do not have DNA.
C. All living things have the same fundamental molecular makeup and genetic code.
D. Fungi, animals and plants are all examples of eukaryotes.

Display Results

After all students have entered a response, immediately display the aggregated class responses in a histogram. Student response system software allows tracking of the number of responses and, in some cases, individual student responses. Display the questions along with the histogram for students to reference.

Student Responses

Which is a false statement about the characteristics of living things?

A. Life forms can be categorized into prokaryotes and eukaryotes.

B. The main difference between prokaryotes and eukaryotes is that prokaryotes do not have DNA.

C. All living things have the same fundamental molecular makeup and genetic code.

D. Fungi, animals and plants are all examples of eukaryotes.

Example of response display

The histogram provides the teacher with an instant assessment of student's current understanding regarding the broad concepts of categorization of living things as prokaryotes and eukaryotes, the molecular commonalities between living things and the differentiation of eukaryotic life forms. A histogram that is similar to the diagram above indicates that students are still developing understanding of this concept. What the histogram does not provide are the

specific misunderstandings or gaps in knowledge students may have. In order to evaluate these, students need to be allowed to express their own reasoning.

Facilitating Student Discussion

Students should be asked to share with the class their reasoning for choosing a particular answer without any indication from the teacher of the correct answer. If a student indicates that their answer choice was A because life forms are categorized as plant an animal, first allow time for other students to give feedback about why they think the statement is incorrect. If students do not respond, the teacher can ask students to consider bacteria and propose a classification. Prompts should be constructed to encourage students to give thoughtful responses rather than one word answers. For example, "what is the difference between prokaryotes and eukaryotes?" and "what are examples of other life forms that are neither plants nor animals?"

Students may also ask about the terms prokaryote and eukaryote, or other unknown vocabulary. The teacher should first provide time for other students to suggest answers and to contradict each other. The teacher can facilitate learning of accurate definitions *after* allowing student discussion that do not lead to correct understanding by giving explicit statements or acknowledging that the concept is misunderstood and letting students know the topic will be revisited in another lesson.

While students are sharing reasoning behind their answers, teachers should try to ensure that each answer is addressed with a justification and a discussion. Each answer consists of different conceptual understanding that students can begin to clarify with discussion. For example, students who answer C may not yet be aware of the basic inorganic and organic molecules that living organisms share or they may not understand the structure of DNA.

One goal of the question driven instruction of TEFA is for students to engage in a purposeful exploration of important life science concepts. However, providing opportunities for students to articulate understanding, practice using disciplinary language and constructing evidence based arguments are just as important. Students may not come away from discussions with fully developed conceptual understanding. Other pedagogical approaches, such as direct instruction and inquiry, should be used in subsequent lessons to promote student learning.

Some questions in the modules have secondary questions referring to student confidence. These questions can be used for students to reflect on their confidence when they answered correctly and incorrectly. Teachers should prompt students to share how closely their confidence in their answer matched their accuracy and have students discuss reasons for inconstancy.

Formative Assessment

Along with facilitating discussion, teachers should be notating areas of confusion and conceptual difficulties throughout the lesson that can be addressed through other instructional modalities in subsequent lessons. Likewise, teachers should be notating areas of adequate understanding to guide future lesson planning. Providing students with the correct response to conclude the discussion is optional. In many cases the correct answer is not the goal of the question; it is rather the discussion itself. Teachers may also choose to present the question again and display the change in responses after discussion.

These lessons are intended as initial exposure to concepts rather than assessments of previously learned content. The verbalizations of students should be what is formatively assessed and summative assessment is not required. The information gleaned from student discussion should be used to guide the teacher's suggestions and feedback within the lesson as well as the design of subsequent lessons that should be used to solidify understanding.

Ensuring Participation

Student participation is necessary for the success of TEFA lessons. In most cases, students will be motivated by the structure of the lesson that allows a great deal of student input. Students who are uncomfortable with speaking to the entire class can be encouraged to participate by allowing options to work in pairs or small groups. Teachers can also encourage students to participate by giving overt feedback to responses that shows that each student's voice is valued. Acknowledging productive responses and telling students they have made important points, even if incorrect, can promote involvement.

Timing of Lessons

The lessons in this module are intended to allow flexibility for teachers to engage students and formatively assess student understanding. Question cycles should be allotted enough time for students to have productive discussion. Teachers may choose to spend more time on questions where students are actively expanding their current understanding, and may choose to limit time spent on questions where the lack of foundational knowledge prevents productive discussion. It is possible to complete three to four question cycles within a 60 minute class period, but this should not be strictly adhered to if student progress would be undermined.

It is likely that students will not achieve proficient understanding of chosen concepts through the lesson presentations. The question cycles provide students with a basis for future learning and self –guided purpose for learning through their desire for conformation and clarification of ideas.

Module 1: TEFA Lessons for NGSS HS-LS-1:

From Molecules to Organisms

Lesson 1: NGSS HS-LS1-A: Structure and Function

Central Focus:

Multicellular organisms have a hierarchical structural organization, in which any one system is made up of numerous parts and is itself a component of the next level. Stable internal conditions are maintained in living things through feedback interactions within and between the levels of hierarchical organization of multicellular organisms.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

1.1.2: Cells have particular structures

4.1.2f: Cell organelles have specialized parts and functions

4.1.2g: The processes of diffusion and active transport are important in the movement of materials in and out of cells.

4.1.2d: Cells maintain homeostasis.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Compare and contrast the parts of plants, animals, and one-celled organisms.	Describe and explain the structures and functions of the human body at different organizational levels (e.g. cells, organelles).

Learning Objectives

Question cycle 1: Through question presentation and class discussion students will compare cellular characteristics different life forms share.

Question cycle 2: Through question presentation and class discussion students will differentiate between active and passive transport in cells. (NYLE 1.2g)

Question cycle 3: Through question presentation and class discussion students will identify organelles and their function. (NYLE 1.2f)

Question cycle 4: Through question presentation and class discussion students will explain homeostasis in cells. (NYLE 1.2d)

Instructional Outline:

Pre-class assignment:

Students will review text as homework before class:

      📖 Miller and Levine, Biology (Miller, Levine, Pearson Education, & Prentice-Hall, 2014)Chapter 7 (pp. 338-379)

Lesson begins with question presentation:

Question Cycle 1

Which is a false statement about the characteristics of living things:
- E. Life forms can be categorized into prokaryotes and eukaryotes.
- F. The main difference between prokaryotes and eukaryotes is that prokaryotes do not have DNA.
- G. All living things have the same fundamental molecular makeup and genetic code.
- H. Fungi, animals and plants are all examples of eukaryotes.

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the classifications of prokaryotes and eukaryotes, molecules that make up living things and the function of DNA. Prompts may include: *compare prokaryotes to eukaryotes and give examples, suggest categories of life forms.* Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other

students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that compares the similarities and differences between life forms, specifically prokaryotes and eukaryotes. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Which of the following is a false statement about cellular transport?
   A. Endocytosis and exocytosis are examples of active transport.
   B. Osmosis is a form of facilitated diffusion.
   C. Osmosis and facilitated diffusion are examples of active transport.
   D. Passive transport moves materials without energy using the concentration gradient.

Lesson sequence:
1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of active and passive transport, concentration gradient, diffusion and osmosis. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data

shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that differentiates between active and passive transport, compares endocytosis and exocytosis, and explains examples of facilitated diffusion and osmosis. Prompts may include: *compare active and passive transport, how is facilitated diffusion different from simple diffusion, describe a situation where osmosis would occur*. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Which of the following is a false statement about cellular organelles?
  A. Mitochondria are not found in plant cells.
  B. Both eukaryotes and prokaryotes have ribosomes.
  C. The golgi apparatus packages proteins for storage or secretion out of cells.
  D. In eukaryotes, most of the cell's DNA is found in the nucleus.

How confident are you of your answer?
  A. Not sure at all – I guessed.
  B. Only a little sure of my answer.
  C. Pretty sure I am right.
  D. Completely confident.

Lesson sequence:
  1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the organelles and their functions. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that identifies key organelles, describes their functions and compares cell types for differences in organelles. Prompts may include: explain the function of the mitochondria (or any organelle) and identify organisms need to perform that function, give examples of cells that have different organelles and relate the differences to the function of the cells and organism. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer
   A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 4

Homeostasis refers to:
   A. An organism's growth over time through cell division.
   B. Breaking down food molecules to from molecules that can be used as energy in a cell.
   C. The consistent response of a cell to the external environment.
   D. Monitoring and feedback of external and internal changes to keep internal

conditions within a set range.

How confident are you of your answer?
   A. Not sure at all – I guessed.
   B. Only a little sure of my answer.
   C. Pretty sure I am right.
   D. Completely confident.

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of homeostasis, cell division, digestion, and other life processes. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.
4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.
5. Facilitate a student-led discussion that explains homeostasis in an organism explains the role of positive and negative feedback and suggests intracellular examples. Prompt may include: *describe what happens when you are exposed to very cold or very hot temperatures, describe a life process that relies on feedback to increase or decrease a response, and explain how a stable internal environment would be important for a cell*. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.
6. Discussion should conclude with verification of student understanding of correct answer D. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Lesson 2: NGSS HS-LS1-B Growth and development of organisms

Central Focus:

Cell division through mitosis allows multicellular organisms to grow and ensures that each daughter cell receives the identical genetic material of the parent cell. Cells within multicellular organisms can have different structure and function due to the differential expression of genetic instructions.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.2.1d: Asexual reproduction is the production of genetically identical offspring from a single parent cell

4.2.1k: Cells within multicellular organisms have identical genetic material, but may have different structures and functions because only some genetic instructions are used by specific cell types.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe ~~sexual and~~ asexual mechanisms for passing genetic materials from generation to generation. Describe cell division at the microscopic level	Explain how the structure and replication of genetic material result in offspring that resemble parents.

Learning Objectives

Question cycle 1: Through question presentation and class discussion students explain the need for DNA replication to produce genetically identical cells

*Question cycle 2*Through question presentation and class discussion students explain the need for equal division through mitosis to produce genetically identical cells.

Question cycle 2: Through question presentation and class discussion students infer how genetic information can be expressed or not expressed in cells to create different cells/tissues/organs in multicellular organisms.

Instructional Outline:

Students will review text as homework before class:

       📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 10 (pp. 472-495)

Lesson begins with question presentation:

Question Cycle 1

For a cell with 4 pairs of chromosomes (8 total chromosomes) to divide into two daughter cells that are genetically identical to the starting cell, what needs to happen to the chromosomes?

    A. Each chromosome should divide in half.

    B. One of each pair should go to a different one of the two daughter cells.

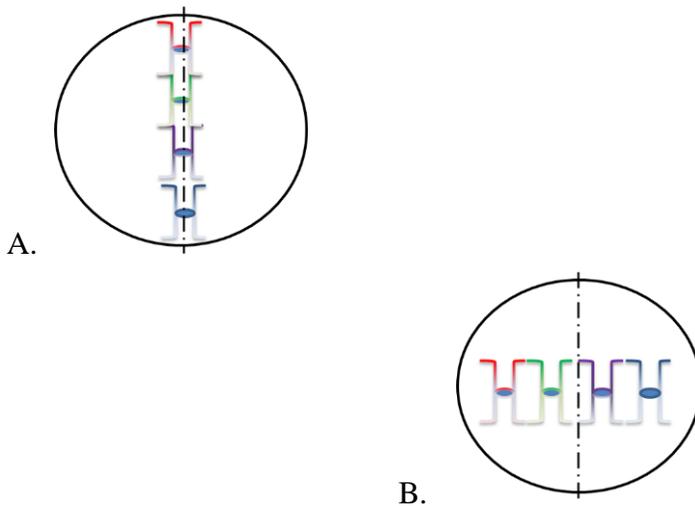   C. Each chromosome should replicate creating 16 strands.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the structure and function of chromosomes, how genetic information is passed from one generation to another, and the concept of genetically identical cells. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains the relationship between DNA, genes and chromosomes, analyzes the steps of mitotic cell division and evaluates the need to duplicate chromosomal DNA. Prompts may include: *explain how a cell with two chromosomes could be divided so that the two resulting cells had exactly the same genetic material as the parent cell.* Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Once the chromosomes of a parent cell are replicated, how can they be arranged and divided to guarantee that each daughter cell will receive identical genetic material?

A.

B.

C.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the process of mitotic cell division. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that evaluates the best way to arrange and divide double stranded chromosomes such that the gene sequence is preserved in each daughter cell. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Which of the following is a false statement about cell differentiation:

    A. Cells become specialized by deleting genes that they don't need and keeping genes that direct a specific cell function.

    B. Bone marrow contains stem cells that can develop into different types of blood cells.

    C. Cells in an early embryo can differentiate into any type of body cell.

    D. Once a cell has differentiated into a specific type of cell, it is possible to alter the genes so the cell can become another cell type.

How confident are you of your answer?

    A. Not sure at all – I guessed.

    B. Only a little sure of my answer.

    C. Pretty sure I am right.

    D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of how gene expression results in cell differentiation, what stem cells are and where they are found. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.
4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that leads students to the explanation of differential gene expression for cell differentiation to occur. Prompts may include: *compare the genetic material in an individual's skin cells to that same individual's muscle cells, describe how you could use one sheet of paper to give instructions to two different people for two different jobs and how that idea could be used for a set of genetic instructions.* Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Lesson 3: NGSS HS-LS-1C: Organization for matter and energy flow in organisms

Central Focus:

All Living things are made up of biomolecules built from the same basic chemical compounds. Living things build up and break down molecules, as well as obtain energy, through chemical reactions. Every life function requires energy that originates from the sun. Through the process of photosynthesis light energy is converted to organic compounds and through the process of cellular respiration, organic compounds broken down to release energy for cells to use in the form of ATP.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.5.1c: In all organisms, organic compounds can be used to assemble other molecules such as proteins, DNA, starch, and fats.

4.5.1f: Enzymes can affect the rates of chemical change. The rate at which enzymes work can be influenced by internal environmental factors such as pH and temperature.

4.5.1b: The process of photosynthesis uses solar energy to combine the inorganic molecules carbon dioxide and water into energy-rich organic compounds (e.g., glucose) and release oxygen to the environment.

4.5.1d: In all organisms, the energy stored in organic molecules may be released as ATP molecules during cellular respiration in the mitochondria using oxygen and releasing carbon dioxide and water as waste products.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Compare the way a variety of living specimens carry out basic life functions and maintain dynamic equilibrium.	Explain the basic biochemical processes in living organisms and their importance in maintaining dynamic equilibrium.
Provide evidence that green plants make food and	

~~explain the significance of this process to other~~ ~~organisms~~.	

Learning Objectives

Question cycle 1: Through question presentation and class discussion students will categorize organic molecules and their building blocks.

Question cycle 2: Through question presentation and class discussion students will evaluate the effect of internal environmental conditions on the activity of enzymes.

Question cycle 3: Through question presentation and class discussion students will explain the process of photosynthesis uses solar energy carbon dioxide and water to synthesize organic compounds (e.g., glucose) and release oxygen to the environment

Question cycle 4: Through question presentation and class discussion students will recognize that the energy stored in organic molecules may be released as ATP molecules during cellular respiration in the mitochondria using oxygen and releasing carbon dioxide and water as waste products.

Instructional Outline:

Pre-class assignment:

Students will preview text as homework before class:

      📖 Miller and Levine, Biology (Miller et al., 2014) Chapter 2 (pp. 87-94) Chapter 8 (pp404-408) Chapter 9 (pp 432-437

Lesson begins with question presentation:

Question Cycle 1

> Which of the following shows the correct combination of organic compounds and
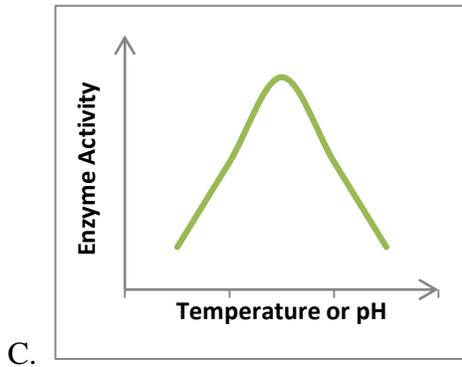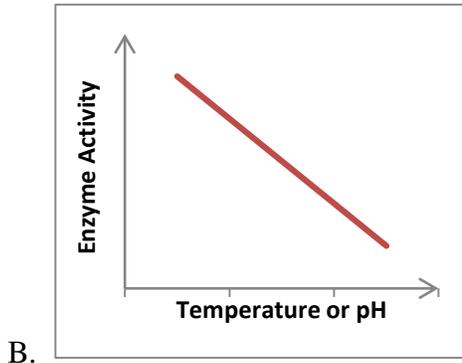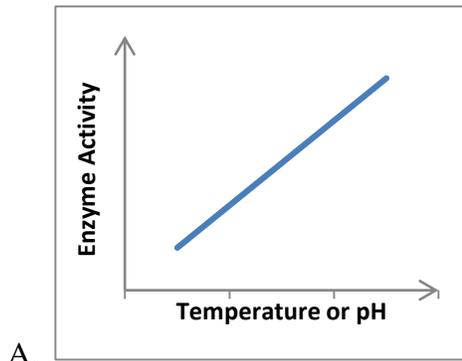
molecules that can be synthesized :

    A. Glucose molecules combine to form nucleic acids to build DNA.

    B. Monosaccharides combine to form polysaccharides to build protein.

    C. Amino acids combine to form polypeptides to build enzymes.

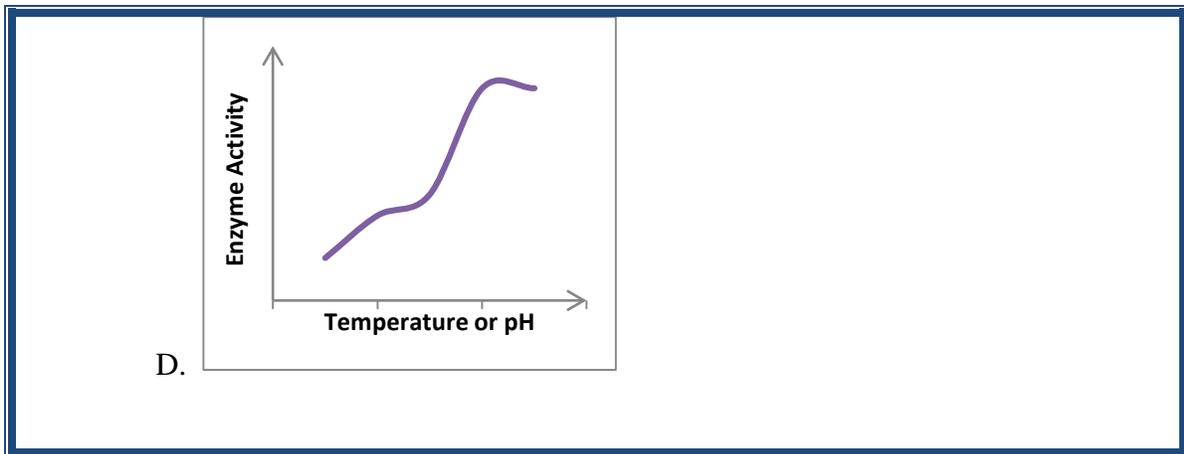   D. Nucleotides combine to form glucose to build starch.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the building blocks and examples of biological molecules. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that analyzes the assembly of complex molecules from organic compounds in organisms and the necessity for large biological molecules to be built from and broken down into monomers. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompted to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Which of the following graphs shows the relationship between temperature or pH and typical enzyme activity:

A.

(Graph A: Enzyme Activity vs. Temperature or pH — straight line increasing)

B.

(Graph B: Enzyme Activity vs. Temperature or pH — straight line decreasing)

C.

(Graph C: Enzyme Activity vs. Temperature or pH — bell-shaped curve)

D.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the function and specificity of enzymes. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that that predicts enzyme function in optimal conditions and evaluates how rate at which enzymes work can be influenced by internal environmental factors such as pH and temperature. Prompts may include: *predict how an enzyme from your stomach would function in your intestine, explain the function of enzymes and why an organism could die if their temperature rises to high*. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Which of the following is an accurate summary of the process of photosynthesis?

    A. $H_2O + CO_2 \xrightarrow{\text{Light}} \text{glucose} + O_2$

    B. $\text{sugars} + O_2 \xrightarrow{\text{Light}} H_2O + CO_2$

    C. $H_2O + O_2 \xrightarrow{\text{Light}} \text{sugars} + CO_2$

    D. $\text{sugars} + CO_2 \xrightarrow{\text{Light}} H_2O + O_2$

How confident are you of your answer?

    A. Not sure at all – I guessed.

    B. Only a little sure of my answer.

    C. Pretty sure I am right.

    D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the process of photosynthesis and the purpose to produce food from inorganic carbon. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains how the process of photosynthesis uses solar energy carbon dioxide and water to synthesize organic compounds (e.g., glucose) and release oxygen to the environment. Students should be encouraged to expand on

responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.
7. Discussion should conclude with verification of student understanding of correct answer
    A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 4

Which of the following is an accurate statement about cellular respiration?

  A. Glucose and carbon dioxide are the raw materials needed for cellular respiration to occur.
  B. Carbon dioxide and water are released as byproducts of cellular respiration.
  C. By breaking down food molecules, cellular respiration releases chemical energy in the form of lactic acid.
  D. The first step in cellular respiration, glycolysis, requires oxygen to occur.

How confident are you of your answer?

  A. Not sure at all – I guessed.
  B. Only a little sure of my answer.
  C. Pretty sure I am right.
  D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the process of cell

respiration, the reactants and products of cell respiration and the difference between glycolysis and citric acid cycle. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that that identifies ATP as the energy released during cellular respiration from organic molecules, often using oxygen and releasing carbon dioxide and water as waste products. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Module 2: TEFA Lessons for NGSS HS-LS2:

Ecosystems: Interactions, Energy and Dynamics

Lesson 1: NGSS HS-LS2-A: Interdependent Relationships in Ecosystems

Central Focus:

Species population size is enhanced or limited by abiotic and biotic factors such as: availability of environmental resources, inter and intra-species competition, disease and predation.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.6.1d: The carrying capacity of any habitat is the number of organisms that can be supported by the available resources and biotic interactions that cycle matter.

4.6.2a: Biodiversity increases the stability of ecosystems.

4.6.3a: Interrelationships and interdependencies of organisms affect the development of stable ecosystems.

4.6.3c: A stable ecosystem can be altered through the activities of organisms, through climatic changes or natural disasters.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe energy flow through food chains and food webs.	Explain factors that limit growth of individuals and populations

Learning Objectives

Question cycle 1: Through question presentation and class discussion students compare density-dependent (competition, herbivory, predation, parasitism, disease, and overcrowding) and density-independent limiting factors (unusual weather, climate change, and natural disasters) on the carrying capacity of habitats.

Question cycle 2: Through question presentation and class discussion students evaluate the impact of decreasing biodiversity in certain populations within an ecosystem on the stability of the ecosystem as a whole.

Question cycle 3: Through question presentation and class discussion students analyzes the interrelationships between organisms that can affect multiple levels of a food web and disrupt ecosystem stability

Question cycle 4: Through question presentation and class discussion students compare the causes (gradual changes to the environment through biotic and abiotic process and abrupt changes due to weather, disaster, and activities of organisms) and the successive changes that lead to stable ecosystems with new communities.

Instructional Outline:

Pre-class assignment:

Students will preview text as homework before class:

  📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 4 (pp.181 -202)

Lesson begins with question presentation:

Question Cycle 1

Which of the following limiting factors that affect carrying capacity of a certain geographic region are not dependent on population density?

  A. Disease
  B. Severe Drought
  C. Herbivory
  D. Predation

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of how ecosystem populations

are limited by density-dependent (competition, herbivory, predation, parasitism, disease, and overcrowding) and density-independent factors (unusual weather, climate change, and natural disasters). Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that compares density-dependent (competition, herbivory, predation, parasitism, disease, and overcrowding) and density-independent limiting factors (unusual weather, climate change, and natural disasters) on the carrying capacity of habitats. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

A forest with many different species of trees would be less likely to survive an infestation of a single species of destructive insect than a tree farm populated with a single tree species.

A. True
B. False

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of biodiversity and ecosystem stability. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that evaluates the impact of decreasing biodiversity in certain populations within an ecosystem on the stability of the ecosystem as a whole. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

What would be a likely result of the elimination of a mountain lion population due to over-hunting on the deer population in a particular geographic location favorable to both deer and mountain lions?

    A. There would be a decrease in competition.

    B. There would be a decrease in incidence of disease.

    C. There would be an increase in autotrophic food sources.

    D. There would be an increase in competition.

How confident are you of your answer?

    A. Not sure at all – I guessed.

    B. Only a little sure of my answer.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of interactions between organisms in an ecosystem and competition for resources. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that analyzes the interrelationships between organisms that can affect multiple levels of a food web and disrupt ecosystem stability. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer D. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 4

Which is a true statement about ecological succession?
    A. Existing communities of organisms are replaced by new communities over a long

time period.

   B. Loss of animal species due to a disaster will increase the speed of ecological
       succession.

   C. Ecosystems can not be rapidly altered by human activity.

   D. Ecological succession only occurs as a result of rapid changes to the environment.

How confident are you of your answer?

   A. Not sure at all – I guessed.

   B. Only a little sure of my answer.

   C. Pretty sure I am right.

   D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using
    the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student
    responses indicate students are developing understanding of environmental and human
    impacts on ecosystems and the concept of succession. Histograms provide immediate
    feedback to the teacher about student understanding and students reevaluate responses
    when data shows other students responded differently. Histograms that display a high
    concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning
    and justifications for answers.

5. Facilitate a student-led discussion that compares the causes (gradual changes to the
    environment through biotic and abiotic process and abrupt changes due to weather,
    disaster, and activities of organisms) and the successive changes that lead to stable
    ecosystems with new communities. Students should be encouraged to expand on
    responses to develop understanding of why they think what they do, as well as prompting
    students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer

   A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Lesson 2: NGSS HS-LS2-B: Cycles of Matter and Energy Transfer in Ecosystems

Central Focus:

Energy for life enters the food web at the level of producers/autotrophs and moves upward providing heterotrophs at each successive level a fraction of the energy available at the lower level due to the utilization of energy within organisms to perform life functions and release of energy as heat.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.6.1a,b: Matter cycles within the biosphere by combining or reducing to different forms of matter while energy is continuously supplied in the form of sunlight that is stored in the bonds of organic compounds and eventually released by cellular processes.

4.6.1c: The chemical elements in organic molecules pass through food webs and are combined and recombined in different ways.

4.6.1d: Population size is limited by the available energy and cycling of matter.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe the flow of energy and matter through food chains and food webs.	Explain how the diversity of populations within ecosystems relates to the stability of ecosystems.

Learning Objectives

Question cycle 1: Through question presentation and class discussion students compare the cycling of matter through organisms in the environment and the process of storing the energy from sunlight in the bonds of organic compounds that can be released by cellular processes.

Question cycle 2 Through question presentation and class discussion students identify biogeochemical processes (biological, geological and chemical) that cycle elements through closed loops resulting in the conservation of matter in the biosphere.

Question cycle 3: Through question presentation and class discussion students explain the role of primary producers to capture energy and of decomposers to recycle matter and how populations within an ecosystem will be limited by the available energy and cycling of matter.

Instructional Outline:

Pre-class assignment:

Students will preview text as homework before class:

    📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 3 (pp. 136-156)

Lesson begins with question presentation:

Question Cycle 1

> In a food chain that includes photoautotrophs, herbivores, carnivores, and decomposers, what function do photoautotrophs perform?
> A. Provide a means of transferring energy throughout the food chain
> B. Release energy from organic compounds
> C. Capture energy and inorganic compounds from the environment to produce organic compounds
> D. A and C
> E. A, B and C

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the definition and function of

photoautotrophs, that respiration is necessary in photoautotrophs and the flow of energy through the food chain. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that compares the cycling of matter through organisms in the environment and the process of storing the energy from sunlight in the bonds of organic compounds that can be released by cellular processes. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer E. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Which of the following statements is false?

    A. Biogeochemical cycles provide materials for organisms to synthesize into organic compounds.

    B. As matter moves through food webs, it is gradually eliminated

    C. Organisms can not create elements (e.g. carbon, oxygen, hydrogen, nitrogen)

    D. Without decomposers and detritivores, nutrients would become unavailable for use by primary producers.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the cycle of matter through the biosphere, conservation of matter and the specific cycling of carbon, oxygen, hydrogen and nitrogen. Prompts may include: explain the carbon cycle and identify the function of a detritivore. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that that identifies biogeochemical processes (biological, geological and chemical) that cycle elements through closed loops resulting in the conservation of matter in the biosphere. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

An ecosystem must include which organisms in order to remain stable?
   A. Decomposers and carnivores.
   B. Carnivores and producers.
   C. Decomposers and autotrophs
   D. Herbivores and producers
How confident are you of your answer?
   A. Not sure at all – I guessed.

B. Only a little sure of my answer.

C. Pretty sure I am right.

D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the roles of organisms within an ecosystem contribute to the availability of matter. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains the role of primary producers to capture energy and of decomposers to recycle matter and how populations within an ecosystem will be limited by the available energy and cycling of matter. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Module 3: TEFA Lessons for NGSS HS-LS3: Heredity: Inheritance and Variation of Traits

Lesson 1: NGSS HS-LS3-A: Inheritance of traits

Central Focus:

Genes carry instructions for protein synthesis that drive expression of species characteristics through the sequence of DNA. Chromosomes consist of gene sequences and other DNA sequences that regulate gene expression. Cells within an organism contain the same genetic information (chromosomes), but express different gene sequences, which allows cells to have different structures and functions

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.2.1f In all organisms, the coded instructions for specifying the characteristics of the organism are carried in DNA, a large molecule formed from subunits arranged in a sequence with bases of four kinds (represented by A, G, C, and T).

4.2.1g Cells store and use coded information. The genetic information stored in DNA is used to direct the synthesis of the thousands of proteins that each cell requires.

4.2.1a Genes are inherited, but their expression can be modified by interactions with the environment.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe simple mechanisms related to the inheritance of some physical traits in offspring (dominance and probability).	Explain how the structure and ~~replication~~ of genetic material result in offspring that resemble their parents

Learning Objectives

Question cycle 1: Through question presentation and class discussion students explain how molecular structure of DNA allows information about characteristics can be reliably coded and transmitted.

Question cycle 2: Through question presentation and class discussion students describe the structure and function of proteins and arrange the order of events that leads to protein synthesis.

Question cycle 3: Through question presentation and class discussion students analyze how gene expression can be modified by interactions with the environment.

Question cycle 4: Through question presentation and class discussion students infer levels of gene regulation: transcription factors, RNA splicing and protein processing.

Instructional Outline:

Pre-class assignment:

Students will preview text as homework before class:

         📖 Miller and Levine, Biology (Miller et al., 2014) Chapter 12 (pp.595 -600) Chapter 13 (pp. 615-628)

Lesson begins with question presentation:

Question Cycle 1

Genetic information can be transmitted from one generation to another because:

    A. DNA contains proteins with specific shapes.

    B. DNA contains specific sequences of the molecular bases A, T, C, G.

    C. DNA contains a sequence of 20 different amino acids.

    D. DNA contains a sequence of RNA molecules.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding structure of DNA and how base pairing allows conservation and transfer of genetic information. Histograms provide

immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains the molecular structure of DNA and how the arrangement of the four bases can reliably code and transmit genetic information. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

The sequence of DNA controls the function of cells by the following steps:

      A. Transcription into nucleotides and then translation into RNA
      B. Replication of DNA and then translation into a protein
      C. Transcription into RNA and then translation into an amino acid sequence
   D. Transcription into amino acids and translation into proteins

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the process and sequence of transcription and translation to convert the DNA instruction sequence into an RNA

instruction sequence that can be used to construct proteins. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that defines replication, transcription and translation, relates the structure and function of proteins to the sequence of amino acids and arranges the order of events that leads to protein synthesis. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer D. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3
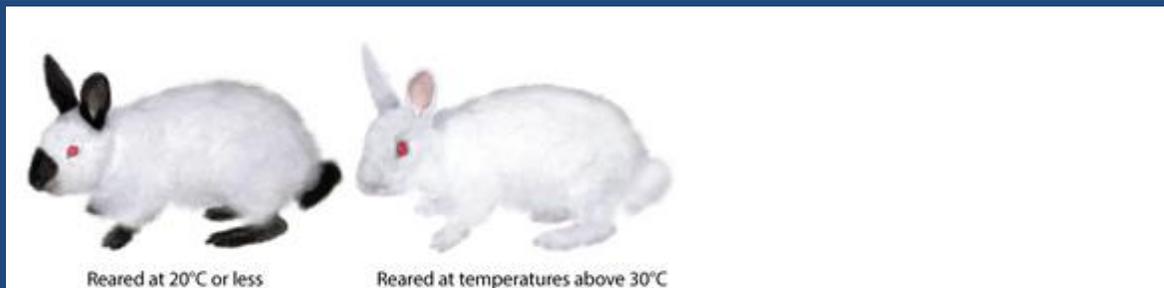
Reared at 20°C or less   Reared at temperatures above 30°C   (Lobo, 2008)

The difference in fur color of the two genetically identical animals pictured above is the result of:

   A. The environment changing the function of enzymes.

   B. The effect of environment on gene expression.

   C. Mutations caused by environmental factors.

   D. The destruction of genetic sequences from environmental changes.

How confident are you of your answer?

    A. Not sure at all – I guessed.

    B. Only a little sure of my answer.

    C. Pretty sure I am right.

    D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that gene expression depends on other factors and an organisms environment can determine the expression of genes. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains the regulation of gene expression through promotors, enhancers and repressors and analyzes how gene expression can be modified by interactions with the environment. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 4

Which of the following statements is false:

    A. Transcription factors regulate the copying of a DNA sequence to an RNA sequence.

    B. A single gene can be influenced by multiple transcription factors.

    C. Regulation of gene expression can occur after mRNA has been translated into protein.

    D. The full transcribed RNA sequence determines the sequence of amino acids in a eukaryotic protein.

How confident are you of your answer?

    A. Not sure at all – I guessed.

    B. Only a little sure of my answer.

    C. Pretty sure I am right.

    D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that gene expression is determined not only by what genes get transcribed, but also through modification of the mRNA sequence and alteration to the protein after translation. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that predicts different levels of gene regulation through analysis of the process of expression from DNA sequence to protein modification: transcription factors, RNA splicing and protein processing. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer D. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Lesson 2: NGSS HS-LS3-B: Variation of traits

Central Focus:

Genetic variation within species results from independent assortment and crossing over as well as errors in DNA that introduces mutations. Viable mutations in gametes can be passed on to offspring.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.2.1e: Sexually produced offspring often resemble, but are not identical to, either of their parents.

4.2.2d: Inserting, deleting, or substituting DNA segments can alter genes. An altered gene may be passed on to every cell that develops from it.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe simple mechanisms related to the inheritance of some physical traits in offspring (dominance and probability).	Explain how the ~~structure~~ and replication of genetic material result in offspring that resemble their parents.

Learning Objectives

Question cycle 1: Through question presentation and class discussion students explain the process of meiosis and evaluates how the number of chromosome pairs determine the amount of variability in gametes.

Question cycle 2: Through question presentation and class discussion students explain the process of crossing over and evaluate the contribution to genetic variation.

Question cycle 3: Through question presentation and class discussion students explain that inheritance of mutations in sexually reproducing organisms can only occur when the mutations are found in gametes while mitotic cell division can pass on mutations to daughter cells .

Instructional Outline:

Pre-class assignment:

Students will review text as homework before class:

    📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 11 (pp. 553-560)

Lesson begins with question presentation:

Question Cycle 1

> In a cell with 3 pairs of chromosomes, how many possible combinations of chromosomes can occur in the gametes?
>
>   A. 6
>
>   B. 3
>
>   C. 1
>
>   D. 9

Lesson sequence:

1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of independent assortment and its contribution to genetic variation. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.
4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.
5. Facilitate a student-led discussion that explains the process of meiosis and evaluates how the number of chromosome pairs, in part, determines the amount of variability in gametes. Students should be encouraged to expand on responses to develop

understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer
   A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Crossing over in diploid organisms increases genetic variation due to:

        A. Independent assortment of chromosomes
        B. Recombination of genes
        C. Gene dominance
        D. Gene mutations

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the process of crossing over and how new combinations of genes result. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.
4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.
5. Facilitate a student-led discussion that explains the process of crossing over and evaluates the contribution to genetic variation through the creation of new combinations of genes in

gametes that are not identical to the parents. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer

B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Which mutation can be passed on to successive generations in sexually reproducing organisms?

    A. Mutation in skin cells from ultraviolet radiation.

    B. Replication error in pollen DNA.

    C. A mutation in a developing fetus that results in fused fingers.

    D. Mutation resulting in ovarian cancer.

How confident are you of your answer?

    A. Not sure at all – I guessed.

    B. Only a little sure of my answer.

    C. Pretty sure I am right.

    D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of how mutations occur and how mutations can be passed on in sexually reproducing organisms. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display

a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that that explains how mutations occur, identifies causes of genetic mutation and differentiates between inheritance of mutations in sexually reproducing organisms when the mutations are found in gametes and the passing on of mutations to daughter cells in mitotic cell division. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Module 4: TEFA Lessons for NGSS HS-LS4: Biological Evolution: Unity and Diversity

Lesson 1: NGSS HS-LS4-A: Evidence of Common Ancestry and Diversity:

Central Focus:

Genetic, molecular, anatomical and embryological similarities among species support common decent and species diversity results from evolutionary branches originating from common ancestors.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.3.1a: The basic theory of biological evolution states that the Earth's present-day species developed from earlier, distinctly different species.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe sources of variation in organisms and their structures and relate the variations to survival. Describe factors responsible for competition within species and the significance of that competition	Explain the mechanisms and patterns of evolution.

Learning Objectives

Question cycle 1: Through question presentation and class discussion students explain how mechanisms of genetic variation led to the evolution of modern species from earlier species.

*Question cycle 2*Through question presentation and class discussion students identify genetic variation as an important factor in evolution

Question cycle 3: Through question presentation and class discussion students differentiate between variation in individuals and evolutionary changes to populations that occur over time and result in new species.

Question cycle 4: Through question presentation and class discussion students

Instructional Outline:

Students will review text as homework before class:

         📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 17 (pp. 819-846)

Lesson begins with question presentation:

Question Cycle 1

Which statement provides evidence that species alive today descended from earlier common ancestors?

     A. Similar bone structures in the forelimbs of humans, whales and birds

     B. Members of different species can have similar genetic sequences.

     C. Living organisms build proteins out of the same 20 amino acids.

     D. B and C

     E. All of the above

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of common ancestry and descent with modification. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that evaluates whether mechanisms of genetic variation (mutation) could explain the evolution of modern species from earlier species and evaluate the evidence for evolution (fossils, conserved genetic sequences, homologous structures). Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.
6. Discussion should conclude with verification of student understanding of correct answer E. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Which factor would both promote the evolution of a species and reduce the possibility of extinction?
     A. Environmental stability over a long time period
     B. Abundant resources
     C. Introduction of new species
     D. Genetic variation within the population

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding without genetic variation and diversity, changes in the environment could more easily lead to species extinction. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.
5. Facilitate a student-led discussion that identifies genetic variation (diversity) as an important factor in evolution as well as survival of species. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.
6. Discussion should conclude with verification of student understanding of correct answer D. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Evolution occurs in
    A. Individual organisms.
    B. Populations.
    C. Both.
    D. Neither.
How confident are you of your answer?
    A. Not sure at all – I guessed.
    B. Only a little sure of my answer.
    C. Pretty sure I am right.
    D. Completely confident.

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding individuals have variation in traits that lead to differential survival, but evolution is change over time to a population.

Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that differentiates between variation in individuals and evolutionary changes to populations that occur over time and result in new species. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Lesson 2: NGSS HS-LS4-B: Natural Selection

Central Focus:

LS4.B.1: Natural Selections occurs only when there is both genetic variation in a population and variation in traits (the expression of genetic information) that leads to differences in performance among individuals

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4.3.1f: Evolution is the consequence of the interactions of (1) the potential for a species to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection by the environment of those offspring better able to survive and leave offspring.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe sources of variation in organisms and their structures and relate the variations to survival. Describe factors responsible for competition within species and the significance of that competition	Explain the mechanisms and patterns of evolution.

Learning Objectives

Question cycle 1: Through class discussion students will explain the processes that cause change in frequency of alleles: variation in populations, mutations and adaptations and by answering presented question students will identify the change in frequency of alleles as contributing to natural selection.

Question cycle 2: Through class discussion students will describe cellular processes that generate mutation and by answering presented question students will infer that selection by the environment acts on existing variation

Question cycle 3: Through question presentation and class discussion students will summarize that natural selection involves the interaction of genetic variability, reproductive success and competition for survival

Question cycle 4: Through question presentation and class discussion students will describe the relationship between mutations, fitness and environmental selection.

Instructional Outline:

Pre-class assignment:

Students will read text and watch short film as homework before class:

         📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 16.3 (pp. 782-787)

         🎬 The Making of the Fittest: Natural Selection and Adaptation

     (http://www.hhmi.org/biointeractive/making-fittest-natural-selection-and-adaptation)

Lesson begins with question presentation:

Question Cycle 1

Natural selection produces evolutionary change by :
   A. Changing the frequency of various versions of genes.
   B. Reducing the number of new mutations.
   C. Producing gene mutations needed for new environments.
   D. Causing individuals in a population to become more genetically similar.

Lesson sequence:
   1. Project the question above so all students can access
   2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of how variation in genes results in variation in traits that can improve or reduce survival and traits that prevent survival are not passed on. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.
4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.
5. Facilitate a student-led discussion that evaluates how the favorability of a genetic trait depends on the specific environment and traits that lead to reduced survival are reduced in the population and not passed on. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.
6. Discussion should conclude with verification of student understanding of correct answer A. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Mutations are caused by selective pressure in the environment
> A. True
> B. False

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding of the classifications of

prokaryotes and eukaryotes, molecules that make up living things and the function of DNA. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains the cellular processes that generate mutation (DNA replication) and examines how selection by the environment acts on existing variation. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Which observation supports the process of natural selection?
   A. Populations of plants and animals in nature most often consist of individuals that are identical to one another
   B. Individuals whose variation gives them an advantage in staying alive long enough to reproduce are more likely to pass their traits on to the next generation
   C. Populations of a species that are isolated have reduced genetic variability.
   D. All of the above

How confident are you of your answer?
   A. Not sure at all – I guessed.
   B. Only a little sure of my answer.
   C. Pretty sure I am right.

Lesson sequence:

1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that natural selection acts on individuals that have genetic variability and leads to changes in the genetic makeup of the population. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.
4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.
5. Facilitate a student-led discussion that examines how natural selection involves the interaction of genetic variability, reproductive success and competition for survival. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.
6. Have students share impressions on how well their confidence level matched their accuracy.
7. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 4

The same genetic mutation in different organisms…
    A. Will either be harmful, beneficial or neutral to all organisms with that mutation.

B. Will provide a fitness advantage if the mutation makes the organism stronger.

C. Can either be advantageous or deleterious depending on the environment that the organism lives in.

D. All of the above.

How confident are you of your answer?

   A. Not sure at all – I guessed.

   B. Only a little sure of my answer.

   C. Pretty sure I am right.

   D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that mutations are not always harmful or beneficial and a mutation can provide a survival advantage in one environment and a disadvantage in another. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains how the same mutation can increase or decrease an individual's fitness depending on an organism's environment. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

Lesson 3: NGSS HS-LS4-C Adaptation

Central Focus:

Individuals within a population that have traits that allow them to survive and reproduce will pass their traits on to the next generation and individuals whose traits do not provide a survival or reproductive advantage will not pass traits on to the next generation. The traits that lead to preferential survival and reproduction will increase in the population. Changes in environmental conditions can change the degree to which a trait provides an advantage or disadvantage.

Content Standard(s) from New York State Living Environment (NYLE) addressed in lesson:

4:3.1g: Some characteristics give individuals an advantage over others in surviving and reproducing, and the advantaged offspring, in turn, are more likely than others to survive and reproduce.

4.3.1h: The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions.

43.1k: Evolution does not necessitate long-term progress in some set direction.

Learning Progressions from NYLE Core Curriculum to inform discussions:

Middle School Expectation- Starting Point	High School Expectation - Objective
Describe sources of variation in organisms and their structures and relate the variations to survival.	Explain the mechanisms and patterns of evolution.
Describe factors responsible for competition within species and the significance of that competition	

Learning Objectives

Question cycle 1: Through question presentation and class discussion students evaluate how traits can provide individuals with survival and reproductive advantage.

Question cycle 2 Through question presentation and class discussion students explain how genetic variation in populations can prevent environmental changes from extinguishing a species.

Question cycle 3: Through question presentation and class discussion students evaluate the unintentional nature of evolutionary processes and the possibility of species having seemingly undesirable traits.

Instructional Outline:

Pre-class assignment:

Students will review text as homework before class:

      📖 Miller and Levine, Biology (Miller et al., 2014)Chapter 10 (pp. 472-495)

Lesson begins with question presentation:

Question Cycle 1

Traits will be passed on to future generations if they:
    A. Are shared by the population.
    B. Increase the likelihood individual's survival.
    C. Provide a reproductive advantage to an individual.
    D. All of the above
    E. B and C

Lesson sequence:
1. Project the question above so all students can access
2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.
3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that organisms need to survive and reproduce for genetic traits to be passed on. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data

shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that compares traits that provide individuals with survival and reproductive advantage to traits that increase the likelihood of one and decrease the likelihood of the other. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer E. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 2

Which factor could cause the other three?

     A. Inability of a population to adapt to environmental changes

     B. Survival rate of a population is reduced

     C. A population lacks genetic variability

     D. Extinction of a population

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that existing genetic variability is necessary for organisms to adapt to environmental changes, so that populations will survive. Histograms provide immediate feedback to the teacher about student

understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that explains how genetic variation that exists in populations can prevent environmental changes from extinguishing a species. Students can be prompted to differentiate between the common definition of adapt and what it means to adapt as a species. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Discussion should conclude with verification of student understanding of correct answer C. Areas of persistent confusion should be noted and re-taught with direct instruction.

Question Cycle 3

Evolution leads to improvements in the design and function of organisms.

   A. True

   B. False

How confident are you of your answer?

   A. Not sure at all – I guessed.

   B. Only a little sure of my answer.

   C. Pretty sure I am right.

   D. Completely confident.

Lesson sequence:

1. Project the question above so all students can access

2. Students discuss with tablemates for 1 minute and each student selects a response using the student response system.

3. Project a histogram of aggregated responses. Histograms that show varied student responses indicate students are developing understanding that evolution is not purposeful that evolution is not the same as becoming more advanced or better. Histograms provide immediate feedback to the teacher about student understanding and students reevaluate responses when data shows other students responded differently. Histograms that display a high concentration of correct responses indicate that the discussion duration can be shortened.

4. Without revealing correct answers, have as many students as possible share reasoning and justifications for answers.

5. Facilitate a student-led discussion that evaluates the unintentional nature of evolutionary processes and the possibility of species retaining seemingly undesirable traits when they do not interfere with survival and reproduction. Students should be encouraged to expand on responses to develop understanding of why they think what they do, as well as prompting students to use the language of science.

6. Have students share impressions on how well their confidence level matched their accuracy.

7. Discussion should conclude with verification of student understanding of correct answer B. Areas of persistent confusion should be noted and re-taught with direct instruction.

Lesson wrap-up:

In time remaining, review lesson objectives with students and reinforce the connection between objectives and question cycles.

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