A Collection of Computer Simulation Enhanced Units for Earth Science

By

Erin Jankowiak

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APPROVED BY:

Advisor | Date

Chairperson, Education and Human Development | Date

Abstract

Inquiry learning has become the big thing in science education. Yet many concepts across the sciences pose challenges that have traditionally made them difficult or even impossible for this kind of learning. This project explored the implementation of computer simulations into the science classroom as a way to overcome many of the traditional challenges. While research has revealed both benefits and issues associated with their use, when implemented properly computer simulations were found to have the potential to help students develop deeper conceptual understandings of scientific concepts. Along with exploring the benefits and issues related to computer simulations, a review of the literature also revealed a collection of research-based strategies for their effective implementation. These strategies include scaffolding and real world connections among others. This research was then used to design a collection of five Earth Science units. Each unit is technologically enhanced through the incorporation of a PhET simulation by the University of Colorado and provides students with an opportunity to engage in simulation-based inquiry.

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Chapter I: Introduction

Rationale

The idea that learning by doing results in the development of deeper understandings and the longer retention of knowledge as compared to learning by listening, seeing or reading has been a main factor for the support of inquiry learning in the science classroom (Rutten, van Joolingen, & van der Veen, 2012). Many concepts across the sciences, however, pose challenges that have traditionally made them difficult or even impossible for inquiry learning. Among these challenges is scale, be it time or size. In Chemistry, for instance, factors such as the microscopic size of molecules or the rapid speed at which some chemical reactions occur can make concepts inaccessible for direct observation. Earth Science, on the other hand, deals with slow geologic processes and the extreme expansiveness of outer space. These scales also make direct observation physically impossible. Challenges for inquiry also arise from the factors among scientific phenomena that are entirely invisible. Friction and air resistance, for instance, are involved in many Physics concepts but they are challenging for students to grasp given that they can't be seen. In addition, factors such as cost, safety and accessibility can make inquiry learning difficult. Due to all of these challenges, it traditionally appears easier to teach many scientific concepts directly.

Models come in a variety of formats but all serve the purpose of representing some "system, process, idea, object or event" (Han-Chin Liu, Andre, & Greenbowe, 2008). They are intended to aid their users in generating questions, gathering data, constructing explanations and sharing ideas making them particularly useful for the process of inquiry learning (NGSS Lead States, 2013). Many members of the educational community have come to recognize the value of using models and their utilization within the science classroom has been increasing over the years. Even the authors of the Next Generation Science Standards went so far as to include “Developing and Using Models” among their eight scientific practices necessary for the development of students’ understandings of the nature of science (NGSS Lead States, 2013).

Models in the form of computer simulations have the potential to overcome most, if not all, of the before mentioned challenges for the inquiry learning of many scientific concepts. As defined by the National Research Council, computer simulations are “computational interactive models that allow users to dynamically explore… natural phenomena by manipulating or modifying parameters within them” (Kukkonen, Kärkkäinen, Dillon, & Keinonen, 2014, p. 409). Computer simulations have become the focus of much research in recent years in an effort to explore the benefits of their use along with how best to implement them within the science classroom.

Significance of Project

The Earth Science curriculum is full of topics involving slow geologic processes, immensely large objects and inaccessible locations both below and beyond the Earth’s surface. Any teacher can easily present students with computer simulations to explore these topics using an inquiry approach. The intent of this project is to make this exploration even more effective for both teachers and students by developing units around computer simulations that incorporate scaffolding and collaboration. According to the research, the scaffolding of student learning should start with activities that build background knowledge. This allows students to understand what is being represented in a computer simulation so that they can take the most information away from it possible. Further scaffolding during students’ interactions with the computer simulation is best done through the use of open-ended conceptual questions. These questions help students put the pieces of information they gather together to look at concepts as a whole while still allowing them to freely explore the simulation. The final scaffolding component of a good unit according to research is an activity that allows students to apply their new understandings of the laws and principles to the real world in some way. This eliminates the traditional view that science is detached from reality. Research has also indicated that collaboration in many forms, such as discussions and partner work, is beneficial to student learning through computer simulations. Collaboration provides opportunities to share thinking, clarify questions and provide extra information needed for understanding. The collection of units in this project will provide me, and any other teachers that use them, with a more effective approach for teaching concepts that are traditionally challenging for inquiry. In addition, students will be able to develop deeper conceptual understandings of these concepts through their use than they would from just the exploration of the computer simulation on its own.

Definition of Terms

Computer Simulation – An interactive model that allows students to explore scientific phenomenon by manipulating variables and observing the effects of their actions on the system

Driving Question – An open-ended conceptual question used to scaffold/guide a student's exploration and learning

Implicit Scaffolding **–** Providing students with a sense of control over their explorations while actually allowing or restricting their actions through the features of a computer simulation's structure and appearance (such as tabs or sliders)

Question Prompt – See Driving Question

Simulation-based Inquiry - A process of posing questions and investigating their answers through the observation of changes that result from the manipulation of a computer simulation

Chapter II: Literature Review

Overview

In the years to come, modeling is bound to become a staple in the science classroom. Models come in a wide variety of forms and have the ability to promote inquiry learning whether they are student designed or pre-constructed. Computer simulations are one of these forms. The literature review that follows serves to explore both the benefits and limitations of their use in facilitating the development of students' conceptual understandings. In addition, it presents teachers with a collection of research-based strategies for the effective implementation of computer simulations into the science classroom. These strategies provide students with opportunities for the most beneficial learning possible when exploring scientific concepts with simulations.

The Benefits of Using Computer Simulations in the Science Classroom

Overcoming Challenges for Inquiry

As stated by Perkins, Moore, Podolefsky, Lancaster, and Denison (2012), computer simulations "have the ability to make the invisible visible, to be dynamic and highly interactive, to scaffold and cue inquiry by what is displayed and what is controlled, to provide multiple representations, to embody causal relationships, and to allow safe (both physically and psychologically) access to multiple trials and rapid inquiry cycles" (p. 295). Computer simulations present visual representations of scientific phenomena that may appear somewhat similar to an animation. These visualizations have the capability to speed up or slow down scientific processes, to shrink or enlarge objects to more comprehensible scales and to illustrate invisible factors in ways that allow them to be seen. However, unlike ordinary animations, computer simulations are also interactive for the user. They allow the user to manipulate variables within them and then to observe the effects the changes they make have on the system. This allows the user to conduct experiments and gather data from which they can draw conclusions about scientific concepts and ideas. It is the interactivity of computer simulations that really allows students to participate in inquiry learning. In addition, since computer simulations require only a computer and internet access for their use, they are easily accessible and very safe for students to use. Often times they are also free, such as the PhET collection developed by the University of Colorado.

Implicit Scaffolding

Inquiry learning through computer simulations is further supported by the implicit scaffolding that is built right into their structure and appearance. This implicit scaffolding is intended to provide students with a "feeling of independent control over their [learning] experience while both affording and constraining students' actions that are productive for learning" (Paul, Podolefsky, & Perkins, 2013, p. 303). Since scientific phenomena are often times complex, advanced representations of these concepts can lead students to feel overwhelmed. Like all models, computer simulations bring certain aspects of scientific concepts into light while obscuring others. This is done through features including sliders that allow for the manipulation variables, tabs that limit the number of features available at a time and default conditions which are usually set at ideal (e.g. no air resistance, friction, etc.). All of these implicit scaffolding features help students to focus their attention on specific ideas; keeping them from becoming overwhelmed and forestalling random interactions that may lead to confusion (Chen, 2010).

Adams, Paulson, and Wieman (2008) suggested that student learning through the use of a computer simulation is greatest when students receive minimal guidance from the instructor and can participate in self-guided exploration at their own pace. Implicit scaffolding provides students with guidance, limiting the amount they require from a teacher for successful exploration. Adams et al. (2008) found that the structures and appearances of the simulations used in their research provided considerable guidance and that only some guiding questions at most were necessary to focus students' explorations and to push them to dig deeper into the features of the scientific concepts they addressed. The researchers did note, however, that implicit scaffolding on its own does not necessarily provide students with enough guidance for poorly designed or more complex simulations.

Impacts on Student Learning and Understanding

In an analysis of over 50 research studies conducted within the last decade or so, Rutten et al. (2012) found that all of these studies agreed that traditional science instruction can be successfully enhanced through the use of computer simulations. In most of the studies, the students showed improvements in their conceptual understandings of scientific concepts and phenomena through their interactions with the simulations. Computer simulations are effective in improving students' conceptual understandings for a variety of reasons. For one, they present students with a way to gather content knowledge on their own in a relatively straightforward manner. Through participating in simulation-based inquiry, students can conduct experiments to observe the relationships between variables or to discover properties that underlie a system as a whole. As noted by Chen (2010) there tends to be a perfect match between the scientific laws and concepts computer simulations present and the data that students collect from them. This makes it very easy for students to draw accurate conclusions and the process enhances their ability to learn this new content knowledge.

Developing conceptual understandings of scientific concepts, however, does not result simply from learning content. Along with allowing students to learn new ideas, computer simulations also encourage them to reconsider their existing ones (Varma & Linn, 2012). Students bring their own ideas about science with them into the classroom. These ideas are often based on students' personal experiences and they are not always scientifically correct. The misconceptions that students possess can pose a great challenge to their learning process. As stated by Schneps et al. (2014), "students often perceive their misconceptions as more plausible, sensible and meaningful than their conception of scientific alternatives presented in instruction" (p. 269). This makes them less likely to want to give them up.

By using computer simulations for the purpose of inquiry learning, students instead discover scientific alternatives for themselves. This forces them to recognize the conflicts between what they think they know and what they have discovered and in turn to modify their understandings based on this new knowledge (Jaakkola & Nurmi, 2008). The research conducted by Kukkonen et al. (2014) looked at the effects of simulation-based inquiry on students' understandings of the greenhouse effect. They found that while students did not necessarily develop perfect understandings of the concepts they explored, the discoveries they made through the simulation encouraged them to revise their previous knowledge and misconceptions resulting in conceptual change. This research indicated that, while computer simulations are not the complete and perfect solution to resolving student misconceptions, they are a great tool for aiding in this task.

In addition to building content knowledge and addressing misconceptions, the development of conceptual understandings can also result from learning that is not consciously done. In their research, Schneps et al. (2014) noted the potential of computer simulations for implicit learning; that is, learning without being aware. The simulation used in this study was a virtual solar system App for the iPad. It contained a “true-to-scale mode” that presented a realistic relationship of the planetary objects and their orbits. This mode required the user to make many pinch motions and movements in order to reveal the different planetary objects. These motions had the potential to embody astronomical scale and create memories of the information for the user. While Schneps et al. (2014) could not definitively state that implicit learning occurred as the result of the pinch-to-zoom feature in their study, it appeared to be highly likely due to the connection of the sensory-motor actions with the movement throughout space and the evident improvement in students’ understandings of astronomical scale after their interaction with the App. However, it still remains to be seen if moving and zooming with a computer mouse would result in implicit learning like the use of fingers. Given that most simulations are designed to be explored through the use of a computer, this is an important area for future research.

In order for students to develop deep conceptual understandings of scientific concepts and phenomena, they need to actively engage with the content (Adams et al., 2008). Computer simulations provide a way to do just that by putting them in control of their own learning. They make students active participants in their learning process by allowing them to manipulate variables, observe the consequences of their actions on an overall system and gather data (Kukkonen et al., 2014). Their explorations are driven by questions, either from the teacher or their own curiosity, which they work to answer. Through this exploration, students are cognitively engaged as they gather knowledge, reflect on it, and revise it in order to develop their own conceptual understandings. In their research on the engagement of students in technology-enhanced classrooms, Wu and Huang (2007) found that the use of computer simulations engaged students not only cognitively but also behaviorally and emotionally as well. They found that the students in these classrooms participated in disengaged behaviors a relatively small amount of time over the course of a simulation-enhanced unit on force and motion. These researchers also noted that students demonstrated a high level of emotional engagement when they had the opportunity to explore the computer simulation in a student-centered manner. They found that these students had "lower anxiety level[s], higher confidence and more positive attitude[s] toward using computers for [the purpose of inquiry] learning" (p. 739).

A student's engagement is a crucial component to his or her cognitive development (Wu & Huang, 2007). To facilitate this engagement, students need to be motivated; that is, they need to want to participate. Perkins et al. (2012) noted that by using computer simulations in the science classroom, teachers can tap into students' tendencies to explore and play games and they can use these tendencies as a source of engagement and motivation for learning. Since technology has become a major part of students' lives in recent years, and a part which many of them thoroughly enjoy, the use of any form of technology in the classroom can serve as a great source of motivation. Computer simulations have the potential to be seen by students as a source of fun, almost like a game, which makes them more likely to want to participate in an exploration. The inquiry mode of learning presented by computer simulations also provides students with a sense of control over their own exploration and learning. This is critical because "greater perceived control results in higher level[s] of intrinsic motivation" which in turn can result in greater learning (Wu & Huang, 2007, p. 730)

The Issues with Implementing Computer Simulations in the Science Classroom

Though there are many benefits to using computer simulations in the science classroom and while they have been found to be effective in improving students' understandings of scientific concept, they do have their issues as well. In their study described earlier, Schneps et al. (2014) used only a virtual solar system App for the iPad and a corresponding worksheet containing questions to instruct students on a variety of concepts about the solar system. This activity was done individually by the students in a self-paced manner with little support from the teacher. While the students did show remarkable improvements in their knowledge of much of the content that was addressed, they continued to struggle with understanding the causes of the seasons. Based on these findings, the researchers stated that simulations on their own are not enough and that further instruction is necessary for student learning, especially for more complex ideas. They suggested that students would benefit from scaffolding and instruction with more explicit guidance along with the exploration using the simulation.

Complexity and Background Knowledge

All computer simulations vary in their levels of complexity and interactivity. The complexity of a computer simulation depends on factors such as the number of controls they have, the number of representations (eg. animations, graphs, charts, etc.) they present and how well those representations illustrate important information and ideas (Podolefsky, Adams, Lancaster, & Perkins, 2010). The more controls and representations computer simulations contain, the more complex they become. However, simulations can become less complex when their representations are easy for students to connect to the information they portray. For instance, using dots to represent the number of molecules in a beaker is less difficult for students to understand as opposed to a graph showing the number of molecules present (Podolefsky et al., 2010). Along with varying complexity, computer simulations also have the potential to exhibit one of two levels of interactivity; either low or high. As defined by Park, Lee, and Kim (2009), computer simulations exhibiting low interactivity allow students to control the pace at which information is presented in the simulation. Low interactivity simulations provide students with features such as pause and replay buttons that allow students to spend more time processing the information they are receiving. High interactivity simulations, on the other hand, present information in a continuous manner and this information is determined by students' actions such as the manipulation of variables.

The complexity and interactivity of computer simulations can present issues for their successful use by students. Simulations that are more complex and exhibit high interactivity have the potential to become overwhelming for students. This can be especially true for middle school students given that many computer simulations are designed with high school and college age students in mind. When students become overwhelmed they may either ignore the representations that do not make sense to them or they may simply not engage in the exploration at all (Adams et al., 2008; Podolefsky et al., 2010). This ultimately defeats the purpose of using computer simulations.

Even further issues related to the complexity and interactivity of computer simulations can arise when the levels of background knowledge that students possess are taken into consideration. In any classroom, some students will have higher levels of background knowledge than others on any given scientific concept. Therefore, these students will "view the same sim[ulation] differently depending on their prior knowledge" (Podolefsky et al., 2010, p. 257). Complex simulations have a greater potential to be deemed overwhelming by students with low background knowledge. In their research, Park et al. (2009) examined the effects of high and low interactivity computer simulations on the explorations and learning of students with high and low prior knowledge. They found that students with high levels of prior knowledge benefited more from using high interactivity simulations than students with low prior knowledge. The opposite was true for low interactivity simulations; students with low prior knowledge benefited more from their use than did those with high prior knowledge. Chen, Wu, and Jen (2013) indicated that this is most likely due to the fact that students with low prior knowledge "might not have adequate schemas to guide them through the process of comprehending concepts" in high interactivity simulations (p. 229). They pointed out that students' levels of background knowledge are strong predictors of their' abilities to develop understandings of scientific concepts from computer simulations.

Detachment from the Real World

In an analysis of 233 virtual laboratories, including simulations from the PhET collection, Chen (2010) found that 80% of the virtual labs used a hypothetical-deductive mode of inquiry. This mode of inquiry focuses specifically on relationships between variables and tends to limit the extremes to which they can be pushed in order to present a more perfect match to scientifically accepted ideas and laws. Hypothetical-deductive inquiry also supports the straightforward confirmation or rejection of a hypothesis based on the results of a single experiment. Chen (2010) argued that this is an issue because the hypothetical-deductive form of inquiry does not promote the development of scientific habits of mind. For instance, it does not encourage students to conduct multiple experiments and then use their reasoning skills the way an actual scientist would to analyze their results and either accept or refute their hypothesis based on their findings. Real science is messy and complicated and requires a holistic approach to come to conclusions. In order to develop students' scientific literacy, Chen (2010) argued that students would benefit more from computer simulations that present a more realistic mode of inquiry.

As previously mentioned, computer simulations contain implicit scaffolding features that are designed to promote students' learning of scientific concepts. These implicit scaffolding features are intended to reduce cognitive loading by limiting what can be seen or done so that students can focus on specific ideas without becoming overwhelmed. However, these features also have the potential to oversimplify the complex systems and laboratory processes that simulations present (Chen, 2010; Jaakkola & Nurmi, 2008). Chen (2010) argued that this simplification, along with the hypothetical-deductive mode of inquiry presented in most virtual laboratories, can lead students to develop "naïve view[s] of how science is conducted and how scientific knowledge is constructed" (p. 1124). Computer simulations make science look easy. They make scientific exploration appear much less time consuming than it actually is, produce no data or human errors to account for and make drawing conclusions a simple task; so unlike the work of real scientists.

Chen (2010) also argued that the ideal conditions presented in many virtual laboratories lead students to "view science as being totally detached from reality" (p. 1127). Ideal conditions are another implicit scaffolding feature that is intended to help students focus on specific ideas and keep them from becoming overwhelmed by removing factors that can lead to confusion. However, these ideal conditions can at times be completely contradictory to those actually experienced in the real world. For instance, air resistance and friction are popular factors to ignore yet students are aware of their presence from everyday life. This can make it challenging for students to believe that the ideas presented in simulations can also pertain to the real world (Jaakkola & Nurmi, 2008).

Strategies for the Effective Implementation of Computer Simulations in the Science Classroom

Computer simulations are particularly useful tools for the science classroom given that they have the ability to overcome many traditional challenges for inquiry and that they contain implicit scaffolding features that help to guide students' inquiry explorations of concepts and phenomena. However, as previously mentioned, the findings of Schneps et al. (2014) indicated that computer simulations alone are not enough to fully support the development of students' conceptual understandings. In actuality, scaffolding is a necessary factor for their successful implementation and use. Scaffolding aids students' in their development of conceptual understandings by providing guidance for the learning process. It involves offering students high levels of guidance when first interacting with a new concept or idea due to their limited knowledge. This guidance is then slowly removed as they build up their knowledge, allowing students to develop a sense of independence over their own learning.

Perhaps one of the best ways to scaffold student learning through the use of computer simulations is to incorporate them into a curricular unit. In their research, Kukkonen et al. (2014) did just that. In their simulation-enhanced unit on the Greenhouse Effect, students spent the three days leading up to their interaction with the computer simulation participating in activities that were intended to activate their prior understandings and to enable them to develop sufficient background knowledge for their interaction with the simulation. These activities included creating annotated diagrams to represent students' initial understandings of the concept as well as worksheets, internet research and discussions addressing background information such as the layers and composition of the atmosphere and the formation of clouds.

This first step of developing students' background knowledge is crucial for their successful interaction with a computer simulation. As mentioned earlier, a student's background knowledge is a strong predictor of how well they will be able to develop understandings of scientific concepts from manipulating and observing a simulation. The lower a student's background knowledge, the less they are likely to get out of the exploration, especially if the computer simulation has a high interactivity level (Park et al., 2009). However, as stated by Khan (2011), this does not mean that students should know what the relationships are between variables or what effects they have on the overall system before participating in simulation-based inquiry. Doing this doesn't allow students to discover this knowledge or take ownership in their learning. It causes the simulation to simply become a way to reinforce the knowledge. Instead, Khan (2011) proposed that teachers need to help students develop just enough background knowledge so that they will know exactly what it is that they are looking at when using the simulation. This way all students will receive greater benefits from interacting with the simulation. Kukkonen et al. (2014) found that by incorporating activities that fostered the development of background knowledge into the unit with the computer simulation, students' understandings of the Greenhouse Effect phenomenon were noticeably enhanced.

Once students have built up an adequate level of background knowledge, they are ready to being exploring with the computer simulation. In order to scaffold student learning, the level of support provided by teachers during this portion of the unit should be reduced to allow for more independence. Yet, computer simulations already provide their own implicit scaffolding. Their features guide students through their explorations while still allowing them to feel in control. With this implicit scaffolding already present, the question becomes how much guidance is really necessary from teachers to support the overall scaffolding of student learning and understanding.

Adams et al. (2008) analyzed the effects of four different levels of teacher guidance on students engaged exploration with computer simulations. These levels included: *no instruction*, *driving questions*, *gently guided* and *strongly guided*. In the *no instruction* guidance level, students were told to simply play with the simulation. For the *driving questions* level, students were presented with open-ended conceptual questions such as “What are some ways you can make a magnet?” (Adams et al., 2008, p. 61). At the *gently guided* level, students were presented with questions such as “What does the strength slider do?” (Adams et al., 2008, p. 61). Lastly, in the *strongly guided* level, students were presented with a cookbook activity that gave step-by-step directions for interacting with the simulation along with questions to answer.

After conducting a couple hundred interviews using these four levels of guidance, the researchers found that a *no instruction* approach for student interaction with computer simulations greatly taps into students’ natural curiosity and that their explorations are self-paced and influenced completely by their own questions and interests. However, this approach also relies heavily on implicit scaffolding which may not always meet the needs of all students such as low-achievers (Wu & Huang, 2007). As Khan (2011) stated, “the vast majority of available computer simulations lack the capability to independently tutor students on the concepts, direct investigations, or guide student inquiry” (p. 217). Though students explore more features of simulations when they are given the freedom of no instruction, they don’t necessarily look at these features very deeply (Adams et al., 2008). On account of this, students do not develop as thorough conceptual understandings of the concepts presented as they could if given some support. Therefore, while the *no instruction* approach does present some benefits, it is not necessarily the best scaffolding choice. Still, Perkins et al. (2012) advised that providing students with some opportunity to freely explore a computer simulations is beneficial. These researchers suggested that students receive five to ten minutes to explore a simulation on their own before being given any guidance. They found that this tactic helped to boost students' confidence and ability in exploring with the simulation. They also found that it decreased the amount of unproductive play by students, keeping them more focused once provided with guidance from the teacher.

On the other hand, using a *strongly guided* approach can reduce the use of computer simulations to a step-by-step cookbook that completely undermines their potential for student exploration. This approach prevents students from creating their own questions and testing and evaluating their own hypotheses (Rutten et al., 2012). Instead of encouraging students to discover things for themselves, students to tend to focus solely on following the directions and answering any accompanying questions. Essentially, it takes away the inquiry which is one of the main points behind the use of computer simulations in the first place. Furthermore, when the student-centered aspect of the activity is taken away, so too is the reflection process. This process is highly important for student learning because it is what leads students to reconsider their previous ideas based on new information and to correct their misconceptions. In their research on the engagement of students in teacher-centered and student-centered technology-enhanced classrooms, Wu and Huang (2007) found that putting students in charge of their own exploration with a simulation encouraged a reflection process. They observed that students in the student-centered class went back and revised their previous answers to the provided questions as they interacted with the simulation. This was due to the fact that they were not provided with the correct answers until the class discussion at the end of the lesson.

In supporting students' explorations through computer simulations, some level of teacher guidance is favorable yet it is important that this guidance not restrict the freedom for exploration too much. Adams et al. (2008) found that the minimal but not entirely absent guidance of the *driving questions* approach promoted the greatest engagement and learning. Providing students with minimal guidance through driving questions, also referred to as question prompts, encourages them to dig deeper into the features of computer simulations while still continuing to ask their own questions. This approach also "lead[s] [students] through the use of computer simulations in a fashion that looks at individual pieces of relationships at a time and then lead[s] them through putting those pieces of the relationships together into an overall concept" (Khan, 2011, p.225)

Question prompts are heavy area of research in relation to the use of computer simulations for inquiry learning. When designed properly, question prompts are intended to "activate students' higher-order thinking skills and their prior knowledge, [to] enable knowledge integration and logical thinking, and [to] facilitate the transfer of existing knowledge to practical knowledge, enabling subsequent problem solving" (Chen et al., 2013, p. 231). Probably the easiest way to go about presenting these questions to students is in the form of a worksheet to be completed as they interact with a simulation such as was done in the study by Schneps et al. (2014). However, Chen et al. (2013) suggested that presenting students with all of the questions at once does not encourage them to carefully analyze what they are asking. In an effort to fix this problem, these researchers developed an online scaffolding system that presented the question prompts to the students' one-at-a-time within the simulation itself. They found that while students may have analyzed each question more closely as a result of seeing only one at a time, they tended to view them as separate entities. This prevented the students from drawing connections between the questions which would take them to a deeper level of understanding about the concepts. The key here appears to be developing open-ended questions that force students to look at the concept as a whole instead of focusing on specific aspects.

When developing question prompts, it is important to also take into consideration the differences among students and to recognize that what works for some may not work for others. Some students may benefit from the minimal guidance described earlier while others may require more structure even after having built background knowledge. Chen et al. (2013) proposed that making different question prompts available for different groups of student during the exploration of the simulation could be beneficial of their learning. The flexibility of computer simulations can easily support this approach. Through differentiating instruction, all students will hopefully be able to get the most out of a simulation-based inquiry experience.

As noted earlier, computers simulations have the potential to make students feel that science is disconnected from the real world (Chen, 2010). Therefore, further scaffolding after the simulation exploration is necessary for more meaningful learning and the development of more complete understandings. Students need to draw connections between what they discover in a computer simulation and real life. Jaakkola and Nurmi (2008) recognized the previously mentioned limitations of computer simulations and proposed their combination with physical laboratory activities as a potential solution. They suggested that this combination would allow students to “bridge the gap between theory and reality” (Jaakkola & Nurmi, 2008, p. 280). In their study, the students first interacted with the simulations to discover the laws and principles at play in electrical circuits and to visualize the unseen factors such as current. They then applied this knowledge to real circuits in order to see that the ideas from the simulation do in fact pertain to the real world. Connections to reality don’t necessarily have to be in the form of laboratory work however. In their unit on the Greenhouse Effect and Global Warming, Varma & Linn (2012) presented students with the task of creating a plan to reduce their families gas emissions that required them to apply what they had learned to everyday life.

Along with scaffolding, another strategy presented in the research for the effective implementation of computer simulations in the science classroom is the use of collaboration. As indicated by its popular use among researchers, having students work with a partner as they explore a simulation is a great way to promote collaboration (Jaakkola & Nurmi, 2008; Perkins et al., 2012; Varma & Linn, 2012; Wu & Huang, 2007). In general, this is particularly helpful for students when the tasks at hand require complex problem-solving processes (Jaakkola & Nurmi, 2008). Through working with a partner, students are able to discuss their thoughts, share ideas and clarify confusions, all of which helps to promote the development of deeper understanding. However, further research on how to most effectively pair students for simulation exploration is necessary. In their study, Wu and Huang (2007) paired students based on similar levels of achievement; low with low and high with high. They found that the low-achieving groups of students "demonstrated more disengaged behaviors and engaged in fewer conceptual discussions" (p. 747). It seems possible that the mixing of low and high-achieving students or those with low and high levels of background knowledge could result in more beneficial pairings.

Providing students with opportunities for discussion can also promote collaboration before, during and after exploring with a computer simulation. For instance, asking students to present the findings of their explorations with a computer simulation can lead to class discussions that can clarify areas of confusion or present more information needed for understanding (Kukkonen et al., 2014). It can also increase the students' sense of ownership over the use of computer simulations and the information that they gather from them (Perkins et al., 2012). The feedback presented by collaboration is also important for student learning. Chen et al. (2013) implemented mechanisms for feedback into their online scaffolding system designed to present students with question prompts one at a time as they explored a simulation. Before and after answering a question prompt the students had the opportunity to access both expert and peer-responses. This feature allowed students to check their thinking and either confirm or correct it in a short span of time. The researchers found this to be highly effective.

Summary

Among the key practices the Next Generation Science Standards define as being critical for the development of students' understandings of the nature of science is their ability to design and use models. Computer simulations bring models, along with technology, into the classroom in a way that taps into students' natural tendencies to explore and provides inquiry opportunities that traditionally are not possible. They are "particularly promising for… the study of phenomena that are not easily observable…or not inherently visual objects" (Park et al., 2009, p. 649). This is because they have the ability speed up or slow down scientific processes, shrink or enlarge items to comprehensible scales and make invisible factors visible.

Computer simulations provide an effective way to enhance traditional instruction and improve students' conceptual understandings of scientific concepts. However, simulations on their own are not enough, especially for complex concepts. Research has indicated that scaffolding is a necessary component for their effective implementation. For starters, students need to have enough background knowledge to understand what they are looking at in a computer simulation. While this might mean explicitly teaching students what factors in a computer simulation are prior to their exploration, it does not include explaining the relationships or effects those factors have for a given phenomenon or concept. Those are the things that students can discover on their own. Only once students developed sufficient background knowledge can they successfully engage in inquiry learning with a computer simulation.

Even though computer simulations contain implicit scaffolding that helps to focus students' attention on certain ideas, support from teachers for their exploration is also necessary. Open-ended conceptual questions can provide students with just enough guidance to learn about key ideas without removing too much of the freedom for exploration presented by simulations. Multiple studies have indicated that these types of questions are effective for helping students discover the scientific content represented in computer simulations as well as to develop conceptual understandings of the concepts and phenomena. Yet, they can also lead students to see this knowledge as being detached from reality. To further scaffold student learning, connections to the real world need to be made so that students can see that science does actually apply to reality. These connections can be made in a variety of ways including physical laboratory and real world applications.

In addition to scaffolding, collaboration is a key factor in the successful implementation of computer simulations for learning in science. This can occur through providing students with opportunities for discussion and allowing them to explore simulations in pairs among others. Collaboration aids student in problem solving processes by allowing for the clarification of confusion and the sharing of thoughts. It can also provide students with feedback or further information to help them reach deeper levels of understanding. When implemented properly through the use of these strategies, computer simulations present a useful tool for both teachers and students which greatly enhances science instruction.

Chapter III: Capstone Project

Overview

This project is composed of a collection of five units for use in the Earth Science classroom. Each unit has been technologically enhanced through the incorporation of a computer simulation and provides students with the opportunity to engage in simulation-based inquiry. A variety of scaffolding techniques, along with collaboration, have also been employed to assist students in deepening their conceptual understandings of the scientific concepts the units address.

Project Outline

Each unit in this collection consists of 5 lessons to be conducted over the course of 5 days. In order to scaffold student learning, each unit begins with a day (or two where needed) for activating students' prior knowledge on the topic/concept it addresses and then building this knowledge to an adequate level for interacting with the computer simulation. The activities and information incorporated into these lessons are intended to allow the students to actually understand and interpret what it is they are looking at when they conduct their exploration with the simulation. On the next day of the unit the students explore the computer simulation with a partner. For the first five minutes of this exploration, the students are able to freely explore the simulation with their partner; no directions or questions given. This allows the students to become familiar with the simulation. It also boosts their confidence and interest in working with it. After the first five minutes are up, the students are then presented with a worksheet containing several driving questions to guide their explorations. These open-ended conceptual questions address the key ideas represented in the simulation. For the two days (or in some cases just one) following the exploration of the computer simulation, the students' findings to the driving questions are discussed, providing opportunities for clarifying any areas of confusion. Any additional information that is needed for understanding the topic/concept is also presented by the teacher during this time. On the final day of each unit, the students begin a culminating activity. This activity serves as an assessment of students' conceptual understandings and requires them to connect the laws and principles they discovered using the computer simulation to the real world in some way.

Project Design Unit Topics

Unit	Topic
1	Plate Tectonics
2	Glaciers
3	The Greenhouse Effect
4	Gravity and Orbits
5	Radiometric Dating

For each unit in this collection, the following is included:

- An overview of the computer simulation used to enhance the unit containing…
  - The title of the simulation
  - The web address through which it can be accessed
  - A brief description of the simulation
  - An evaluation of its level of implicit scaffolding (high or low)

- Rationale for the integration of the computer simulation (eg. the concept presents challenges for inquiry due to time, size, etc…)

- A lesson plan for each day of the unit (5 days per unit) containing…
  - The NYS standards addressed
  - Learning objectives
  - A write-up of the activity(s)
  - Assessment(s)

- Copies of any materials such as handouts, driving questions worksheets, rubrics, etc…

PLATE TECTONICS UNIT

Overview of Computer Simulation

Title	PLATE TECTONICS
Web Address	https://phet.colorado.edu/en/simulation/plate-tectonics
Description	This simulation contains two tabs. The first tab, "Crust", allows the user to explore the differences between oceanic and continental crust related to the properties of density, composition, temperature and thickness. The temperature, composition and thickness of the crust can also be manipulated to see how these features influence the buoyancy of the crust. The second tab, "Plate Motion", allows the user to explore the different types of plate boundaries. The types of crust and boundary involved can be manipulated to explore the motions of the plates and the formation and destruction of various surface features.
Level of Implicit Scaffolding	High

Rationale

The concept of plate tectonics traditionally presents a challenge for inquiry due to multiple reasons. First, the scale of the tectonic plates themselves is too large for students to interact with directly. Secondly, plate motion occurs at time scales too slow to be observed within the science classroom. Finally, some key factors for plate motion and the formation and destruction of surface features occur below the surface of the Earth where they are unobservable to the human eye. The simulation by PhET incorporated into this unit shrinks down, speeds up and makes visible the actions and factors involved in plate tectonics.

DAY 1

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1L** The lithosphere consists of separate plates that ride on the more fluid asthenosphere and move slowly in relationship to one another, creating convergent, divergent, and transform plate boundaries. These motions indicate Earth is a dynamic geologic system.
    - These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.
    - Compared to continental crust, ocean crust is thinner and denser. New ocean crust continues to form at mid-ocean ridges.

OBJECTIVES:

- Students will *recall* information regarding the interior layers of the Earth. (*Knowledge*)
- Students will *infer* how the density of the Earth changes with depth. (*Comprehension*)
- Students will *infer* what happens to rocks in the mantle as they heat up and cool down. (*Comprehension*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 2-10**)
- Earth Layers Notes (**p. 34-35**)
- Large graduated cylinder
- Equal amounts: light corn syrup, dish soap, vegetable oil, rubbing alcohol

PREPARATION:

- Construct a density column in a large graduated cylinder by pouring equal amounts of the following liquids into the graduated cylinder in the exact order listed:
    - light corn syrup
    - dish soap
    - vegetable oil
    - rubbing alcohol

  * *Add food coloring to the liquids to help make the layers stand out*

INTRODUCTION:

- Share the image of Pangea (**Slide 2**) with the students and explain that it shows what the Earth looked like 237 million years ago. That was right about the time dinosaurs were getting their start!
- Ask the students to share their thoughts on the image. Use the following questions to prompt their thinking if needed:
    - What stands out to you?
    - How is this Earth different from Earth today? The same?

- Explain that at this time in Earth's history all the land was grouped together in a supercontinent known as Pangea. To get from Pangea to the arrangement of continents we know today, the land had to move (**Slide 3**).
- Explain to the students that in order to understand how the land can move, they need to understand a process called plate tectonics. Over the next 5 days they will be taking a closer look at what this process is and how it works.

LESSON/ACTIVITY:

- Pass out the **Earth Layers Notes**.
- Remind the students that the interior of the Earth has several layers.
- Bring up the layers of the Earth diagram (**Slide 4**) on the board and ask the students to name the layers from the outside in. Write their responses on the board. The students should add the labels to their notes as well.
- Pose the question: Why would the Earth's interior form layers?
- Share the density column with the students and tell them what liquid each layer is composed of.
- Pose the questions:
    - What property would cause these different liquids to form layers/float on top of each other? *Density*
    - Why is the rubbing alcohol on top? *it has the lowest density*
- Pose the question: Based on what we know about density, what we can infer about the interior of the Earth? *the layers get denser as you move towards the center of the Earth*
- Share the 'Inferred Properties of Earth's Interior' diagram from page 10 of the Earth Science Reference Tables (**Slide 5**) with the students. Draw their attention to the densities given for each layer of the Earth and how they increase with depth. They should add the bold information to their notes.
- Explain to the students that in order to understand how land can move around the surface of the Earth, they need to take a closer look at the mantle, the crust and the interaction between the two.
- Explain to the students that the mantle can actually be divided into three sections.
- Share the information on the lithosphere (**Slide 6**) with the students. They should add the bold information to their notes, including the labels (**click to reveal**) for the picture.
- Share the information on the asthenosphere (**Slide 7**) with the students. They should add the bold information to their notes, including the labels (**click to reveal**) for the picture. Make sure to explain that viscous means resistant to flow. Honey and molasses are great examples of viscous liquids.
- Explain that the temperature of the mantle increases with depth. The asthenosphere is considered "plastic" because over very long periods of time heat gives it the ability to flow. Yet as you move deeper into the mantle, the mantle actually becomes more viscous or "stiff" because even though temperature increases, pressure increases as well.
- Share the information on the mesosphere (**Slide 8**) with the students. They should add the label to the picture in their notes.
- Explain that the mantle moves through the process of convection. To show how convection works, play the video linked to the picture on **Slide 9** which demonstrates this process with water.

- Pose the questions:
  - What happened to the cold water? *it stayed at the bottom*
  - What happened to the warm water? *it rose to the top*
  - What happened to the warm water when the ice cubes were added? *it cooled down and sunk to the bottom*
- Explain to the students that convection occurs in all different materials – water, air and even rock. The mantle convects because heat from the core warms the rock at the bottom of the mantle. This rock then rises because it is less dense. The cooler rock at the top of the mantle must sink then to take the place of the rising rock. This creates convection cells.
- Share the information on mantle convection (**Slide 10**) with the students. They should add the bold information to their notes.
- Draw mantle convection currents on the image and ask the students to do the same in their notes.

CLOSURE:

- Explain to the students that tomorrow they will be exploring the crust and looking at what this convective motion does to it.

ASSESSMENT:

- The students' ability to *recall* information regarding the interior layers of the Earth will be informally assessed through student responses during class discussion.
- The students' ability to *infer* how the density of the Earth changes with depth will be informally assessed through student responses during class discussion.
- The students' ability to *infer* what happens to rocks in the mantle as they heat up and cool down will be informally assessed through student responses during class discussion.

REFERENCES:

- National Geographic. *Triassic Period.* http://science.nationalgeographic.com/science/prehistoric-world/triassic/
- Steve Spangler Science (2013). *Seven Layer Density Column*. http://www.stevespanglerscience.com/lab/experiments/seven-layer-density-column
- The University of the State of New York. *Reference Tables for Physical Setting/EARTH SCIENCE*. http://www.p12.nysed.gov/assessment/reftable/earthscience-rt/esrt2011-eng

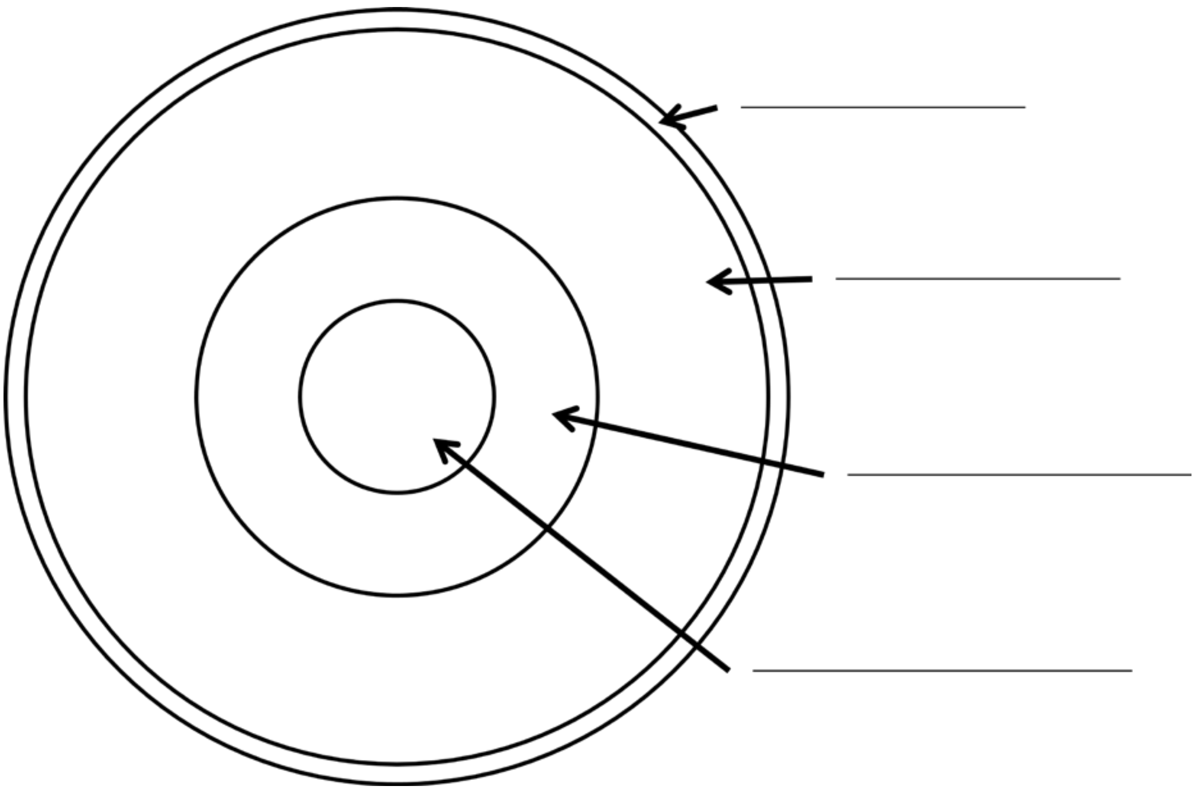
IMAGES/VIDEOS:

- Azar, Scott (2013). *My Convection Demo*. https://www.youtube.com/watch?v=sFB5GGSP6PY&list=UUBiOAw7S8oeCRAOaIHswFqQ
- http://upload.wikimedia.org/wikipedia/commons/thumb/2/27/Oceanic_spreading.svg/2000px-Oceanic_spreading.svg.png

Name ____ Date ______________

Earth Layers Notes Period ______

The Earth consists of four main layers:



The density of rock within the Earth ____

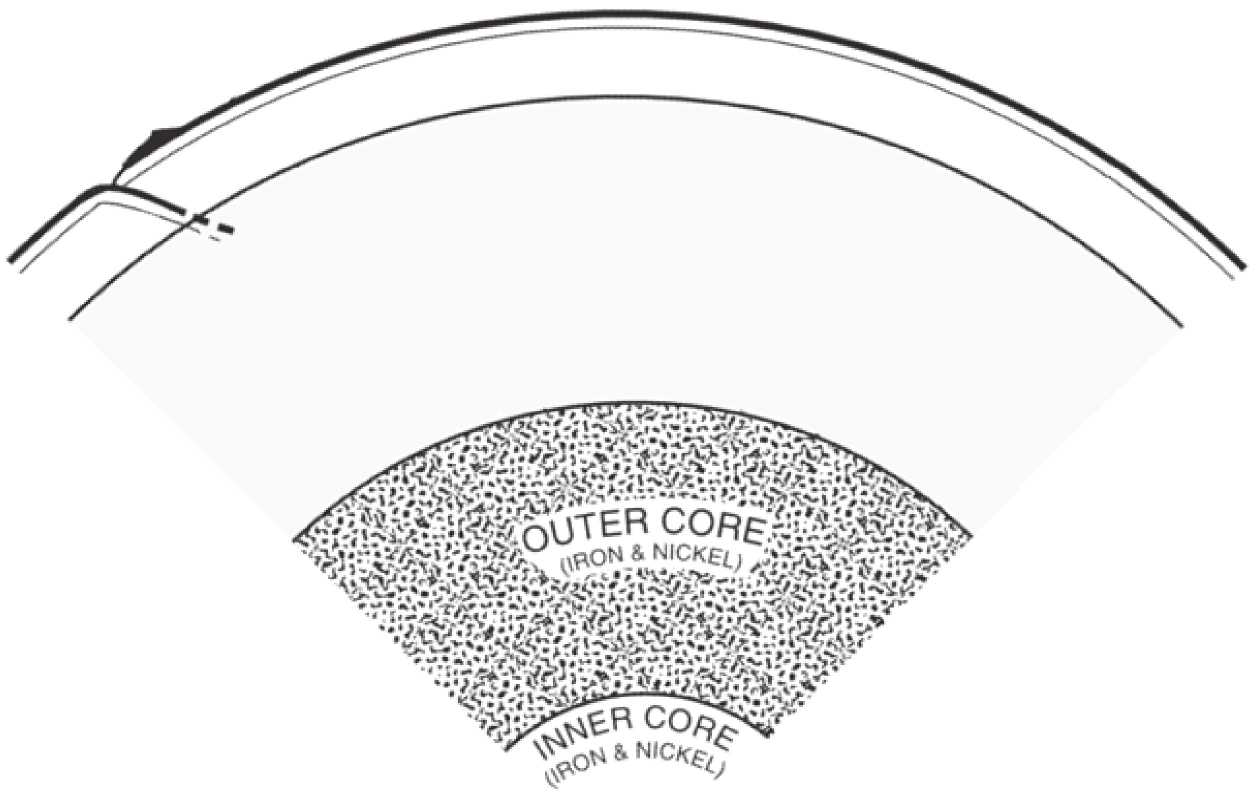
Lithosphere: ____

____

Asthenosphere: ____

____

The mantle can be divided into three sections:



_________________________ occurs in the mantle. Heat from the ____________ warms rock at the _______________ of the mantle. This _________________________ rock then __________ and cooler rock from the top of the mantle ___________ to take its place.

DAY 2

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1L** The lithosphere consists of separate plates that ride on the more fluid asthenosphere and move slowly in relationship to one another, creating convergent, divergent, and transform plate boundaries. These motions indicate Earth is a dynamic geologic system.
    - These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.
    - Compared to continental crust, ocean crust is thinner and denser. New ocean crust continues to form at mid-ocean ridges.

OBJECTIVES:

- Students will *compare and contrast* oceanic and continental crust based on their properties. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 10-16**)
- PhET Plate Tectonics simulation (http://phet.colorado.edu/en/simulation/plate-tectonics)
- Crust Comparison Chart (**p. 39**)

INTRODUCTION:

- Pose the question: How does convection in the mantle occur? *When rock at the bottom of the mantle is heated by the core it rises. Cooler rock at the top of the mantle sinks down to replace the rock that has moved. This produces convection cells.*
- Share the cross-section of the Earth (**Slide 10**) with the students and draw a convection cell on it again to demonstrate the process and what it looks like.
- Explain to the students that while today they will be taking a closer look at the crust, they should keep the process of mantle convection in mind. They will be coming back to it later in the class.

LESSON/ACTIVITY

- Ask the students to share what they know about the crust. Jot down their ideas on the board (**Slide 11**). Use the following questions to prompt their thinking if needed:
    - What is the crust made of? *rock*
    - How does it compare to the other layers of the Earth in terms of density and thickness? *least dense, very thin*
- Share the image of Earth from space (**Slide 12**) with the students.
- Ask the students to imagine that they are aliens observing the Earth for the first time and pose the question: What about it would stand out to you?

- Explain to the students that the blue of our oceans and the green and brown of our land is very special to the Earth. We are the only planet, in our solar system at least, that has continents and oceans.
- Remind the students that the crust covers the entire surface of the Earth. Even though you can't see it everywhere, like where it is covered by the ocean, it's still there. This crust, however, is not entirely the same in every place. Differences in the properties of the crust actually determine where we will find oceans and land.
- Explain to the students that there are two types of crust: oceanic and continental. These types of crust differ in their compositions, thicknesses and densities.
- Pass out the **Crust Comparison Chart**.
- Explain that they are going to explore the differences between the two types of crust using a computer simulation together as a class.
- Ask the students to make predictions to the following questions by raising their hands:
    - Which type of crust is thicker: oceanic or continental?
    - Which type of crust is denser: oceanic or continental?
- Bring up the PhET Plate Tectonics simulation on the board. The **Crust** tab will be used for this activity.
- Point out the continental crust shown on the screen to the students and explain that their first task is going to be to replicate it. They need to suggest how to move the sliders that manipulate the temperature, composition and thickness of the crust in order to create a piece of crust as identical as possible to the continental crust shown.
- Manipulate the sliders according to student suggestions until the desired crust is achieved.
- Ask the students to take a minute to observe the continental crust on the board. They should record their observations about its composition, thickness and density on their Crust Comparison Chart.
- Bring up the Crust Comparison Chart (**Slide 13**) on the board.
- Ask the students to share their observations. Jot down their ideas on the board.
- Provide the students with further information about continental crust by explaining that it is composed of rocks like granite which are rich in silica. Use the ruler tool to measure the thickness of the continental crust in km. Ask the students to record this information in their charts as well for future reference.
- Explain to the students that they are now going to do the same thing for oceanic crust.
- Manipulate the sliders according to student suggestion until the desired crust is achieved. They should then record their observations on its properties.
- Ask the students to share their observations. Jot down their ideas on the board.
- Provide the students with further information about oceanic crust by explaining that it is composed of rocks like basalt which are rich in iron. Again, use the ruler tool to measure the thickness of the crust and ask the students to record this information in their charts for future reference.
- Use the density tool to further compare the densities of the two types of crust by sliding it slowly from the oceanic crust to the continental crust. The students will see that the density drops a slight but still noticeable amount.
- Ask the students to note which type of crust is more dense and which is less dense on their chart.

- Ask the students to think back to the previous class and pose the question: Why does the crust appear to float upon the mantle? *it's less dense*
- Explain that we often think of the crust as being one giant solid surface made of rock. Yet, like they learned in the last class, the mantle below it is convecting. It's moving.
- Pose the question: So how does the crust deal with this movement?
- Explain to the students that we can model what happens to the crust by imagining that we are making a giant batch of hot chocolate on the stove. We would need to take a big pot and fill it with milk. This milk would act like the mantle. The heat from the stove would cause it to convect just like heat from the core does to the mantle. On top of the milk we would pour the hot chocolate mix. This would float on top of the milk like the crust floats on top of the mantle.
- Play the video (from 1:40-3:45) linked to the picture on **Slide 14** which shows what would happen to the hot chocolate crust in response to the convection occurring below.
- Explain to the students that the rock that makes up the crust is very rigid and the stress put on it by the mantle's convection causes it to break apart into tectonic plates.
- Share the image of Earth's tectonic plates (**Slide 15**) with the students.
- Explain that the same convection that causes these plates to form also causes them to move. Tomorrow they will be using a computer simulation to explore what happens at the boundaries between plates as they move in relation to one another.

CLOSURE

- Ask the students to complete the writing task (**Slide 16**) on a separate sheet of paper without looking at their notes and submit it as their ticket out the door.

ASSESSMENT:

- The students' ability to *compare and contrast* oceanic and continental crust based on their properties will be formally assessed through their exit ticket responses.

REFERENCES:

- Mathex, E.A. and Webster, J.D. (2004). *The Earth Machine*.
- Moutoux, D. (2013). Teaching Ideas - *PhET Plate Tectonics*. http://phet.colorado.edu/en/contributions/view/3770
- National Geographic. *Crust.* http://education.nationalgeographic.com/education/encyclopedia/crust/?ar_a=1

IMAGES/VIDEOS:

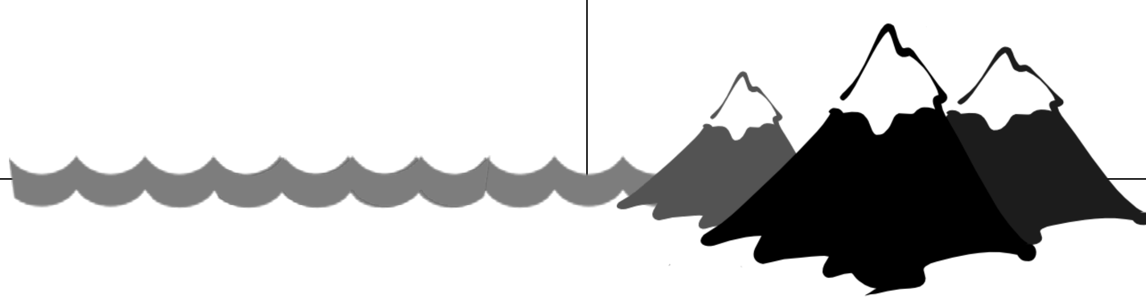
- http://www.clker.com/cliparts/a/d/A/5/i/j/new-high-def-mountain2.svg
- http://www.clker.com/cliparts/X/o/e/b/F/h/wave-pattern.svg
- https://www.youtube.com/watch/?v=PdWYBAOqHrk

Name ____ Date ______________
Crust Comparison Chart Period ______

There are two types of crust on Earth: **oceanic** and **continental**. These types of crust differ in their compositions, thicknesses and densities. It's these properties that are responsible for determining where we find land and where we find oceans here on Earth.

Directions: Observe the crust you see on the board. Take notes on its composition, thickness and density in the boxes below.

	OCEANIC	**CONTINENTAL**
COMPOSITION		
THICKNESS		
DENSITY		



DAY 3

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1L** The lithosphere consists of separate plates that ride on the more fluid asthenosphere and move slowly in relationship to one another, creating convergent, divergent, and transform plate boundaries. These motions indicate Earth is a dynamic geologic system.
  - These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.
  - Compared to continental crust, ocean crust is thinner and denser. New ocean crust continues to form at mid-ocean ridges.

OBJECTIVES:

- Through the manipulation of the computer simulation, students will:
  - *Infer* the types of plate movements. (*Analysis*)
  - *Analyze* how different plates interact with one another. (*Analysis*)
  - *Identify* the types of surface features that are formed or destroyed at the different plate boundaries. (*Knowledge*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 15&17**)
- Driving Questions Worksheet (**p. 42-44**)
- Computers
- PhET Plate Tectonics simulation (http://phet.colorado.edu/en/simulation/plate-tectonics)

INTRODUCTION:

- Ask the students to recall what happens to the crust due to mantle convection. *it breaks into tectonic plates*
- Share the image of Earth's tectonic plates (**Slide 15**) with the students again.
- Remind them that mantle convection also causes the plates to move. With all these plates moving around, they are going to have to interact with each other in some way.
- Explain to the students that today it will be their job to discover the different ways tectonic plates interact with each other through the use of a computer simulation; the same one used in the previous class.

LESSON/ACTIVITY:

- Ask the students to get together with a partner and then log on to a computer. They should follow the directions on the board (**Slide 17**) to launch the simulation.
- Give the students 5 minutes to play around with the simulation on their own in order to familiarize themselves with it and to see what they can make it do.
- Once time is up, give each student a copy of the **Driving Questions Worksheet**.

- Ask the students to make predictions about the answers to the questions based on what they already know and/or have discovered from their exploration with the simulation thus far.
- Give the students the remainder of the period to work on answering the driving questions with their partner using the simulation. Any groups that finish prior to the end of class may further explore with the simulation beyond what was addressed in the driving questions. The students should write down any further discoveries they make or questions that they have in the space provided on their worksheet.

CLOSURE:

- Ask the students to hold on to their worksheets as they will be used during the next class.

ASSESSMENT:

- The students' ability to *infer* the types of plate movements through the manipulation of the computer simulation will be informally assessed through their responses to the driving questions.
- The students' ability to *analyze* how different plates interact with one another through the manipulation of the computer simulation will be informally assessed through their responses to the driving questions.
- The students' ability to *identify* the types of surface features that are formed or destroyed at the different plate boundaries through the manipulation of the computer simulation will be informally assessed through their responses to the driving questions.

IMAGES:

- http://pubs.usgs.gov/gip/dynamic/graphics/Fig1.jpg

Name ____ Date ______________
Driving Questions – Plate Tectonics Period ______

PhET: Plate Tectonics

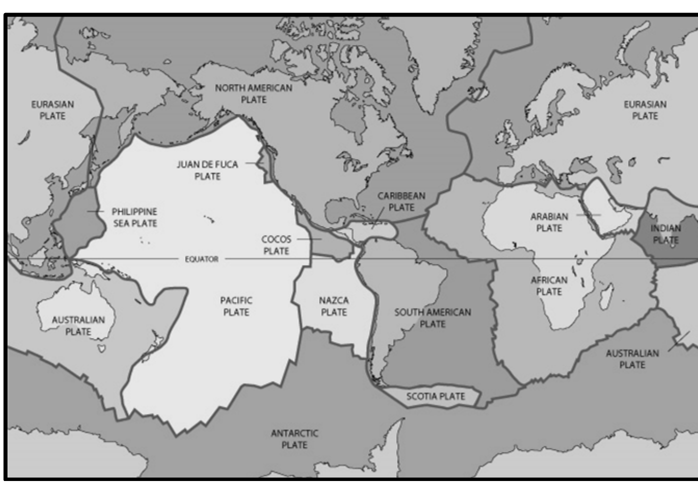
Click on the **Plate Motion** tab at the top of the screen if you're not already there. Check to make sure you are in **Manual Mode** in the box near the top of the screen. Turn on **Labels** and **Seawater** in the view box at the bottom whenever possible.

1. How does a **continental** plate interact with an **oceanic** plate? Are any features created or destroyed?

PREDICTION	FINDINGS

2. How do **two continental** plates interact with each other? Are any features created or destroyed?

PREDICTION	FINDINGS



FUN FACT:

There are currently 8 large plates on Earth and several smaller ones.

3. How do **two oceanic** plates interact with each other? Are any features created or destroyed?

PREDICTION	FINDINGS

FINISHED EARLY?

Freely explore with the simulation on your own. Write down any observations you make in the space below.

DAY 4

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1L** The lithosphere consists of separate plates that ride on the more fluid asthenosphere and move slowly in relationship to one another, creating convergent, divergent, and transform plate boundaries. These motions indicate Earth is a dynamic geologic system.
  - These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.
  - Compared to continental crust, ocean crust is thinner and denser. New ocean crust continues to form at mid-ocean ridges.

OBJECTIVES:

- Students will *infer* the three general motions (convergent, divergent and transform) of tectonic plates from their observations of different plate interactions using a computer simulation. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 18-31**)
- Driving Questions Worksheet
- Plate Motions Notes (**p. 47-49**)

INTRODUCTION:

- Ask the students to pull out their driving questions worksheet from the previous class.
- Explain to the students that they are going to be sharing their observations from their explorations of the computer simulation in the last class in order to figure out the main ways that plates move**.**

LESSON/ACTIVITY:

- Ask the students to share their findings on how a continental plate interacts with an oceanic plate and the features created or destroyed by this interaction. *They should have noticed things such as the convergent motions between the plates and the formation of volcanoes on the land.* Jot down the students' responses on the board (**Slide 18**) as they share.
- Recall the students' attention to the properties of oceanic and continental crust they learned on Day 2.
- Pose the question: Why does the oceanic plate dive down under the continental plate in this case? *it's more dense*
- Ask the students to share their findings on how two continental plates interact and the features created or destroyed by this interaction. *They should have noticed things such as the divergent, transform and convergent motions between the plates, the formation of new*

oceanic crust where the plates spread apart and the formation of mountains where they come together. Jot down the students' responses on the board (**Slide 19**) as they share.

- Ask the students to share their findings on how two oceanic plates interacts and the features created or destroyed by this interaction. *They should have noticed things such as the divergent and transform motions between oceanic plates of the same age and the addition of convergent motion between those of different ages as well as the formation of new oceanic crust where plates spread apart and the formation of volcanic islands when one plate sinks.* Jot down the students' responses on the board (**Slide 20**) as they share.
- Pose the question: Why does an older oceanic plate sink when it comes together with a younger plate? *it's more dense*
- Explain to the students that there are three general ways that plates can move with respect to each other. Ask the students to try to indentify these ways from the observations they made. *The students should recognize that they come together, move apart or slide past each other.*
- Pass out the **Plate Motions Notes** to the students.
- Share the information on the three types of plate motion (**Slides 21-30**) with the students. Make sure to explain how the mantle's convection causes each form of motion (where the mantle rises, divergent boundaries form; where it sinks, convergent boundaries form). The students should fill in the definitions, descriptions and bullets on their notes as they go.

CLOSURE:

- Share the 'Tectonic Plates' map from page 5 of the NYS Earth Science Reference Tables (**Slide 31**) with the students. Explain that the map shows some of the major boundaries and motions between tectonic plates here on Earth.
- Play the video linked to the picture on **Slide 31.** This video is a song that describes some of the basic information about plate tectonics including how mantle convection makes it go.

ASSESSMENT:

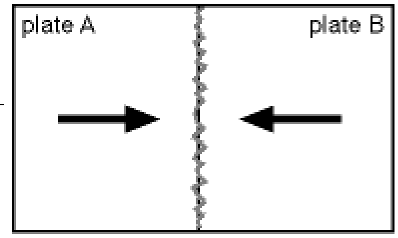
- The students' ability to *infer* the three general motions (convergent, divergent and transform) of tectonic plates from their observations of different plate interactions using a computer simulation will be informally assessed through student responses during class discussions.

IMAGES/VIDEOS:

- http://www.columbia.edu/~vjd1/plate_bounds.gif
- http://hoopmanscience.pbworks.com/f/1348757835/transform_20boundary.jpg
- http://www.geogrify.net/GEO1/Lectures/PlateTectonics/RiftValley.jpg
- http://geology8b-9.wikispaces.com/Plate%20Boundary%20images%20and%20captions
- http://php.auburn.edu/academic/classes/geol/lee/GEOL2100/Dynamic%20Earth/chapter%205/unit%20data_chp%205/etde_unit_5/media/divergent%20boundary.jpg
- http://media-2.web.britannica.com/eb-media/34/3534-004-8B3097CF.jpg
- http://www.youtube.com/watch?v=hhxjAAnwNKM

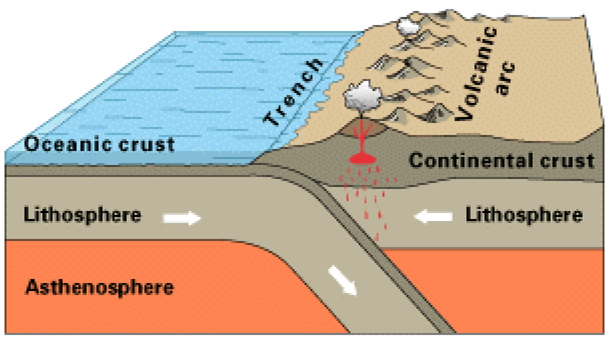
Name ____ Date ______________
Plate Motions Notes Period ______

CONVERGENT BOUNDARIES



DEFINTION:

OCEANIC – CONTINENTAL



CREATES:

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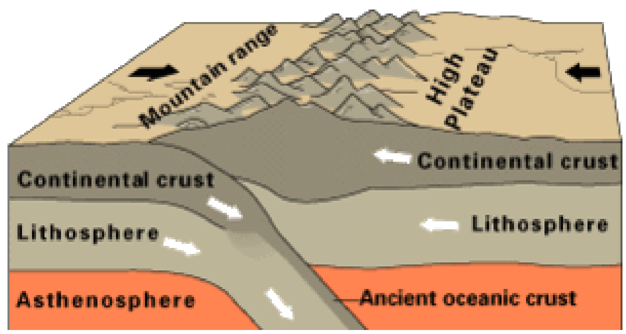
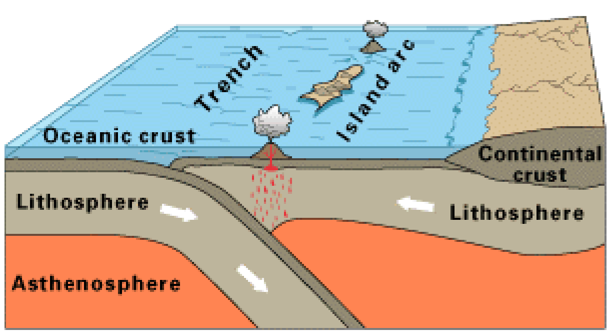
CONTINENTAL – CONTINENTAL



CREATES:

-

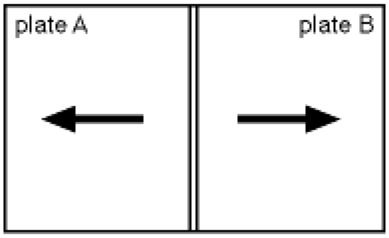
OLD OCEANIC – YOUNG OCEANIC



CREATES:

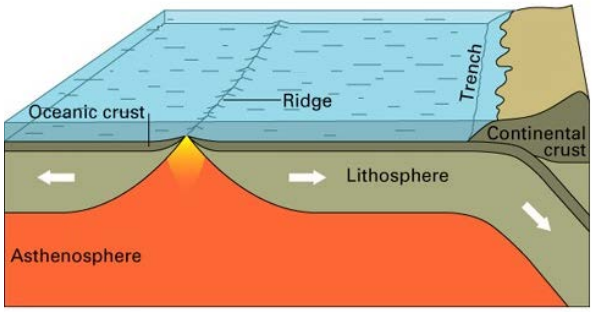
-
-

DIVERGENT BOUNDARIES



DEFINTION:

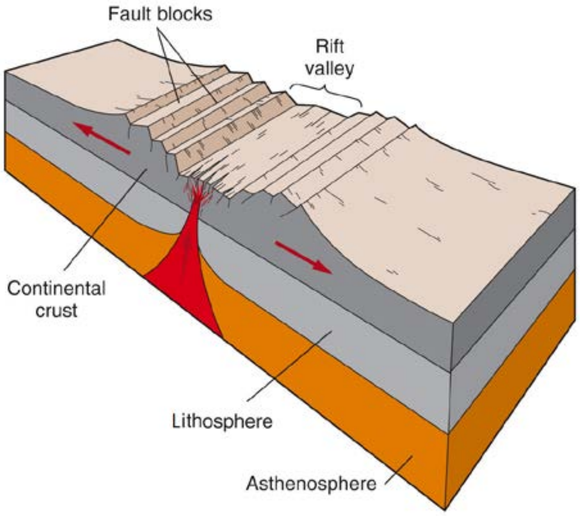
OCEANIC – OCEANIC



CREATES:

-

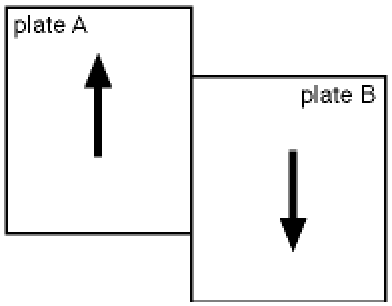
CONITNENTAL – CONTINENTAL



CREATES:

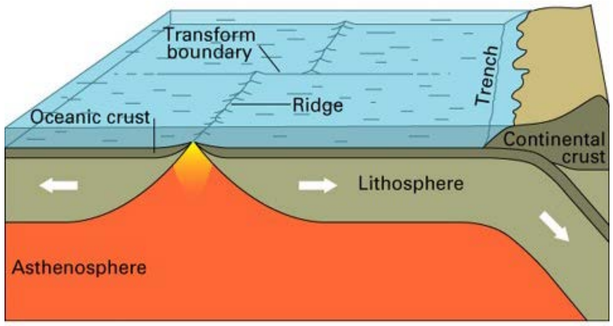
-

TRANSFORM BOUNDARIES



DEFINTION:

OCEANIC – OCEANIC



CREATES:

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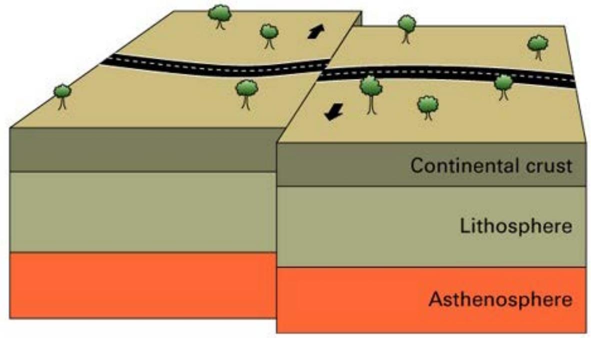
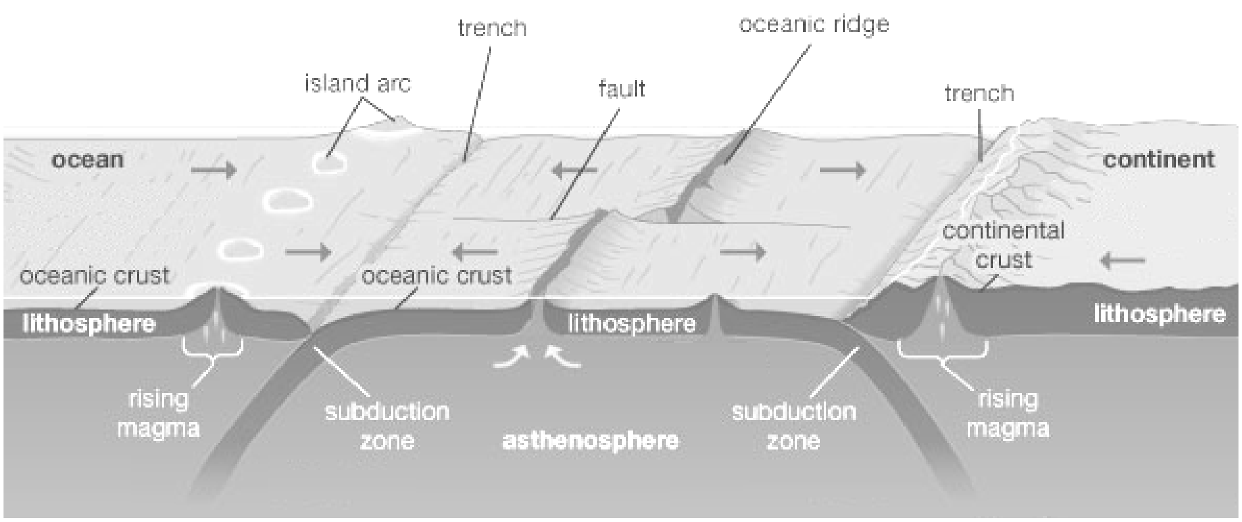
CONITNENTAL – CONTINENTAL



CREATES:

-

Can you label the boundaries?



DAY 5

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1L** The lithosphere consists of separate plates that ride on the more fluid asthenosphere and move slowly in relationship to one another, creating convergent, divergent, and transform plate boundaries. These motions indicate Earth is a dynamic geologic system.
    - These plate boundaries are the sites of most earthquakes, volcanoes, and young mountain ranges.
    - Compared to continental crust, ocean crust is thinner and denser. New ocean crust continues to form at mid-ocean ridges.

COMMON CORE ELA STANDARDS:

WRITING: Grades 9-10

- **7.** Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
- **8.** Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

OBJECTIVES:

- Students will *illustrate* the plate movements occurring at real world locations through annotated drawings. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 32-33**)
- Plate Motions Notes
- Project Guidelines Handout (**p.52-53**)
- Computers
- White Paper
- Colored pencils

INTRODUCTION:

- Ask the students to pull out their Plate Motions Notes from the previous class.
- Bring up the ‘Can You Label the Boundaries?’ image (**Slide 32**) on the board and ask the students to find it on the last page of their notes.
- Give the students a few minutes to try and label the boundaries in their picture. Then go over the answers – 2 convergent boundaries, 1 divergent and 1 transform.

- Explain to the students that evidence of plate tectonics can be found at locations all over the world. Some of the evidence we find is caused by the motions of the plates that currently make up the crust of the Earth. Other evidence can come from the remains of past plates.

LESSON/ACTIVITY:

- Explain to the students that today they will be to researching a location where plates are currently interacting with one another.
- Bring up the list of numbers and their corresponding locations on the board (**Slide 33**):
    - 1 – the Himalayas
    - 2 – the Mid-Atlantic Ridge
    - 3 – the San Andreas Fault
    - 4 – the Japanese Archipelago
    - 5 – the Peru-Chili Trench
- Ask the students to count off by fives. Whatever number they get determines the location they will research.
- Pass out the **Project Guidelines** handout. Ask the students to write down their location in the space provided on their handout.
- Go over the directions with the students and remind them to refer to the rubric as they create their annotated drawings.
- The students will have a few additional days to work on their annotated drawings at home before they are due to give the students enough time to conduct their research and work neatly. Tell the students the due date and ask them to write it in the spot provided on their handout.
- Explain to the students that they have the rest of the class period to use the computers to work on conducting their research. If/when they finish their research they may get started on their drawings. Paper and colored pencils are available for their use.

ASSESSMENT:

- The students' ability to *illustrate* the plate movements occurring at real world locations through annotated drawings will be formally assessed through their final product for this project. A rubric will be used to assess their work.

REFERENCES:

- Pragmatic. *Google Map: Topography of Plate Tectonics*. https://maps.google.com/maps/u/0/ms?msid=202977559498639344429.0004f306429540aff190e&msa=0&dg=feature

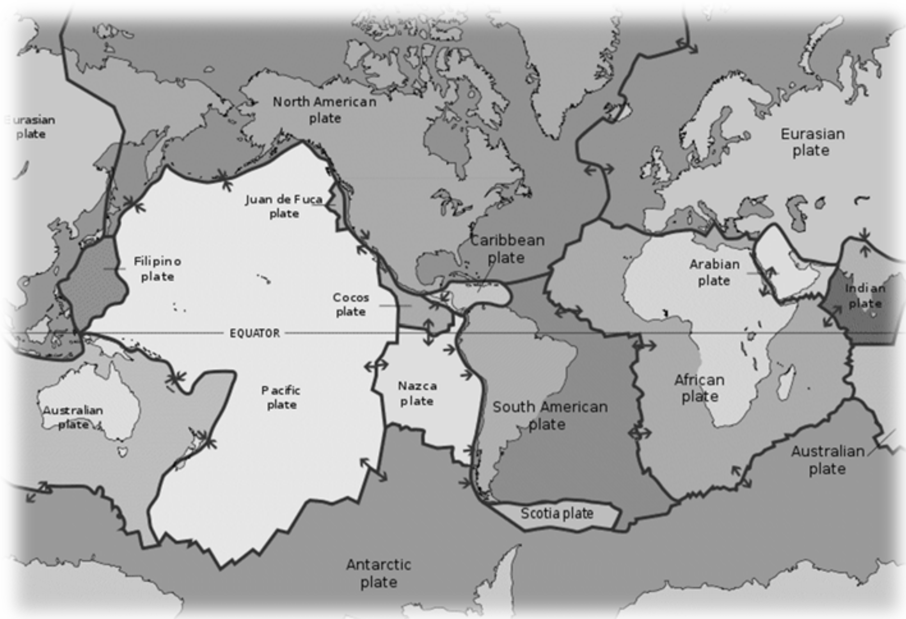
IMAGES:

- http://www.age-of-the-sage.org/tectonic_plates/tectonic_plates_boundaries.gif
- http://www.geosci.usyd.edu.au/users/prey/Teaching/Geol-3101/EReport03/GroupD/Report1/images/subduction.jpg

Name ____ Date ______________
Project Guidelines Period ______

REAL PLATE BOUNDARIES

Due: _______________



My plate boundary location is: ____

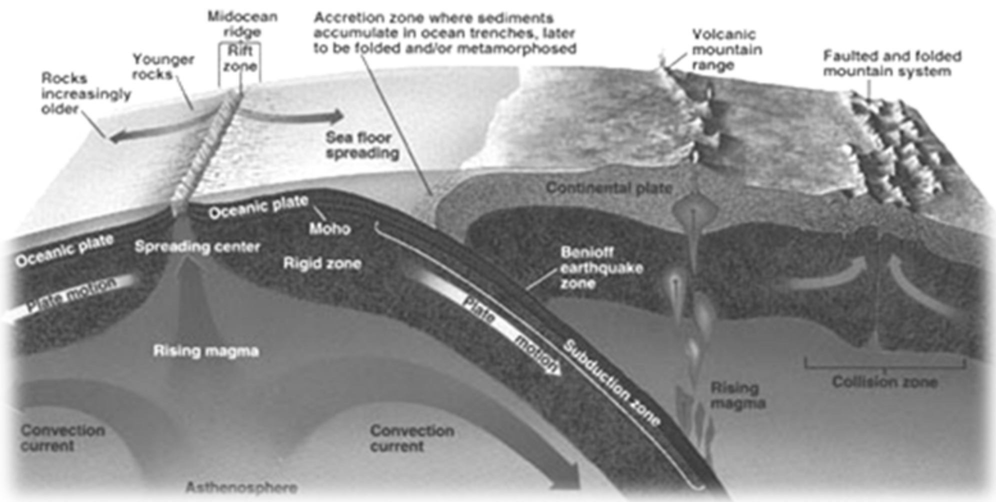
PART I:
Research your plate boundary location using various internet sources (NO Wikipedia!). The guiding questions below will help you to focus your research and clue you in on important information to take notes on. Be sure to write down your sources. You will need to cite them in Part II.

Guiding questions:

1. What type of boundary (convergent, divergent, transform) are you dealing with?
2. What are the names of the plates involved?
3. How exactly are the plates interacting? What is each plate doing? (Is one subducting, are they folding back on themselves, etc.?)
    - Look for details such as the type of crust that makes up the plates, the directions they're moving, their speeds, etc. to add detail to your explanation
4. Are any features (mountains, faults, trenches…) being created by the interaction of your plates? What are their names?

PART II:
On a piece of computer paper, **create an annotated drawing** of your location to the best of your artistic ability! This drawing should include the plates that are producing the boundary and any features created by them.

Remember, an annotated drawing is NOT just a picture. It includes notes and labels that help the viewer to better understand what the picture is showing. Here's an example:



Your annotations must:

- ☐ Identify the names of all plates
- ☐ Identify the type of boundary
- ☐ Provide details that explain exactly how the plates are interacting
- ☐ Identify features created by the boundary (Give their names!)

On your paper, also be sure to:

- ☐ Identify your location
- ☐ Cite your sources on the back

REFER TO THE RUBRIC ON THE NEXT PAGE AS YOU WORK.
FEEL FREE TO ADD COLOR TO YOUR DRAWING. MAKE IT FUN!

RUBRIC

	3	2	1	0
Location			Location **is** identified somewhere on the page	Location **is not** identified
Drawing	Drawing **clearly** depicts the plate boundary. It includes *all* plates involved and *all* features created by their interaction	Drawing **generally** depicts the plate boundary. It includes *all* plates involved and *some* features created by their interaction	Drawing **slightly** depicts the plate boundary. It includes *all* plates involved but *no* features created by their interaction	Drawing **does not** depict the plate boundary.
Plate Names		**All** plates are labeled	**Some** plates are labeled	**No** plates are labeled
Features		**All** features are labeled. Names are used were applicable	**Some** features are labeled. Names are used were applicable	**No** features are labeled
Type of Boundary			Type of boundary **is** identified	Type of boundary **is not** identified
Explanation of Plate Interaction	Annotations provide **many details** that help the viewer to understand how the plates are interacting	Annotations provide **some details** that help the viewer to understand how the plates are interacting	Annotations provide **minimal details** that help the viewer to understand how the plates are interacting	Annotations provide **no details** that help the viewer to understand how the plates are interacting
Neatness/ Legibility		Drawing is **neat** and handwriting **legible**.	*Either* drawing is **sloppy** or handwriting is **illegible**.	Drawing is **sloppy** and handwriting is **illegible**.
Spelling/ Grammar		No more than 1 grammar or spelling errors	2-3 grammar or spelling errors	4 or more grammar or spelling errors
Sources			Sources are cited	Sources are not cited

TOTAL: ___________/ 17

COMMENTS:

GLACIERS UNIT

Overview of Computer Simulation

Title	GLACIERS
Web Address	http://phet.colorado.edu/en/simulation/glaciers
Description	The "Introduction" tab of this simulation allows the user to manipulate the temperature and snowfall in a mountainous region to explore how these factors influence the advancement, retreat and even equilibrium of a glacier. A collection of scientific tools also allows the user to measure factors such as the glacial budget, ice thickness and the speed at which the glacier is moving.
Level of Implicit Scaffolding	High

Rationale

The concept of glacial erosion traditionally presents a challenge for inquiry learning due to the relatively long time scale on which it operates. While something like the retreat of a glacier may be visible in images over the years, it still occurs on time scales much too slow to directly observe within the classroom. In addition, the abrasion and plucking of rocks by glaciers occurs at their base. With a thick layer of ice lying on top of the rock this too is very difficult to observe directly. The simulation by PhET incorporated into this unit speeds up the process of glacial movement and allows the user to take a look inside the glacier.

DAY 1

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1t** Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.
- **2.1u** The natural agents of erosion include:
    - *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, parallel scratches, and grooves in bedrock. Glacial features include moraines, drumlins, kettle lakes, finger lakes, and outwash plains.

OBJECTIVES:

- Students will *compare and contrast* valley glaciers and continental glaciers. (*Analysis*)
- Students will *identify* two differences between a valley glacier and a continental glacier. (*Comprehension*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 35-43**)
- Glaciers Notes (**p.59**)
- Valley and Continental Glaciers Pictures (**p.60-61**)

INTRODUCTION:

- Play the video (from 12:50-16:25) linked to the picture on **Slide 35**. This video clip comes from the BBC show *The Power of the Planet* and discusses ice ages and provides a glimpse at the effect glaciers have on the land over which they flow.
- Explain to the students that while ice may be something we mainly associate with winter weather, especially here in New York State, it is actually one of the major agents of erosion here on Earth. Ice has played a huge role in shaping much of the landscape of North America. Over the next week they will be taking a closer look at this agent of erosion.

LESSON/ACTIVITY:

- Pass out the **Glaciers Notes**.
- Pose the question: What do you think of when you hear the word glacier?
- Share the definition of glacier (**Slide 36**) with the students. They should write the definition in their notes.
- Explain that there are two different types of glaciers: valley glaciers and continental glaciers.
- Bring up the chart (**Slide 37**) for comparing valley and continental glaciers on the board.

- Ask the students to get into groups of 2 or 3 and give each group a copy of the **Valley and Continental Glaciers Pictures**.
- Give the students 2-3 minutes to compare and contrast the glaciers in the two pictures using the T-chart in their notes. Then ask the students to share their observations.
- Add the following information to the chart on the board and ask the students to add anything they are missing to their notes as well.

VALLEY GLACIERS	CONTINENTAL GLACIERS
▪ Form between mountain slopes (confined) ▪ Smaller in size	• Spread over entire land surface (unconfined) • Large in size

- Share the image showing where glaciers form (**Slide 38**) with the students.
- Pose the questions: Broadly speaking, where on the planet do valley glaciers form? Continental glaciers?
- Add the following information to the chart on the board (**Slide 37**) and ask the students to do the same in their notes.

VALLEY GLACIERS	CONTINENTAL GLACIERS
▪ Form at high elevations	• Form at high latitudes

- Explain to the students that a multitude of valley glaciers exist today. They can be found all over the world; even near the equator! However, only two continental glaciers exist today: one covering Greenland and one covering Antarctica.
- Add the following information to the chart on the board and ask the students to do the same in their notes.

VALLEY GLACIERS	CONTINENTAL GLACIERS
▪ Many can be found all over the Earth today	• Only two exist today: one covering Greenland and one covering Antarctica

- Explain to the students that while the extent of glaciers is pretty limited today, there have been many times in Earth's past where large portions of the planet were covered by ice. These periods of time are called ice ages. An ice age is a period of extreme cooling of the Earth. Over the last 2.6 million years, the Earth has gone through multiple ice ages with warmer interglacial periods in-between. The last Ice Age started around 21,000 years ago and lasted for almost 10,000 years. Right now we are in an interglacial period.
- Share the information on ice age (**Slide 39**) with the students. They should add the bold information to their notes.

- Share the image of the extent of the glaciation in North America during the last Ice Age (**Slide 40**) with the students.
- Explain that during the last Ice Age, glaciers expanded to cover a large portion of the Northern Hemisphere due to the cold temperatures. At the height of their extent, the Laurentide ice sheet covered much of North America including almost the entire state of New York!
- Share the information on the Laurentide Ice Sheet (**Slide 41**) with the students. They should add the bold information to their notes.
- Pose the question: How do you get a glacier that is almost 2 miles thick?
- Explain that to figure this out, they need to understand how glaciers form.
- Remind the students that glaciers form at high elevations or latitudes where temperatures are always cold. This means that, unlike here in NY where the snow melts in the spring, any snow that falls will remain all year long. This is a key factor to the formation of a glacier.
- Share the image of the transformation of snow to glacial ice (**Slide 42**) with the students.
- Explain that glacial ice forms in a manner somewhat like making a snowball. Basically you take snow and compact it, making it harder and harder until you get ice. For a glacier this compaction is caused by the weight of new snow that falls on top of old. This process transforms the shape of the snow crystals and squeezes out much of the air that was originally trapped in the snow to produce a dense ice.
- If there is time, play the video (from 5:38-7:56) linked to the picture on **Slide 42**. This video clip from the BBC show *The Power of the Planet* shows the transformation of snow to ice in a cross section of a real glacier.

CLOSURE:

- Ask the students to answer the following question (**Slide 43**) on a separate sheet of paper and submit it as their ticket out the door:
  What are two differences between a valley glacier and a continental glacier?

ASSESSMENT:

- The students' ability to *compare and contrast* valley glaciers and continental glaciers will be informally assessed through student responses during class discussions.
- The students' ability to *identify* two differences between a valley glacier and a continental glacier will be informally assessed through student responses to the exit ticket question.

REFERENCES:

- BBC. Ice Ages. http://www.bbc.co.uk/science/earth/water_and_ice/ice_age
- Erosion. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 467-471). Whitestone, New York: Barron's Educational Series.
- National Geographic. *Ice Sheet.* http://education.nationalgeographic.com/education/encyclopedia/ice-sheet/?ar_a=1

IMAGES:

- http://1.bp.blogspot.com/-WmBFb34CZV8/UNSoXYFJkmI/AAAAAAAAAEI/8bLJ_PGS7U8/s1600/glacier.jpg
- http://cdn4.sci-news.com/images/enlarge/image_1346_2e-Greenland.jpg

Name ____ Date ______________

Glacier Notes Period ______

Glacier (initial defintion)**:** ____

There are two types of glaciers: **valley** glaciers and **continental** glaciers.

VALLEY GLACIERS	CONTINENTAL GLACIERS

Ice Age: ____

During an ice age, ____

____

Last Ice Age - ____

Laurentide Ice Sheet: ____

____

Almost _______________ thick (tall)

VALLEY GLACIER

CONTINENTAL GLACIER

DAY 2

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1t** Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.
- **2.1u** The natural agents of erosion include:
  - *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, parallel scratches, and grooves in bedrock. Glacial features include moraines, drumlins, kettle lakes, finger lakes, and outwash plains.

OBJECTIVES:

- Through the manipulation of the computer simulation, students will:
  - *Identify* the type of glacier present in the simulation. (*Comprehension*)
  - *Infer* how temperature and snowfall influence the advance, retreat and equilibrium of a glacier. (*Analysis*)
  - *Infer* how ice moves within a glacier. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slide 44**)
- Computers
- PhET Glaciers Simulation (http://phet.colorado.edu/en/simulation/glaciers)
- Driving Questions Worksheet (**p.64-66**)

INTRODUCTION:

- Pose the following questions to the class:
  - What is a glacier? *a large mass of ice*
  - What are the two types of glaciers? *valley and continental*
  - How are they different? *see chart from day 1*
  - How does a glacier form? *the compaction of snow*
- Remind the students that glaciers are one of the main agents of erosion here on Earth.
- Explain that today they will be using a computer simulation to begin exploring how glaciers are able to cause this erosion.

LESSON/ACTIVITY:

- Ask the students to get together with a partner and then log on to a computer. They should follow the directions on the board (**Slide 44**) to launch the simulation.
- Give the students 5 minutes to play around with the simulation on their own in order to familiarize themselves with it and to see what they can make it do.
- Once time is up, give each student a copy of the **Driving Questions Worksheet**.

- Ask the students to make predictions about the answers to the questions based on what they already know and/or have discovered from their exploration with the simulation thus far.
- Give the students the remainder of the period to work on answering the driving questions with their partner using the simulation. Any groups that finish prior to the end of class may further explore with the simulation beyond what was addressed in the driving questions. The students should write down any further discoveries they make or questions that they have in the space provided on their worksheet.

CLOSURE:

- Ask the students to hold on to their worksheets as they will be used during the next class.

ASSESSMENT:

- The students' ability to *identify* the type of glacier present in the simulation will be informally assessed through their responses to the driving questions (**#1**).
- The students' ability to *infer* how temperature and snowfall influence the advance, retreat and equilibrium of a glacier will be informally assessed through their responses to the driving questions (**#2-4**).
- The students' ability to *infer* how ice moves within a glacier will be informally assessed through their responses to the driving questions (**#5**).

Name ______________________________________ Date ____________
Driving Questions – Glaciers Period _____

PhET: Glaciers

Click on the **Introduction** tab at the top of the screen if you're not already there. Turn off **Snowfall** in the view box to make things easier to see (anytime you hit the reset all button you will need to turn it off again).

1. What type of glacier appears in the simulation? How can you tell?

TYPE	EVIDENCE

2. How do changes in air temperature affect a glacier?

PREDICTION	FINDINGS

3. How do changes in snowfall affect a glacier?

PREDICTION	FINDINGS

4. What happens to a glacier if the air temperature and snowfall are left unchanged over a period of time?

PREDICTION	FINDINGS

5. Where within a glacier (top, middle, bottom) does the ice move the fastest? The slowest?

PREDICTION	FINDINGS
[**HINT:** You're going to want to break out the drill from your toolbox for this question. Just make sure to pause the glacier's movement before using it. Then hit play.]	

FINISHED EARLY?

Freely explore with the simulation on your own. Write down any observations you make or questions you have in the space below.

DAY 3

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1t** Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.
- **2.1u** The natural agents of erosion include:
  - *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, parallel scratches, and grooves in bedrock. Glacial features include moraines, drumlins, kettle lakes, finger lakes, and outwash plains.

OBJECTIVES:

- Students will *infer* how a glacier can flow while its terminus appears to be stationary. (*Analysis*)
- Students will *predict* the effect that global warming is having on glaciers around the world. (*Application*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 45-49**)
- PhET Glaciers Simulation (http://phet.colorado.edu/en/simulation/glaciers)
- Driving Questions Worksheet
- Glacial Motion Notes (**p.70**)

INTRODUCTION:

- Bring up the PhET Glaciers simulation on the board and ask the students to pull out their driving questions worksheet from the previous class.
- Pass out the **Glacial Motions Notes** to the students.

LESSON/ACTIVITY:

- Ask the students to share their thoughts on the type of glacier that appeared in the simulation and their evidence for why they think that. *They should recognize that the glacier is a valley glacier. Evidence – mountains, high elevation, etc…*
- Ask the students to share their findings on how changes in air temperature affect a glacier. *They should have noticed that an increase in temperature caused the glacier to shrink/move back up the mountain and a decrease caused it to grow/move down the mountain.*
- Ask the students to share their findings on how changes in snowfall affect a glacier. *They should have noticed that an increase in snowfall caused the glacier to grow/move down the mountain and a decrease caused it to shrink/move back up the mountain.*
- Explain that scientists use the words "advance" and "retreat" to describe the glacial movements up and down the mountain that they observed.

- Pose the question: What do you think it mean for a glacier to advance?
- Share the definition of glacial advance (**Slide 45**) with the students. They should add it to their notes.
- Ask the students to think back to their findings from the computer simulation and pose the question: What two conditions would cause a glacier to advance?
- Click the mouse/spacebar to reveal the two conditions that cause a glacier to advance and ask the students to add this information to their notes.
- Pose the question: What do you think it mean for a glacier to retreat?
- Share the definition of glacial retreat (**Slide 46**) with the students. They should add it to their notes.
- Ask the students to think back to their findings from the computer simulation and pose the question: What two conditions would cause a glacier to retreat?
- Click the mouse/spacebar to reveal the two conditions that cause a glacier to retreat and ask the students to add this information to their notes.
- Ask the students to share their findings on what happens to a glacier if air temperature and snowfall are left unchanged over a period of time. *They should have noticed that given enough time the glacier would stop moving up or down the valley. It would appear to be staying in one place.*
- To reinforce this idea, decrease the air temperature in the simulation on the board and allow the glacier to reach the point at which it stops advancing (use the slider to speed up time).
- Pose the questions:
    - Is the glacier completely unmoving at this point? *no*
    - How can you tell? *the black dots in the ice are continuing to move*
- Explain that when we talk about glaciers' advancing and retreating we're referring just to the change in position of their end or terminus. Even when the terminus of a glacier isn't changing position, the glacier itself is still in constant motion due to the nature of ice. Ice behaves like a really thick fluid. It flows, though it does so extremely slowly. It's kind of like molasses or honey but even slower!
- Pose the question: What do you think causes the ice to flow?
- Share the official definition of glacier (**Slide 47**) with the students. They should add it to their notes.
- Remind the students that ice flows differently throughout a glacier.
- Ask the students to share their findings on where within a glacier (top, middle, bottom) the ice moves fastest and slowest. *They should have noticed that the ice flowed the fastest near the top of the glacier and the slowest near the bottom.*
- Explain to the students that the difference in flow speed throughout a glacier is due to friction from the floor of the valley. It slows the ice on the bottom down. The walls of the valley also create friction, so we find the fastest flowing ice near the top and center of a glacier.
- Bring the simulation glacier back up and pose the question: Since we know the ice in a glacier is always flowing, how is it possible for the terminus of this glacier to remain in the same position?

- Explain that when a glacier's terminus is stationary we say that it is in equilibrium. This happens because the end of the glacier is melting as quickly as new ice is forming higher up.
- Share the definition of equilibrium (**Slide 48**) with the students. They should add it to their notes.
- Explain that the advancement and retreat of a glacier as it adjusts to environmental changes in temperature or snowfall plays a major role in shaping the landscape over which it flows. Tomorrow they will begin taking a closer look at the effects of glacial erosion on the land.

CLOSURE:

- Ask the students to answer the following questions (**Slide 49**) on a separate sheet of paper and submit it as their ticket out the door:
    - *The Earth is currently in a state of global warming. What affect do you think this is having on glaciers around the world?*
    - *How is it possible for a glacier to be in constant motion but its end (terminus) to not change position?*

ASSESSMENT:

- The students' ability to *infer* how a glacier can flow while its terminus appears to be stationary will be informally assessed through student responses during class discussion as well as their responses to the exit ticket question.
- The students' ability to *predict* the effect that global warming is having on glaciers around the world will be informally assessed through student responses to the exit ticket question.

RESOURCES:

- Erosion. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 467-471). Whitestone, New York: Barron's Educational Series.

IMAGES:

- http://phet.colorado.edu/en/simulation/glaciers

Name ____ Date ________________
Glacial Movement Notes Period _______

Glacier: ____

____

Advance: ____

____

Glaciers advance when ____

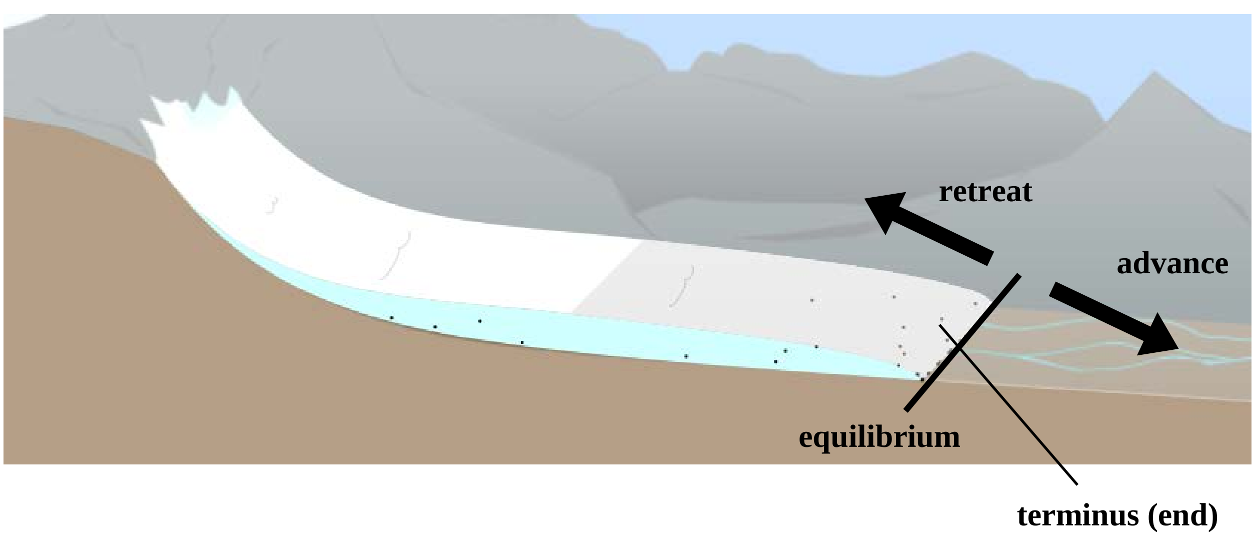
Retreat: ____

____

Glaciers retreat when ____

Equilibrium: ____

____



DAY 4

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1t** Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.
- **2.1u** The natural agents of erosion include:
    - *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, parallel scratches, and grooves in bedrock. Glacial features include moraines, drumlins, kettle lakes, finger lakes, and outwash plains.

OBJECTIVES:

- Students will *discover* some of the features produced by glacial activity through the use of a model. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 50-60**)
- Glacial Features Notes (**p.74-76**)
- Ice Cube Glaciers Activity Sheet (**p.77-78**)
- Paper Bowls
- Cardboard (pieces approximately 6" by 12")
- Play Dough
- Ice cube Glaciers

PREPARATION:

- Add 1 tbs. of a mixture of sand and rock to each spot in an ice cube tray.
- Fill with water and freeze.

INTRODUCTION:

- Share the before and after images of two glaciers (**Slides 50-51**) with the students and ask them to describe what is going on. *the first glacier is advancing, the second is retreating*
- Pose the question: Whether a glacier is advancing, retreating or at equilibrium, what do we know about the ice within the glacier? *it's moving*
- Play the video (from 45:02-46:17) linked to the picture on **Slide 52**. This video clip from the BBC show *The Power of the Planet* shows a time lapse of the glacial flow within a retreating glacier.
- Remind the students that glaciers have played a big role in shaping the landscape of North America as we know it today. Yet, explain that while a glacier flows over land it's not so much the ice itself that does the eroding but all the sediment that the ice picks up along the way.

LESSON/ACTIVITY:

- Play the video linked to the picture on **Slide 53**. This video takes you inside a glacier and provides a look at the bottom of the glacier and all the sediment it carries.
- Explain to the students that the sediment they saw in the ice in the video was picked up through a process called plucking.
- Share the information on plucking (**Slide 54**) with the students. They should add the definition to their notes.
- Explain to the students that they are now going to do a little activity to explore how glaciers erode the land over which they flow.
- Ask the students to get into groups of three and pass out the **Ice Cube Glaciers Activity Sheet**.
- Give the students 10 minutes to work on steps 1-7 in the activity.
- Ask the students to share their observations of the ice cube glaciers (step 4). *They should have noticed that sediment is imbedded in the bottom of the ice, the sediment ranges in size, it looks like the bottom of the glacier in the video, etc…*
- Explain to the students that glaciers leave both erosional and depositional features in their wake.
- Pass out the **Glacial Features Notes** to the students.
- Ask the students to share their observations of their play dough land after dragging the ice cube glacier over it (step 6). *They should have noticed marks in the play dough, sediments left behind, etc…*
- Share the information on striations, grooves, polish and erratic (**Slides 55-59**) with the students. These features are similar to the ones they observed in their play dough/ ice cube model. Add ask the students to add the bulleted information to their notes.
- Give the students a minute or two to observe how their ice cube glacier is melting. They should take notes on what they see on their activity sheet (step 8).
- Pose the question: What happened to the sediments in your ice cube glacier as it melted? *They should have noticed that the sediment came out of the ice, formed piles, etc…*
- Explain to the students that unlike water which sorts the sediments it carries, glaciers tend to leave behind a jumbled mess of all different sized sediment.
- Share the information on till (**Slide 60**) with the students. Add ask them to add the bulleted information to their notes.

CLOSURE:

- Explain to the students that there are several more features that result from the presence of glaciers. They will take a closer look at them in the next class.

ASSESSMENT:

- The students' ability to *discover* some of the features produced by glacial activity through the use of a model will be informally assessed through the observations the students make as they complete the Ice Cube Glaciers activity.

REFERENCES:

- Deposition. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 503-505). Whitestone, New York: Barron's Educational Series.

- Erosion. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 467-471). Whitestone, New York: Barron's Educational Series.
- MSU Science Zone. *What is a Glacier?* http://eu.montana.edu/pdf/outreach/msuscizone28.pdf

IMAGES:

- http://theblondecoyote.files.wordpress.com/2012/08/p7258416.jpg
- http://shoresandislands.files.wordpress.com/2010/08/grooves1.jpg
- http://marlimillerphoto.com/images/Gl-24.jpg
- http://upload.wikimedia.org/wikipedia/commons/b/b9/Erratic_boulder_-_geograph.org.uk_-_194536.jpg
- http://www.yosemite.ca.us/library/geologic_story_of_yosemite/images/60.jpg
- http://www.swisseduc.ch/glaciers/glossary/icons/outwash-plain-axel.jpg
- https://staging.nsidc.org/sites/nsidc.org/files/images/cryosphere/glaciers/gallery/bylot_island_valley_large.jpg
- http://jupiter.plymouth.edu/~sci_ed/Turski/Courses/Earth_Science/Images/4.drumlin.jpg
- http://www.eoearth.org/files/119601_119700/119640/300px-Kettles_lake_canada.jpg
- http://www.drivewaycam.com/fingerlakes2.jpg
- http://www.longpassages.org/images/U%20shaped%20glacier%20carved%20valley.jpg
- http://www.teacherspayteachers.com/Product/Glacier-Project-Weathering-Erosion-Earth-Science-Geography-90183

Name ____ Date ______________

Glacier Features Notes Period ______

Plucking: ____

____

Glaciers leave behind a variety of erosional and depositional features which include:

EROSIONAL

Glacial Striations

- ____
  ____
- ____
  ____
- ____
  ____

Glacial Grooves

- ____
  ____
- ____
  ____
- ____
  ____

Glacial Polish

- ____
  ____
- ____
  ____

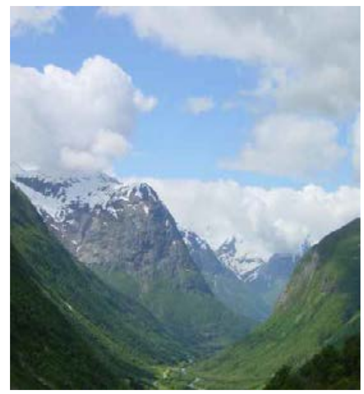
EROSIONAL

Drumlins

- ______________________________
- ______________________________
  ____
- ______________________________
  ____
  ____

U-Shaped Valley

- ______________________________
  ____



DEPOSITIONAL

Erratics

- ______________________________
  ____
- ______________________________
  ____
- ______________________________
  ____

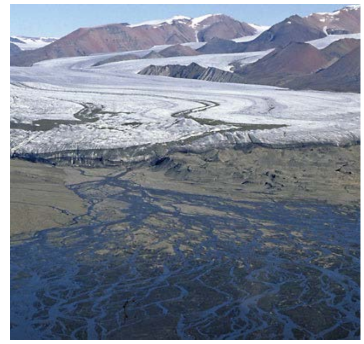
Till (Unsorted Deposits)

- ____
  ____
- ____
  ____

DEPOSTITIONAL

Outwash Plain

- ______________________________
- ______________________________



Moraine

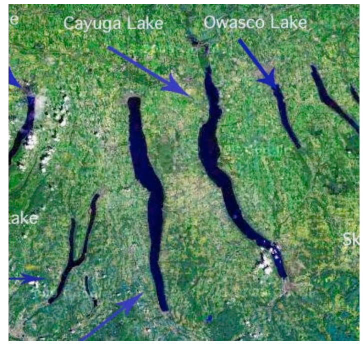
- ______________________________
- ______________________________
- ______________________________
- ______________________________
- ______________________________

Kettle Lake

- ______________________________
- ______________________________
- ______________________________

Finger Lake

- ____________________
- ____________________
  ____
  ____



Name ____ Date ______________
Ice Cube Glaciers Activity Sheet Period ______

ICE CUBE GLACIERS

MATERIALS:

- Paper bowl
- Cardboard
- Play dough
- Ice cube

DIRECTIONS:

1. Take the play dough and spread it out (not too thin!) on the piece of cardboard. The play dough will represent the land in this model.
2. Obtain an ice cube glacier from your teacher.
3. Take a minute as a group to observe your glacier (It's ok if it starts to melt. It will actually make step 4 more realistic!). Record your observations below:

4. Drag the ice cube (dirty side down) very slowly across the play dough, applying a bit of pressure.
5. Place the ice cube in your paper bowl and leave it alone!
6. Take a look at how the glacier affected your land. Record your observations below:

7. Now that your glacier has had a few minutes to melt, observe what is happening to the ice and the sediments within it. Record your observations below:

8. Come back to your glacier later in class to observe its melting progress! Record your observations below:

DAY 5

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.1t** Natural agents of erosion, generally driven by gravity, remove, transport, and deposit weathered rock particles. Each agent of erosion produces distinctive changes in the material that it transports and creates characteristic surface features and landscapes. In certain erosional situations, loss of property, personal injury, and loss of life can be reduced by effective emergency preparedness.
- **2.1u** The natural agents of erosion include:
    - *Glaciers (moving ice):* Glacial erosional processes include the formation of U-shaped valleys, parallel scratches, and grooves in bedrock. Glacial features include moraines, drumlins, kettle lakes, finger lakes, and outwash plains.

OBJECTIVES:

- Students will *design* a travel brochure highlighting glacial features from around North America. (*Synthesis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 61-72**)
- Student Whiteboards
- Dry Erase Markers
- Glacial Features Notes
- PhET Glaciers Simulation (http://phet.colorado.edu/en/simulation/glaciers)
- Glacial Tour of North America Project Guidelines (**p.82-83**)
- Computers

INTRODUCTION:

- Ask each student to grab a whiteboard and a dry erase marker.
- Share the images of the glacial features (**Slides 61-65**) with the students. Ask them to name the feature and to identify whether it is an erosional or depositional feature on their whiteboards.
    - #1 – *erratic, depositional*
    - #2 – *glacial polish, erosional*
    - #3 – *glacial striations, erosional*
    - #4 – *till, depositional*
    - #5 – *glacial grooves, erosional*
- Remind the students that there are several more features produced by glaciers that they are going to take a look at. Two of them they probably already observed in the PhET Glaciers simulation.

LESSON/ACTIVITY:

- Ask the students to pull out their **Glacial Features Notes** from the previous class.

- Pull up the PhET Glaciers simulation on the board and point out the stream flowing down slope from the glacier.
- Explain that meltwater from a glacier tends to form streams at its front end. These streams carry sediment away from the glacier.
- Pose the question: As the streams slow down, what happens to the sediment they are carrying? *it is deposited*
- Share the information on Outwash Plains (**Slide 66**) with the students. Ask them to add the bulleted information to their notes.
- Return to the simulation. A good pile of sediment should have formed at the front edge of the glacier.
- Pose the question: What do the black dots represent? *sediment*
- Make the glacier in the simulation retreat so that the pile of sediment becomes exposed.
- Explain to the students that the line of black dots they are seeing at the end of the glacier represents a moraine.
- Share the information on Moraines (**Slide 67**) with the students. Ask them to add the bulleted information to their notes. Point out the lateral and terminal moraines in the picture.
- Share the information on Drumlins, Kettle Lakes and Finger Lakes (**Slides 68-70**) with the students. Add ask them to add the bulleted information to their notes.
- Explain to the students that one final major clue of glacial activity comes from the shape of a valley.
- Share the information on U-Shaped Valleys (**Slide 71**) with the students. Ask them to add the bulleted information to their notes.
- Share the images of a V-shaped valley carved by a stream and a U-shaped valley carved by a glacier (**Slide 72**).
- Explain that a glacier doesn't flow as fluidly as a stream. Since it prefers to follow a straighter path, it eventually just plows through anything that comes in its way. A valley glacier actually cuts away at the walls of the valley as it flows down slope. This creates a U-shaped valley.
- Play the video (from 17:25-18:10) linked to the U-shaped valley picture on **Slide 72**. This video clip from the BBC show *The Power of the Planet* shows the transformation of a V-shaped valley to a U-shaped valley.
- Pass out the **Glacial Tour of North America Project Guidelines**.
- Go over the directions with the students and remind them to refer to the rubric as they create their brochures.
- The students will have a few additional days to work on their brochures at home before they are due to give the students enough time to conduct their research and work neatly. Ask the students to write the due date in the spot provided on their project sheet.
- Explain to the students that they have the rest of the class period to begin working on their brochures.

ASSESSMENT:

- The students' ability to *design* a travel brochure highlighting glacial features from around North America will be formally assessed through their final product for this project. A rubric will be used to assess their work.

REFERENCES:

- Deposition. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 503-505). Whitestone, New York: Barron's Educational Series.
- Erosion. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 467-471). Whitestone, New York: Barron's Educational Series.
- Williams, Addie. *Glacier Research Project*. http://www.teacherspayteachers.com/Product/Glacier-Project-Weathering-Erosion-Earth-Science-Geography-90183

IMAGES:

- http://unravellinggenesis.com/picture-gallery/

Name ______________________________ Date ______________
Project Guidelines Period ______

GLACIAL TOUR
of North America

Due: _______________

YOUR TASK: Create a travel brochure highlighting **spectacular** glacial features across the North American continent.

GLACIAL FEATURES
Glacial Striations
Glacial Grooves
Glacial Polish
U-shaped Valley
Drumlin
Moraine (terminal or lateral)
Kettle Lake
Finger Lake

YOUR BROCHURE SHOULD INCLUDE:

- A short blurb informing tourists about the last Ice Age and the ice sheet that covered North America
- A map of North America – mark the locations of the features you pick on it so tourists can easily see where they are!
- For each glacial feature listed in the chart to the left:
  - The name of the feature
  - The location of your feature (City, State/Province)
  - A brief description of what it is and how it formed
  - A picture of the feature

EXAMPLE:

ESKER

Artillery Lake, North West Territories, Canada

Eskers are winding ridges of sediment. They are deposited by streams flowing through tunnels in a glacier

REFER TO THE RUBRIC BELOW AS YOU WORK.
MAKE IT FUN!

GLACIAL TOUR OF NORTH AMERICA RUBRIC	
	Blurb about the last Ice Age and the North American ice sheet (3 points) * When was it? What was the name of the ice sheet? How far did it reach? Etc…
	Locations of your features marked on a map of North America (1 point each)
	Feature Name (1 points each)
	Location of feature (1 point each)
	Brief description of feature and how it formed (2 points each)
	Picture of feature (1 point each)
	Legible Writing (2 points)
	Spelling (2 points) * Full credit = no more than 2 mistakes
	TOTAL (out of 55)

COMMENTS:

GREENHOUSE EFFECT UNIT

Overview of Computer Simulation

Title	THE GREENHOUSE EFFECT
Web Address	http://phet.colorado.edu/en/simulation/greenhouse
Description	This simulation contains three tabs. The first tab, *Greenhouse Effect*, allows the user to manipulate the concentration of greenhouse gases within the atmosphere and the amount of cloud cover to explore how these factors effect global temperature. The second tab, *Glass Layers*, allows the user to explore how the glass panes of a greenhouse affect the temperature within. The third tab, *Photon Absorption*, allows the user to test how different atmospheric gases interact with visible and infrared radiation in order to determine which are greenhouse gases and which are not.
Level of Implicit Scaffolding	High

Rationale

The concept of the greenhouse effect traditionally presents a challenge for inquiry due to the invisible nature of its components. Both the greenhouse gases and the radiation that produce this effect cannot be seen by the naked eye making it much more challenging for students to comprehend. Between all three tabs, the simulation by PhET incorporated into this unit makes visible both the visible and infrared radiation involved in this process as well as how these types of radiation interact with different atmospheric gases, particularly the greenhouse ones.

DAY 1

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.2d** Temperature and precipitation patterns are altered by:
  - Human influences including deforestation, urbanization, and the production of greenhouse gases such as carbon dioxide and methane.

OBJECTIVES:

- Students will *examine* how a greenhouse works. (*Analysis*)
- Students will *explain* why the inside of a car becomes hotter than the air outside after sitting in the sun. (*Comprehension*)

MATERIALS:

- Glass Bowl
- 2 Thermometers
- PowerPoint for Simulation Enhanced Units (**Slides 74-80**)
- Greenhouse Notes Sheet (**p.89**)
- PhET Greenhouse Effect Simulation (http://phet.colorado.edu/en/simulation/greenhouse)

PREPARATION:

- Create a simple greenhouse model outside by placing a thermometer under a glass bowl in a grassy area exposed to the sun.
- Place the other thermometer on the grass outside the bowl.

INTRODUCTION:

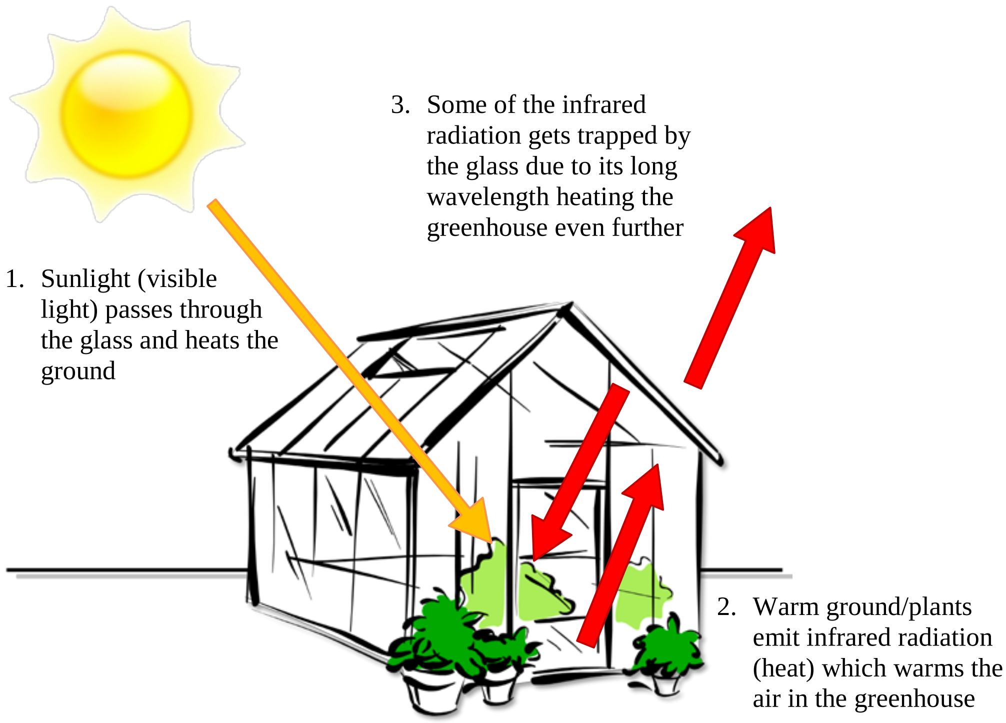
- Share the image of Mars (**Slide 74**) and ask the students to share what they know about the planet's climate.
- Explain that Mars is cold (average global temperature = -80°F), dry (no liquid water exists on its surface) and barren (no plants). Its winds create swirling dust storms that can engulf the whole planet. It's a lot like a desert here on Earth except that it's cold.
- Share the image of ancient Mars (**Slide 75**) and explain that Mars was a very different place 4 billion years ago. Ask the students to share what they notice about ancient Mars.
- Explain that Mars used to be a lot like Earth is today. It was warm and wet. It had rivers, lakes and oceans filled with liquid water. It may have even supported microbial life.
- Explain that Mars transformed into the planet we know today because of the loss of much of its atmosphere. Scientists aren't entirely sure how this happened – it may have been stripped away by solar wind or absorbed by the planet's surface and locked away in rocks. Either way, what happened to Mars shows us just how important an atmosphere and more specifically a process known as the Greenhouse Effect are to life here on Earth. (**Slide 76**).

- Explain to the students that over the next 5 days they will be talking a closer look at the Greenhouse Effect. Exploring what a greenhouse is and how it works is a good place to start since it's part of the name.

LESSON/ACTIVITY:

- Pass out the **Greenhouse Notes**.
- Pose the following questions: What is a greenhouse? What is its purpose?
- Based on student responses to the previous questions, add a description for greenhouse to the students' notes (**Slide 77**).
- Take the students outside to observe the greenhouse model. Explain that it was set up earlier in the day so it has had some time to sit in the sun.
- Ask the students to predict how the temperatures on the two thermometers will compare.
- Have two students read the temperatures on the thermometers. [Don't lift the bowl – read the thermometer through the glass]
- Pose the following questions:
    - Why do you think the temperature under the bowl is warmer?
    - What could be causing that to happen?
- Take the students back inside and pull up the PhET Greenhouse Effect simulation on the board. Click on the **Glass Layers** tab.
- Point out to the students the two types of photon, or light particles, that appear in the simulation: sunlight photons (yellow) and infrared photons (red).
- Share the image of the electromagnetic spectrum (**Slide 78**) with the students. Explain that the sun radiates energy from across the entire electromagnetic spectrum. Our atmosphere blocks most of this radiation from reaching the Earth's surface. Only visible light and radio waves have an easy time getting through though some ultraviolet and infrared radiation does manage.
- Explain that the sunlight photons in the simulation represent visible light and that the infrared photons are heat energy.
- Pose the question: How does the wavelength of infrared radiation compare to visible light? *it's longer*
- Hit the play button on the simulation and allow the students to observe what is happening with the photons. Ask the students to share what they see.
- Explain that the sunlight photons are being absorbed by the ground, causing it to warm up. The warm ground then reemits the energy in the form of heat/infrared photons. Right now that heat is just floating off to space.
- Add a glass pane to the simulation and allow the students to observe what happens.
- Ask the students to share what they observed. Use the flowing questions if necessary to prompt their sharing/discussion:
    - What happened to the temperature? *went up a lot*
    - What happened to the sunlight photons? *passed through the glass*
    - What happened to the infrared photons? *some bounced off the glass and back towards the Earth, they were reabsorbed, others passed through the glass*
- Pose the question: Based on what you've seen, how would you say a greenhouse works? *The students should recognize that the glass of a greenhouse traps some of the infrared radiation from the Earth within it causing temperature to heat up*

- Complete the annotated drawing on the students' notes sheet (**Slide 79**) as follows:



CLOSURE:

- Ask the students to answer the following question (**Slide 80**) on a separate sheet of paper and submit it as their ticket out the door:
  When you get into a car that's been sitting in the sun on a summer day, you find that it is stifling hot! Explain why the inside of the car feels so much warmer than the air outside.

ASSESSMENT:

- The students' ability to *examine* how a greenhouse works will be informally assessed through student responses during class discussion.
- The students' ability to *explain* why the inside of a car becomes hotter than the air outside after sitting in the sun will be informally assessed through student responses to the exit ticket question.

REFERENCES:

- NASA (a). *Goal 2: Characterize the Climate of Mars.* http://mars.nasa.gov/programmissions/science/goal2/
- NASA (b). *What Happened to Mars? A Planetary Mystery.* http://science.nasa.gov/science-news/science-at-nasa/2013/12nov_maven/
- Schlumberger Excellence in Education Development (SEED), Inc. *SEED Science Laboratory Activity – The Greenhouse Effect: Warming the Earth*. http://www.planetseed.com/laboratory/greenhouse-effect-warming-earth
- Sharp, T. (2012). *Mars' Atmosphere: Composition, Climate & Weather*. http://www.space.com/16903-mars-atmosphere-climate-weather.html

IMAGES:

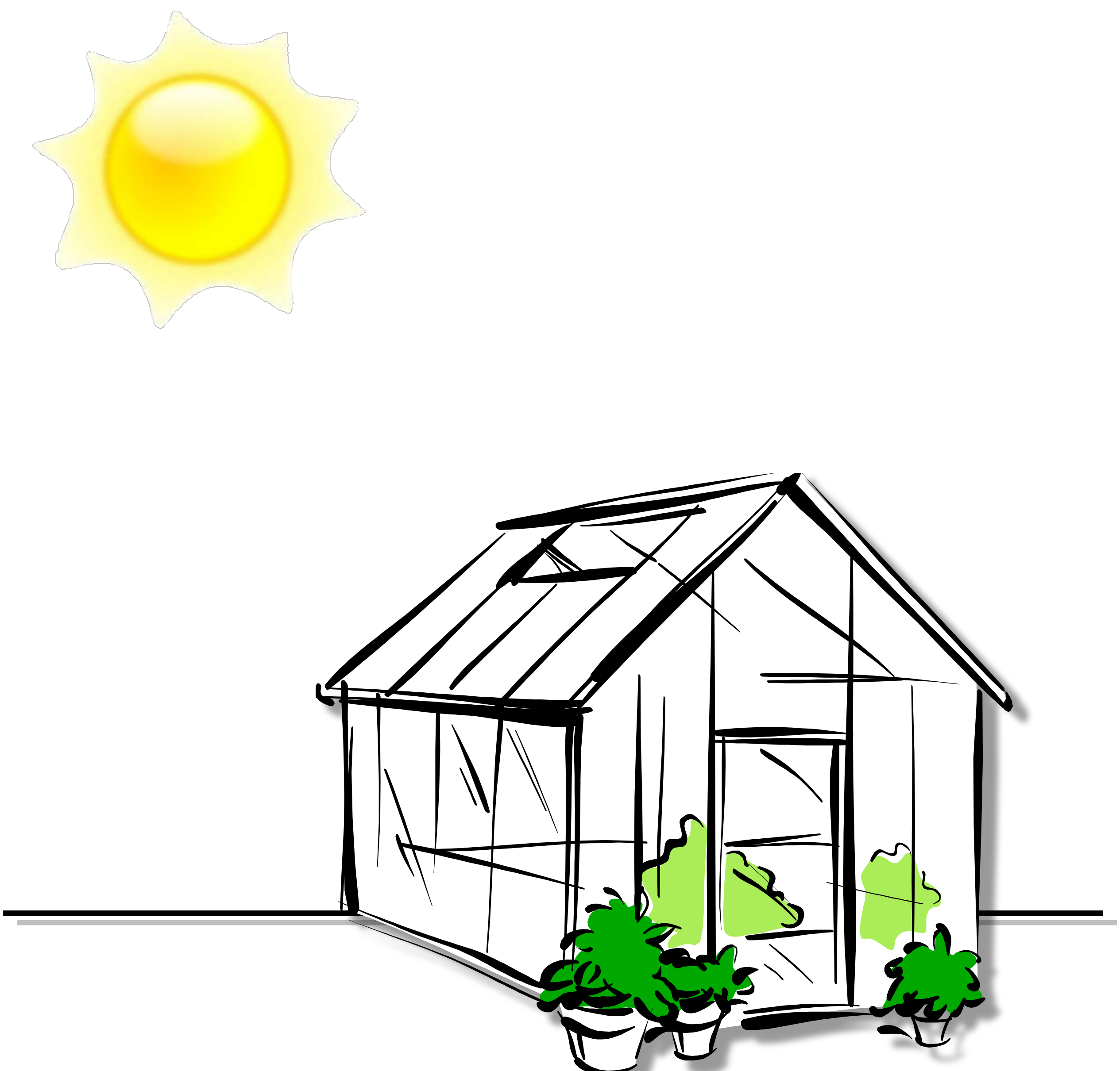
- http://images.all-free-download.com/images/graphiclarge/sun_rays_clip_art_25762.jpg
- Microsoft Clip Art

Name ______________________________________ Date ____________

Greenhouse Notes Period ______

WHAT IS A GREENHOUSE?

HOW DOES IT WORK?



DAY 2

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.2d** Temperature and precipitation patterns are altered by:
  - Human influences including deforestation, urbanization, and the production of greenhouse gases such as carbon dioxide and methane.

OBJECTIVES:

- Through the manipulation of the computer simulation, students will:
  - *Infer* which atmospheric gases are greenhouse gases. (*Analysis*)
  - *Analyze* how the concentration of greenhouse gases in the atmosphere affects photon behavior and temperature. (*Analysis*)
  - *Analyze* how clouds affect photon behavior and temperature. (*Analysis*)
  - *Describe* how conditions on Earth have changed over time due to the greenhouse effect. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slide 81**)
- Computers
- Driving Questions Worksheet (**p.92-94**)
- PhET Greenhouse Effect Simulation (http://phet.colorado.edu/en/simulation/greenhouse)

INTRODUCTION:

- Go over the exit ticket question from the previous class with the students. *Visible light passes through the car's windows and heats the interior surfaces. The warm interior surfaces heat the air in the car and give off infrared radiation. Some of this infrared radiation is trapped by the windows due to its long wavelength causing the car to heat up even more. It works just like a greenhouse.*
- Remind the students that the Earth experiences a process known as the Greenhouse Effect. Life as we know it could not exist on Earth without it.
- Explain to the students that today it will be their job to discover how the Greenhouse Effect works through the use of a computer simulation.

LESSON/ACTIVITY:

- Ask the students to get together with a partner and then log on to a computer. They should follow the directions on the board (**Slide 81**) to launch the simulation.
- Give the students 5 minutes to play around with the simulation on their own in order to familiarize themselves with it and to see what they can make it do.
- Once time is up, give each student a copy of the driving questions worksheet.
- Ask the students to make predictions about the answers to the questions based on what they already know and/or have discovered from their exploration with the simulation thus far.

- Give the students the remainder of the period to work on answering the driving questions with their partner using the simulation. Any groups that finish prior to the end of class may further explore with the simulation beyond what was addressed in the driving questions. The students should write down any further discoveries they make or questions that they have in the space provided on their worksheet.

CLOSURE:

- Ask the students to hold on to their worksheets as they will be used during the next class.

ASSESSMENT:

- The students' ability to *infer* which atmospheric gases are greenhouse gases will be informally assessed through their responses to the driving questions (**#1-2**).
- The students' ability to *analyze* how the concentration of greenhouse gases in the atmosphere affects photon behavior and temperature will be informally assessed through their responses to the driving questions (**#3-4**).
- The students' ability to *analyze* how clouds affect photon behavior and temperature will be informally assessed through their responses to the driving questions (**#5**).
- The students' ability to *describe* how conditions on Earth have changed over time due to the greenhouse effect will be informally assessed through their responses to the driving questions (**#6**).

REFERENCES:

- PhET. The Greenhouse Effect – Teaching Resources. http://phet.colorado.edu/en/simulation/greenhouse

Name ____ Date ______________
Driving Questions – Greenhouse Effect Period ______

PhET: Greenhouse Effect

PART I: Click on the **Photon Absorption** tab at the top of the screen if you're not already there.

1. How do infrared photons interact with the atmospheric gases (CH_4, CO_2, H_2O, N_2, O_2)? Visible light photons?

PREDICTION	FINDINGS
[**HINT:** To make the photons start firing you need to move the slider on the flashlight]	

2. Greenhouse gases are responsible for the Greenhouse Effect. Based on your observations from question #1, which atmospheric gases do you think are greenhouse gases?

PREDICTION	FINDINGS

PART II: Click on the **Greenhouse Effect** tab at the top of the screen.

3. How does the concentration of greenhouse gases in the atmosphere affect the behavior of the photons (visible and infrared)?

PREDICTION	FINDINGS

4. How does the concentration of greenhouse gases in the atmosphere affect the temperature?

PREDICTION	FINDINGS

5. How do clouds affect the behavior of the photons (visible and infrared)? The temperature?

PREDICTION	FINDINGS

6. How have conditions on Earth changed over time (Ice Age → 1750 → Today) due to the Greenhouse Effect?

PREDICTION	FINDINGS

FINISHED EARLY?

Freely explore with the simulation on your own. Write down any observations you make in the space below.

DAY 3

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.2d** Temperature and precipitation patterns are altered by:
  - Human influences including deforestation, urbanization, and the production of greenhouse gases such as carbon dioxide and methane.

OBJECTIVES:

- Students will *infer* how increasing the concentration of greenhouse gases in the atmosphere causes temperatures to rise. (*Analysis*)
- Students will *illustrate* how the greenhouse effect works. (*Application*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (Slides 82-83)
- Driving Questions Worksheet
- PhET Greenhouse Effect Simulation (http://phet.colorado.edu/en/simulation/greenhouse)
- Greenhouse Effect Notes (**p.98**)
- Exit Ticket (**p.99**)

INTRODUCTION:

- Bring up the PhET Greenhouse Effect simulation on the board and ask the students to pull out their driving questions worksheet from the previous class.
- Pass out the **Greenhouse Effect Notes**.

LESSON/ACTIVITY:

- Ask the students to share their findings on the interaction between visible light photons and atmospheric gases. *They should have noticed that the visible light photons passed right through the gases.*
- Explain that just like the glass in a greenhouse, the atmosphere is transparent to the incoming visible light from the sun. The gases allow the light to pass through and reach the Earth's surface.
- Ask the students to share their findings on the interaction between infrared photons and atmospheric gases. *They should have noticed that the* N_2 *and* O_2 *let them pass right through yet the* CO_2, CH_4 *and* H_2O *molecules absorbed the infrared photons and then shot them back out.*
- Remind the students that greenhouse gases are responsible for producing the Greenhouse Effect and pose the question: Which atmospheric gases from the simulation do you think are greenhouse gases? Why?
- Pose the question: What is a greenhouse gas? How could we define it?
- Complete the first two bullets in the students' notes as follows (**Slide 82**):
  - Student definition for greenhouse gas

    - List of greenhouse gases: carbon dioxide (CO_2), methane (CH_4), water vapor (H_20), nitrous oxide (N_2O), CFC's
- **S**hare the atmospheric composition chart for Earth and Mars (**Slide 83**) with the students.
- Pose the following questions:
    - What do you notice about the percentage of greenhouse gases in Earth's atmosphere? In Mars' atmosphere?
    - If Mars' atmosphere is composed largely of a greenhouse gas, why is it not warmer?
- Explain to the students that the volume of Mars' atmosphere is much smaller than Earth's. So while it may look like Mars' atmosphere has a lot of CO_2, its total volume isn't actually all that large. It is, however, larger than the volume of CO_2 in Earth's atmosphere.
- Explain that the amount of greenhouse gases in an atmosphere isn't the only factor that plays a role in producing the greenhouse effect. Mars' atmosphere is also very thin, which means that its molecules are spaced much further apart than here on Earth. Between the thinness of the atmosphere and relatively small volume of greenhouse gases available, Mars' atmosphere is not very effective at hanging on to heat. So while the percentage of greenhouse gases in our atmosphere might seem pretty small, together with our thick atmosphere they produce an effect that makes Earth comfortable for life**.**
- Complete the remaining two bullets in the students' notes as follows (**Slide 82**):
    - Make up a small portion of the atmosphere's volume
    - Together with Earth's thick atmosphere they produce the Greenhouse Effect
- Ask the students to share their findings on how the concentration of greenhouse gases in the atmosphere affects the behavior of the photons. *They should have noticed that it had no effect on the visible light but that the higher the concentration, the more infrared photons there were near the surface of the Earth and the more infrared photons there were being bounced back towards the Earth.*
- Explain that since greenhouse gases absorb and reemit infrared radiation, increasing their concentration in the atmosphere results in more infrared radiation making its way back to the surface. The gases essentially trap the infrared radiation near the surface of the Earth. [Demonstrate using the simulation on the board]
- Ask the students to share their findings on how the concentration of greenhouse gases in the atmosphere affects the temperature of the Earth. *They should have noticed that the higher the concentration, the warmer the temperature got.*
- Pose the question: Why would increasing the concentration of greenhouse gases cause the temperature to rise?
- Explain to the students that when the greenhouse gases absorb the infrared radiation it heats up the atmosphere. This causes the molecules to reemit the radiation. Some of this radiation makes its way back to the surface where it is reabsorbed. This causes even further heating and therefore a rise in temperature.
- Ask the students to share their findings on how clouds affected the behavior of the photons. *They should have noticed that the clouds caused some of the visible light to be reflected back to space. They also caused some of the infrared particles to be bounced back towards the Earth.*
- Ask the students to share their findings on how clouds affected the temperature. *They should have noticed that the most cloud cover caused a cooling effect.*

- Explain to the students that while the clouds may not have produced an effect right away or might have caused a slight warming at first, over long periods of time they produce a cooling effect. This is because clouds have a relatively high albedo, meaning that they are able to reflect some incoming solar radiation back to space. While they do trap infrared radiation near the surface of the Earth, over time they can limit the amount of visible light reaching the Earth's surface. Less visible light means less heating of the surface and therefore less infrared radiation being emitted. With less infrared radiation to be trapped, temperatures drop. [Demonstrate using the simulation on the board]

CLOSURE:

- Pass out the **Exit Ticket** to the students.
- Ask the students to create an annotated drawing of how they think the Greenhouse Effect works and submit it as their ticket out the door.

ASSESSMENT:

- The students' ability to *infer* how increasing the concentration of greenhouse gases in the atmosphere causes temperatures to rise will be informally assessed through student responses during class discussion.
- The students' ability to *illustrate* how the greenhouse effect works will be informally assessed through their exit ticket pictures.

RESOURCES:

- Kidger, M. (2005). A Poor Greenhouse. In *Astronomical Enigmas: Life on Mars, the Star of Bethlehem, and Other Milky Way Mysteries* (pp. 218-219). Baltimore: John Hopkins University Press. http://books.google.com/books?id=DKYJaBd-znAC&pg=PA218&lpg=PA218&dq=why+does+mars+have+a+poor+greenhouse+effect&source=bl&ots=RJ_5Y6tKk0&sig=FHRp8Bi2T3SrJQAGyiHrRegV9fA&hl=en&sa=X&ei=i9A2VIKBBvbIsASc3oKYBQ&ved=0CCwQ6AEwAg#v=onepage&q=why%20does%20mars%20have%20a%20poor%20greenhouse%20effect&f=false

IMAGES:

- http://images.all-free-download.com/images/graphiclarge/earth_clip_art_23263.jpg
- http://images.all-free-download.com/images/graphiclarge/sun_rays_clip_art_25762.jpg

Name ____ Date ____________
Greenhouse Effect Notes Period _____

The Greenhouse Effect

GREENHOUSE GASES

-
-
-
-

HOW DOES THE GREENHOUSE EFFECT WORK?

Name ____ Period ______

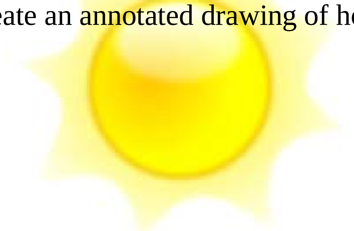
Greenhouse Effect Exit Ticket

Create an annotated drawing of how you think the Greenhouse Effect works using the picture below.

Name ____ Period ______

Greenhouse Effect Exit Ticket

Create an annotated drawing of how you think the Greenhouse Effect works using the picture below.



DAY 4

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.2d** Temperature and precipitation patterns are altered by:
  - Human influences including deforestation, urbanization, and the production of greenhouse gases such as carbon dioxide and methane.

OBJECTIVES:

- Students will *describe* how the runaway greenhouse effect works. (*Comprehension*)

MATERIALS:

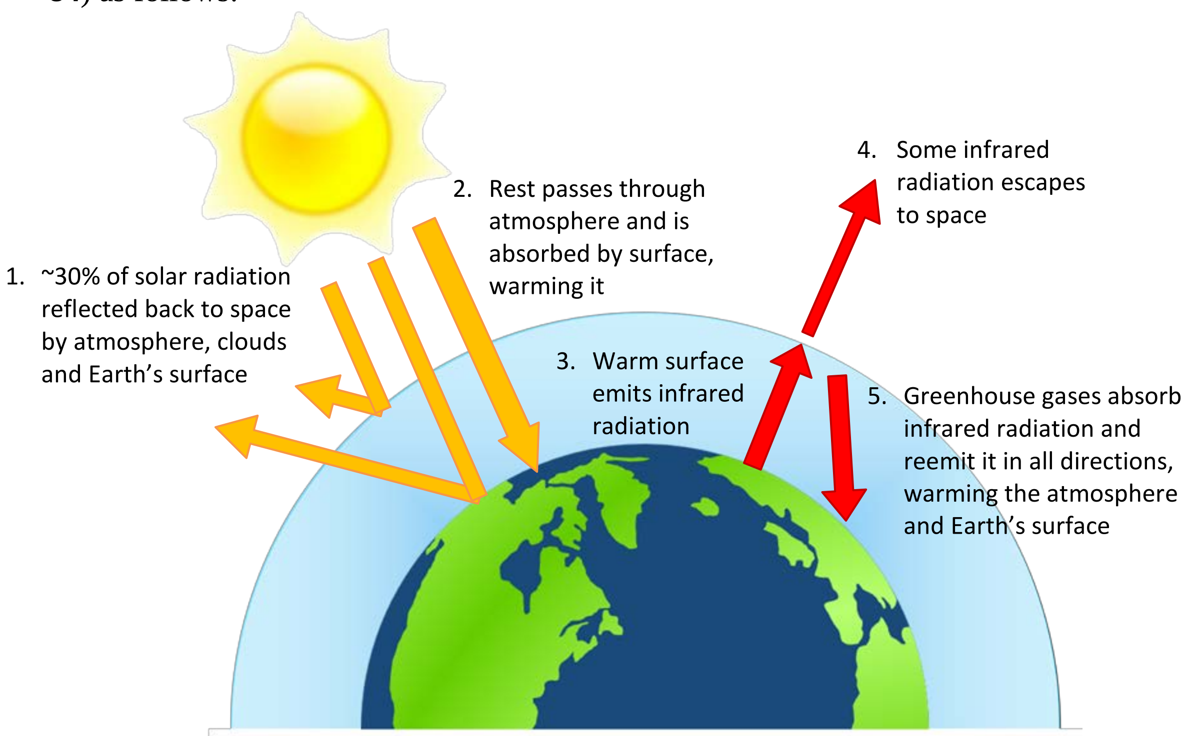
- PowerPoint for Simulation Enhanced Units (**Slides 84-86**)
- Greenhouse Effect Notes
- Runaway Greenhouse Effect on Venus Reading (**p.102-103**)

INTRODUCTION:

- Pass back the exit tickets from the previous class and ask some of the students to share their thoughts on how the Greenhouse Effect works.

LESSON/ACTIVITY:

- Complete the annotated drawing of the Greenhouse Effect in the students' notes (**Slide 84**) as follows:



- Explain that while Mars provides us with evidence of the importance of the Greenhouse Effect in creating habitable conditions for life here on Earth, Venus paints another, more negative picture of the effect.
- Share the image of Venus (**Slide 85**) and ask the students to share what they know about the planet's climate.
- Explain that Venus is hot (average global temperature = 880°F) and dry (no water exists on its surface, only trace amounts in its atmosphere). A thick layer of clouds envelopes the entire planet.
- Explain that just like Mars, Venus was a much more Earth like place 4 billion years ago. Its transformation into the inferno we know today is the result of a process called the runaway greenhouse effect.
- Pass out a copy of the Runaway Greenhouse Effect on Venus reading to the students. Read it together as a class.

CLOSURE:

- Ask the students to answer the following question (**Slide 96**) on a separate sheet of paper and submit it as their ticket out the door [They may use the reading to help them]: *How does the runaway greenhouse effect work?*

ASSESSMENT:

- The students' ability to *describe* how the runaway greenhouse effect works will be informally assessed through student responses to the exit ticket question.

REFERENCES:

- Chaisson, E., & McMillan, S. (2008). The Runaway Greenhouse Effect on Venus. *Astronomy Today (6th ed.).* http://www.castlerock.wednet.edu/HS/stello/Astronomy/TEXT/CHAISSON/BG306/HTML/BG30608.htm
- Koshland Science Museum. *Climate Processes.* https://www.koshland-science-museum.org/explore-the-science/earth-lab/processes#.VDh2xhZtNFs
- NASA. *Venus: Read More.* https://solarsystem.nasa.gov/planets/profile.cfm?Display=OverviewLong&Object=Venus

IMAGES:

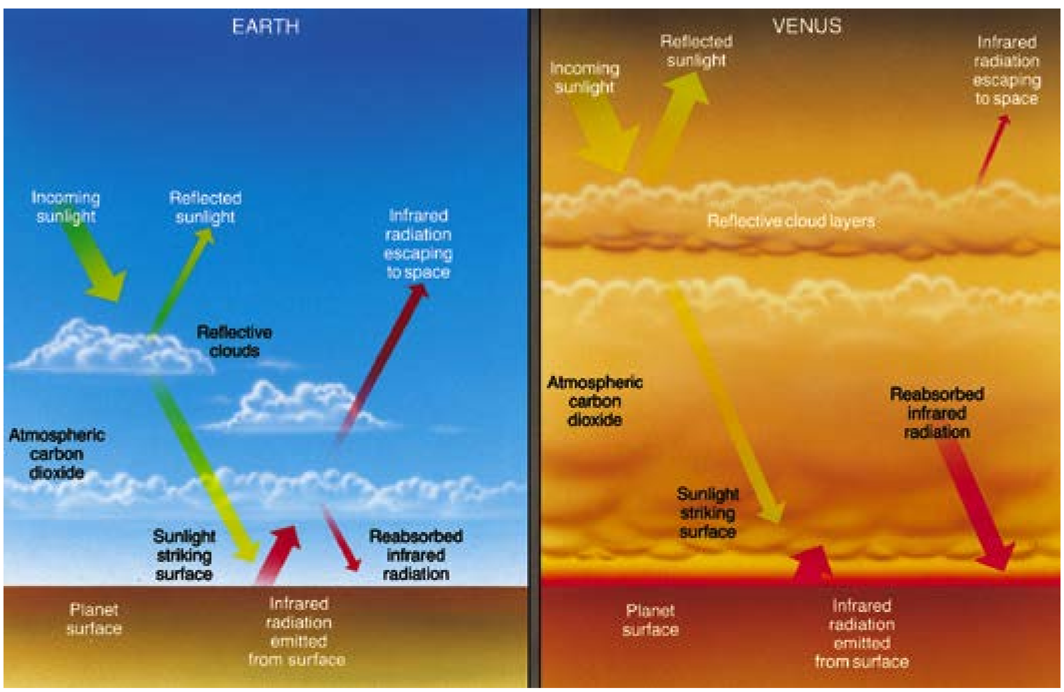
- Chaisson, E., & McMillan, S. (2008). The Runaway Greenhouse Effect on Venus. *Astronomy Today (6th ed.).* http://www.castlerock.wednet.edu/HS/stello/Astronomy/TEXT/CHAISSON/BG306/HTML/BG30608.htm

Name ____ Date ______________
Runaway Greenhouse Effect Period ______

The Runaway Greenhouse Effect on Venus

Given the distance of Venus from the Sun, the planet was not expected to be such a pressure cooker. Why is Venus so hot? And if, as we believe, Venus started off like Earth, why is its atmosphere now so different from Earth's?

The answer to the first question is fairly easy. Given the present composition of its atmosphere, Venus is hot because of the greenhouse effect. Recall that greenhouse gases in Earth's atmosphere, particularly water vapor and carbon dioxide, tend to warm our planet. By stopping the escape of much of the infrared radiation emitted by Earth's surface, these gases increase the planet's temperature much as an extra blanket keeps you warm on a cold night. Venus's dense atmosphere is made up almost entirely of a prime greenhouse gas, carbon dioxide. This thick blanket absorbs about 99 percent of all the infrared radiation released from the surface of Venus and is the immediate cause of the planet's sweltering 730 K (~850 °F) surface temperature.



Venus's Atmosphere Because Venus's atmosphere is much deeper and denser than Earth's, a much smaller fraction of the infrared radiation leaving the planet's surface escapes into space. The result is a much stronger greenhouse effect than on Earth and a correspondingly hotter planet.

The answer to the second question—Why is Venus's atmosphere so different from Earth's?—is more complex. The initial stages of atmospheric development on Venus probably took place in more or less the same way as our own planet. However, on Earth much of the atmosphere became part of the planet surface, as carbon dioxide and sulfur dioxide dissolved in the oceans or combined with surface rocks. If all the dissolved or chemically combined carbon dioxide on Earth were released back into our present-day atmosphere, its new composition would be 98 percent carbon dioxide and two percent nitrogen, and it would have a pressure about 70 times its current value. In other words, apart from the presence of oxygen (which appeared on Earth only after the development of life) and water (whose absence on Venus will be explained shortly), Earth's atmosphere would look a lot like that of Venus. The real difference between Earth and Venus, then, is that Venus's greenhouse gases never left the atmosphere the way they did on Earth.

When Venus's atmosphere appeared, the temperature was higher than on Earth because Venus is closer to the Sun, but the exact atmospheric temperature is uncertain. If it was so high that water vapor could not become liquid, no oceans would have formed. Consequently, outgassed water vapor and carbon dioxide would have remained in the atmosphere, and the full greenhouse effect would have gone into operation immediately. If oceans did form and most of the greenhouse gases left the atmosphere to become dissolved in the water, the temperature must still have been sufficiently high to allow a process known as the **runaway greenhouse effect** to come into play.

To understand the runaway greenhouse effect, imagine that we took Earth from its present orbit and placed it in Venus's orbit. At its new distance from the Sun, the amount of sunlight hitting Earth's surface would be almost twice its present level, and so the planet would warm up. More water would evaporate from the oceans, leading to an increase in atmospheric water vapor. At the same time, the ability of both the oceans and surface rocks to hold carbon dioxide would diminish, allowing more carbon dioxide to enter the atmosphere. As a result, the greenhouse heating would increase, and the planet would warm still further, leading to a further increase in atmospheric greenhouse gases, and so on. Once started, the process would "run away," eventually leading to the complete evaporation of the oceans, restoring all the original greenhouse gases to the atmosphere. Basically the same thing would have happened on Venus long ago, leading to the planetary inferno we see today.

The greenhouse effect on Venus was even more extreme in the past, when the atmosphere also contained water vapor. By intensifying the blanketing effect of the carbon dioxide, the water vapor helped the surface of Venus reach temperatures perhaps twice as hot as at present. At those high temperatures, the water vapor was able to rise high into the planet's upper atmosphere—so high that it was broken up by solar ultraviolet radiation into its components, hydrogen and oxygen. The light hydrogen rapidly escaped, the reactive oxygen quickly combined with other atmospheric gases, and all water on Venus was lost forever.

DAY 5

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **2.2d** Temperature and precipitation patterns are altered by:
  - Human influences including deforestation, urbanization, and the production of greenhouse gases such as carbon dioxide and methane.

OBJECTIVES:

- Students will *design* a poster to inform others about the enhanced greenhouse effect. (*Synthesis*)

MATERIALS:

- Driving Questions Worksheet
- Enhanced Greenhouse Effect Project Guidelines (**p.106-107**)

INTRODUCTION:

- Go over the exit ticket question from the previous class with the students. *Heating of the planet causes greenhouse gases to be released into the atmosphere. These gases trap some of the infrared radiation emitted by the planet, preventing it from escaping to space. The trapped infrared radiation causes the planet to warm. This causes more greenhouse gases to be released into the atmosphere increasing its ability to trap heat which in turn causes further warming and the cycle continues on and on.*

LESSON/ACTIVITY:

- Ask the students to pull out their driving questions worksheet from a few classes ago.
- Ask the students to share their findings on how conditions on Earth have changed over time (Ice Age → 1750 → Today) due to the Greenhouse Effect. *They should have noticed that the concentration of greenhouse gases has increased along with the temperature.*
- Pass out the **Enhanced Greenhouse Effect Project Guidelines** to the students.
- Read the first two paragraphs with the students and explain that the changes in the conditions on Earth that they observed in the computer simulation are some of the evidence that an enhanced greenhouse effect is occurring. Their task in this project will be to explore the enhanced greenhouse even further.
- Go over the directions for the project with the students and remind them to refer to the rubric as they create their posters.
- The students will have a few additional days to work on their posters at home before they are due to give the students enough time to conduct their research and work neatly. Ask the students to write the due date in the spot provided on their project sheet.
- Explain to the students that they have the rest of the class period to begin working on gathering information for their posters.

ASSESSMENT:

- The students' ability to *design* a poster to inform others about the enhanced greenhouse effect will be formally assessed through their final product for this project. A rubric will be used to assess their work.

REFERENCES:

- Billings, L.. *Fact or Fiction?: We Can Push the Planet into a Runaway Greenhouse Apocalypse*. http://www.scientificamerican.com/article/fact-or-fiction-runaway-greenhouse/

IMAGES:

- http://scitechdaily.com/images/Runaway-Greenhouse-Climates-More-Easily-Triggered-than-Previously-Thought.jpg

Name ____ Date _____________
Project Guidelines Period _____

The ENHANCED Greenhouse Effect

Due: ______________

Scientists propose that in a billion years or so Earth will undergo a runaway greenhouse effect. "Its surface temperature will steadily rise until the boiling oceans throw a thick blanket of steamy water vapor around the planet. All that water vapor, itself a potent greenhouse gas, will raise temperatures higher still to cook another greenhouse gas, carbon dioxide, out of Earth's rocks. The end result will be a 'runaway greenhouse' in which the planet loses its water to space and bakes beneath a crushing atmosphere of almost pure carbon dioxide."

Thought the Earth is still a long time away from becoming Venus's identical twin, thanks to human activity it's already experiencing what is referred to as an **enhanced greenhouse effect**.

PART I:
Research the enhanced greenhouse effect using various internet sources (**NO Wikipedia!**).

- A great place to start: *http://www.climatechange.gov.au/greenhouse-effect*
  [**Greenhouse Effect and Indicators tabs**]

Use the guiding questions below will help you to focus your research. Be sure to write down any sources you use. You will need to cite them in Part II.

Guiding questions:
1. What is the enhanced greenhouse effect? How does it work?
2. How are humans contributing to the enhanced greenhouse effect?
3. What are some the effects the enhanced greenhouse effect is having on the Earth?

PART II:
Design a poster to inform other about the enhanced greenhouse effect - how humans are contributing to it and the consequences it is having on the planet. You poster must:

- ☐ Provide a description of the enhanced greenhouse effect
- ☐ Give at least 3 examples of human activities that are contributing to the effect and describe how they are doing so
- ☐ Give at least 3 examples of concequences the effect is having on the planet
- ☐ Include graphics
- ☐ Have sources cited on the back

REFER TO THE RUBRIC BELOW AS YOU WORK. MAKE IT FUN!

ENHANCED GREENHOUSE EFFECT POSTER RUBRIC	
	Description of the Enhanced Greenhouse Effect (**10 points**) * What is it? How does it work?
	Examples (3) of human activities that contribute to the effect (**2 point each**)
	Details about how each of your activities contributes to the effect (**4 points each**)
	Examples (3) of consequences the effect is having on the planet (**2 points each**) * What changes are happening to the planet because of the enhanced greenhouse effect?
	Graphics (**6 points**) *Support information
	Neatness/ Legible Writing (**3 points**)
	Spelling (**2 points**) * Full credit = no more than 2 mistakes
	TOTAL (out of 42)

`

GRAVITY AND ORBITS UNIT

Overview of Computer Simulation

Title	GRAVITY AND ORBITS
Web Address	http://phet.colorado.edu/en/simulation/gravity-and-orbits
Description	This simulation contains two tabs. The first tab, *Cartoon*, allows the user to manipulate the size and distance between the Sun, Earth, Moon and a space station to explore how these factors affect the strength of gravity. The second tab, *To Scale*, allows the user to explore everything the first tab does just to scale, allowing the user to visualize the actual distances between the bodies.
Level of Implicit Scaffolding	High

Rationale

The concept of gravity and orbits traditionally presents a challenge for inquiry for a couple of reasons. For one, the scale of the solar system is too large for students to interact with directly. In addition, the revolution of many celestial bodies around the Sun occurs at time scales to slow to be observed within the science classroom. The simulation by PhET incorporated into this unit shrinks down bodies within the solar system and speeds up their movements. It also allows the user to control gravity and to manipulate the sizes of celestial bodies and the distances between them making visible the factors involved in determining an object's orbit.

DAY 1

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.1a** Most objects in the solar system are in regular and predictable motion.
  - Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.

OBJECTIVES:

- Students will *define* gravity based on their background knowledge. (*Knowledge*)
- Students will *identify* the Law of Motion that is illustrated in a statement. (*Comprehension*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 88-94**)
- Dollar Bill (as new and unfolded as possible)
- Gravity and Newton's Laws Notes (**p.112-113**)

INTRODUCTION:

- Inform the students that you have a challenge for them: all they have to do is catch a dollar bill between their thumb and fingers after you drop it. The only rules are that they can't close their hand until they see the dollar bill drop and they can't move their hand down to catch it. (Instructions: http://www.youtube.com/watch?v=eaZ9Gdj93kg)
- Demonstrate dropping and catching the bill for the students. This will make the challenge look very easy.
- Ask for a volunteer who thinks they can complete the challenge and select a student.
- Have the student hold their hand out like they are holding a glass of water with their thumb and the rest of their fingers a couple inches apart.
- Place the dollar bill between the student's hand so that it doesn't touch their fingers. Remind the student that they can't close their hand until they see the dollar bill drop and they can't move their hand down to catch it.
- Release the dollar. Give the student three tries at catching it.
- Bring up another student volunteer to try three times as well.
- Pose the question: Why do you think your classmates weren't able to catch the dollar?
- Explain that when their eyes see the dollar bill drop, they tell the brain that it's time to close their fingers. The brain then sends the message all the way to their fingers but by the time their fingers get the message, the dollar is already out of their reach. This is because gravity pulls the bill away from their grasp quicker than the brain can send the message to their fingers to close.
- Pose the question: What if we were to go into outer space and try this again. Do you think your classmates would have better luck catching the dollar? Why? *They will mostly like guess yes because there would be "no gravity" to pull the bill away.*

- Explain to the students that over the next 5 days they will be talking a closer look at gravity and its role in our solar system. By the end of the unit they will be able to determine if their prediction and the reasoning behind it is correct.

LESSON/ACTIVITY:

- Pass out the **Gravity and Newton's Laws Notes**.
- Pose the questions: What is gravity? How could we define it?
- Jot the students' ideas down on the board (**Slide 88**).
- Compile the ideas on the board into one definition along the lines of: *Gravity – the force that pulls things to Earth* (it will later be proved that gravity is more than this). The students should add this definition to their notes.
- Explain that the credit for discovering gravity goes to a man named Sir Isaac Newton. Share the legend of his discovery (**Slide 89**) with the students. They should add the bold information to the first bullet in their notes.
- Share the information on Newton and his contributions to science (**Slides 90-91**) with the students. They should add the bold information to the remaining bullets in their notes.
- Explain to the students that in order to understand the motions of objects on Earth and the distant motions of celestial objects as Newton explained them, they must first understand his laws.
- Share the information on Newton's three Laws of Motion (**Slides 92-94**) with the students. They should write the laws in the boxes on the back side of their note sheet.

CLOSURE:

- Give the students the rest of the period to begin the 'Which Law?' activity with a partner. Whatever they do not finish in class is homework.

ASSESSMENT:

- The students' ability to *define* gravity based on their background knowledge will be informally assessed through student responses during class discussion.
- The students' ability to *identify* the Law of Motion that is illustrated in a statement will be informally assessed through student responses to the 'Which Law?' activity.

REFERENCES:

- BASIC/Not Boring Middle Grades Science Book. Which Law? http://www.high.plainview.k12.ok.us/common/pages/DisplayFile.aspx?itemId=3009822
- National Geographic. *Isaac Newton: Who He Was, Why Google Apples Are Falling*. http://news.nationalgeographic.com/news/2010/01/100104-isaac-newton-google-doodle-logo-apple/
- Nemzer, B. (2011). *How to Do the Catch the Dollar Trick.* http://www.youtube.com/watch?v=eaZ9Gdj93kg
- Newton's Laws of Motion Review Sheet. http://www.teacherspayteachers.com/Product/Newtons-Laws-of-Motion-Review-Sheet-825152
- NTTI. *Introductory activity: The $20 challenge.* http://www.thirteen.org/edonline/ntti/resources/lessons/gravity/b.html

IMAGES:

- http://whatthafact.com/wp-content/uploads/2013/10/isaac-newton-portrait.jpg
- http://thumbs.dreamstime.com/z/apple-tree-cartoon-isolated-white-background-31951320.jpg
- http://images.clipartpanda.com/teacher-apple-clipart-black-and-white-apple-20clip-20art-Anonymous_Another_apple.png

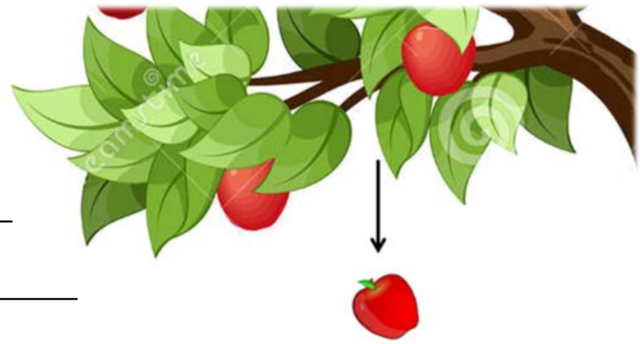
Name ____ Date ______________
Gravity and Newton's Laws Notes Period ______

GRAVITY AND NEWTON'S LAWS

Gravity (initial definition)**:** ____

____

Sir Isaac Netwon



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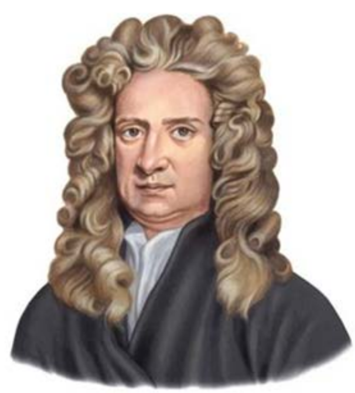

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Now on to **Netwon's Laws of Motion…**

WHICH LAW?

1st LAW OF MOTION

____

2nd LAW OF MOTION

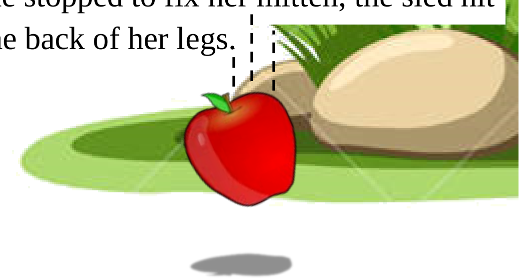
____

3rd LAW OF MOTION

____

Directions: Label each statement 1, 2 or 3 for the Law of Motion it illustrates.

1. _______ A swimmer pushes water back with her arms, but her body moves forward.
2. _______ When you are standing up on the bus, and the bus suddenly stops, your body continues to go forward.
3. _______ A magician pulls a table cloth out from under dishes and glasses on a table without distrubing them.
4. _______ A soccer ball that is kicked very hard goes farther than one that is kicked lightly.
5. _______ When you jump on a trampoline, the trampoline pushes you back up into the air.
6. _______ Pushing a baby on a swing is easier than pushing an adult on the same swing.
7. _______ A little boy pulls harder on his wagon when his dog is riding in it than when it is empty.
8. _______ A frog leaping upward off a lily pad is pulled downward by gravity and lands on another lily pad.
9. _______ When you paddle a canoe, the canoe goes forward.
10. _______ A little girl who has been pulling a sled behind her in the snow is crying because when she stopped to fix her mitten, the sled hit her in the back of her legs.



DAY 2

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.1a** Most objects in the solar system are in regular and predictable motion.
  - Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.

OBJECTIVES:

- Through the manipulation of the computer simulation, students will:
  - *Identify* the variables that affect the strength of gravity between the Sun and a planet. (*Comprehension*)
  - *Analyze* how the motion of a planet would change if the gravity acting on it was stronger or weaker. (*Analysis*)

MATERIALS:

- Gravity and Newton's Laws Notes
- PowerPoint for Simulation Enhanced Units (**Slide 95**)
- Driving Questions Worksheet (**p.116-118**)
- Computers
- PhET Gravity and Orbits Simulation (http://phet.colorado.edu/en/simulation/gravity-and-orbits)

INTRODUCTION:

- Ask the students to pull out their Gravity and Newton's Laws Notes from the previous class.
- Go over the answers to the 'Which Law?' activity, discussing how each statement illustrates the law.
  Answer key: 1. **(3)** 2. **(1)** 3. **(1)** 4. **(2)** 5. **(3)** 6. **(2)** 7. **(2)** 8. **(1)** 9. **(3)** 10. **(1)**
- Explain to the students that today it will be their job to explore Newton's Law of Universal Gravitation through the use of a computer simulation.

LESSON/ACTIVITY:

- Ask the students to get together with a partner and then log on to a computer. They should follow the directions on the board (**Slide 95**) to launch the simulation.
- Give the students 5 minutes to play around with the simulation on their own in order to familiarize themselves with it and to see what they can make it do.
- Once time is up, give each student a copy of the **Driving Questions Worksheet**.
- Ask the students to make predictions about the answers to the questions based on what they already know and/or have discovered from their exploration with the simulation thus far.
- Give the students the remainder of the period to work on answering the driving questions with their partner using the simulation. Any groups that finish prior to the end of class

may further explore with the simulation beyond what was addressed in the driving questions. The students should write down any further discoveries they make or questions that they have in the space provided on their worksheet.

CLOSURE:

- Ask the students to hold on to their worksheets as they will be used during the next class.

ASSESSMENT:

- The students' ability to *identify* the variables that affect the strength of gravity between the Sun and a planet will be informally assessed through their responses to the driving questions (**#3 and 5**).
- The students' ability to *analyze* how the motion of a planet would change if the gravity acting on it was stronger or weaker will be informally assessed through their responses to the driving questions (**#4 and 6**).

Name ____ Date ______________
Driving Questions – Gravity and Orbits Period ______

PhET: Gravity and Orbits

Click on the **Cartoon** tab at the top of the screen if you're not already there. In the control panel on the right, click on the **Sun-Earth system** and turn on **Gravity Force**, **Velocity** and **Path**.

1. What would happen to the Earth (and all the other celestial bodies for that matter) if gravity were turned off?

PREDICTION	FINDINGS

2. What do you observe about the Gravity Force and Velocity arrows?

GRAVITY FORCE	VELOCITY

3. How can you make the force of gravity weaker between the Sun and the Earth?

PREDICTION	FINDINGS

4. What effects does weaker gravity have on the motion of the planet?

PREDICTION	FINDINGS

5. How can you make the force of gravity stronger between the Sun and the Earth?

PREDICTION	FINDINGS

6. What effects does stronger gravity have on the motion of the planet?

PREDICTION	FINDINGS

FINISHED EARLY?

Freely explore with the simulation on your own. Write down any observations you make in the space below.

DAY 3

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.1a** Most objects in the solar system are in regular and predictable motion.
  - Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.

OBJECTIVES:

- Students will *explain* why the Earth and the Sun exert gravitational forces on each other. (*Comprehension*)
- Students will *solve* universal gravitation problems. (*Application*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slide 96-99**)
- Driving Questions Worksheet
- Newton's Law of Gravity Notes (**p.122-123**)
- Exit Ticket (**p.124**)

INTRODUCTION:

- Ask the students to pull out their driving questions worksheet from the previous class.
- Pass out the **Newton's Law of Gravity Notes**.

LESSON/ACTIVITY:

- Pose the question: Is there gravity in outer space? *Yes*
- Remind the students that Copernicus's heliocentric model (**Slide 96**) showed the planets orbiting around the sun but the problem with the model, and one of the big reasons why it had difficulty gaining acceptance, was that it couldn't explain why the planets did that.
- Explain that when Newton began contemplating why the Moon continued to orbit the Earth instead of traveling off into space, he realized there must be some force pulling it towards Earth's center. After much thought he came to the brilliant conclusion that the same gravity that made things fall to the ground on Earth was what was keeping the Moon in orbit around the Earth. He realized that gravity is a universal force, meaning that it applies everywhere to everything.
- Ask the students to share their observations of the Gravity Force in the simulation. *They should have noticed that there were two gravity arrows, one for the Earth and one for the Sun, and that they came from the center of each body.*
- Pose the questions:
  - Why were there two gravity arrows?
  - Which of Newton's Laws of Motion explains this?
- Explain that according to Newton's 3rd Law, when the Sun pulls on the Earth, the Earth pulls back on the Sun. This is because all objects are attracted to each other.

- Explain to the students that knowing all this, their definition of gravity from Day 1 needs to be expanded. Share the official definition of gravity (**Slide 97**) with the students. They should write this definition in their notes.
- Bring up the stronger and weaker gravity chart (**Slide 98**) on the board.
- Ask the students to share their findings on how the force of gravity can be made weaker between the Sun and the Earth. Record their findings on the chart. *They should have noticed that the force of gravity could be made weaker by increasing the distance between the bodies, decreasing the size of the Sun and decreasing the size of the Earth*.
- Ask the students to share their findings on the effects weaker gravity has on the motion of a planet. Record their findings on the chart. *They should have noticed that under various circumstances weaker gravity allowed the planet to fly off into space, resulted in a larger orbit (and thus longer time of revolution) or even had no effect.*
- Ask the students to share their findings on how the force of gravity can be made stronger between the Sun and the Earth. Record their findings on the chart. *They should have noticed that the force of gravity could be made weaker by decreasing the distance between the bodies, increasing the size of the Sun and increasing the size of the Earth*.
- Ask the students to share their findings on the effects stronger gravity has on the motion of a planet. Record their findings on the chart. *They should have noticed that under various circumstances stronger gravity caused the planet to crash into the sun, resulted in a smaller orbit (and thus shorter time of revolution), resulted in a more elliptical orbit or even had no effect.*
- Explain to the students that their findings from the simulation can be explained by Newton's Law of Universal Gravitation.
- Share the information on the Law of Universal Gravitation (**Slide 99**) with the students. They should add the bold information to their notes.
- Walk the students through how to solve the four problems on the back of their notes.

CLOSURE:

- Pass out the **Exit Ticket**.
- Ask the students to answer the questions and submit their work as their ticket out the door.

ASSESSMENT:

- The students' ability to *explain* why the Earth and the Sun exert gravitational forces on each other will be informally assessed through student responses during class discussion.
- The students' ability to *solve* universal gravitation problems will be formally assessed through student responses to the exit ticket questions.

REFERENCES:

- The Origin and History of Life on Earth. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 29-30, 33-34). Whitestone, New York: Barron's Educational Series.
- Syvum. *Earth Science - New York Regents June 2004 Exam.* http://www.syvum.com/cgi/online/mult.cgi/exam/regents/earth_science/regents_earth_jun_2004.tdf?0

Name ____ Date ________________
Newton's Law of Gravity Period _______

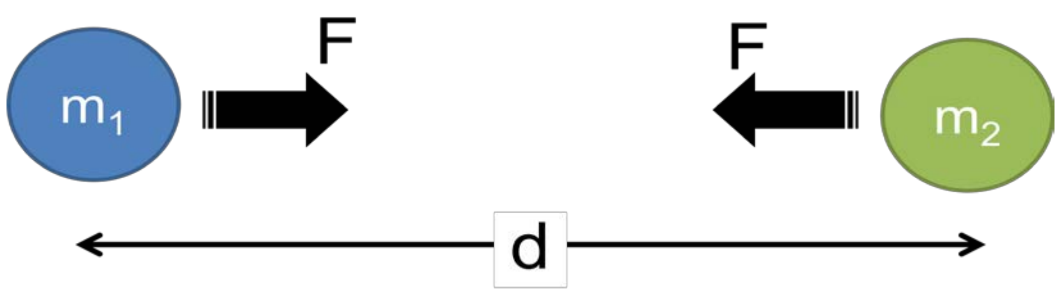
UNIVERSAL GRAVITATION

Gravity: ____

____

Law of Universal Gravitation: ____

____

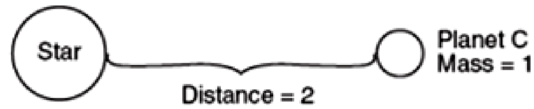


$$F = -G\frac{m_1 m_2}{d^2}$$

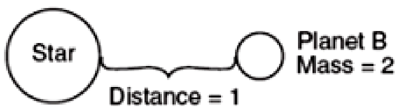
F = force of gravity
G = gravitational constant
m = mass
d = distance the two masses

1. In each diagram below, the mass of the star is the same. In which diagram is the force of gravity greatest between the star and the planet shown?

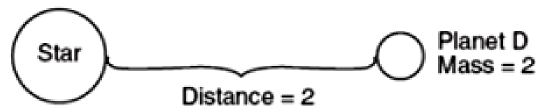
(1)



(3)



(2)



(4)

2. If the distance from Earth to the Sun were doubled, the gravitational attraction between the Sun and Earth would become

   (1) one-fourth as great
   (2) one-third as great
   (3) twice as great
   (4) four times as great

3. Planet A has a greater mean distance from the Sun than planet B. On the basis of this fact, which other comparison can be correct made between the two planets?

   (1) Planet A is larger
   (2) Planet A’s revolution period is longer
   (3) Planet A’s speed of rotation is greater
   (4) Planet A’s day is longer

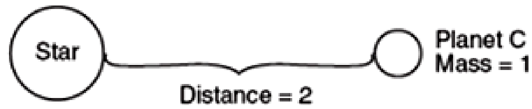
4. If the mass of the Earth were doubled, the gravitational attraction between the Sun and Earth would become

   (1) one-third as great
   (2) four times as great
   (3) one-fourth as great
   (4) twice as great

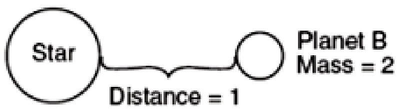
Name ____ Date ______________
Newton's Law of Gravity Exit Ticket Period ______

1. In each diagram below, the mass of the star is the same. In which diagram is the force of gravity smallest between the star and the planet shown?

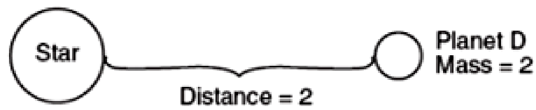
(1)



(3)



(2)



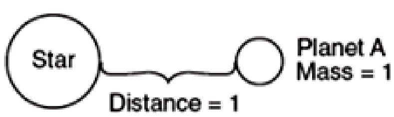
(4)

2. If the distance from Earth to the Sun were tripled, the gravitational attraction between the Sun and Earth would become

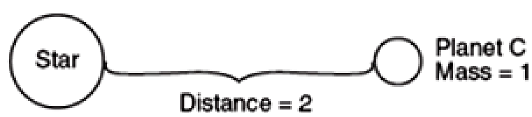
(1) three times as great
(2) one-third as great
(3) nine times as great
(4) one-ninth as great

Name ____ Date ______________
Newton's Law of Gravity Exit Ticket Period ______

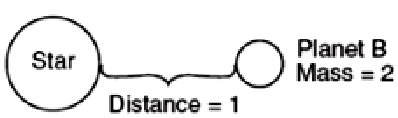
1. In each diagram below, the mass of the star is the same. In which diagram is the force of gravity smallest between the star and the planet shown?



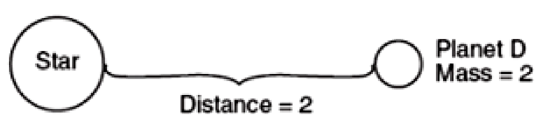
(1)



(3)



(2)



(4)

2. If the distance from Earth to the Sun were tripled, the gravitational attraction between the Sun and Earth would become

(1) three times as great
(2) one-third as great
(3) nine times as great

(4) one-ninth as great

DAY 4

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.1a** Most objects in the solar system are in regular and predictable motion.
    - Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.

OBJECTIVES:

- Students will *explain* why the Earth would travel off in a straight line without gravity. (*Comprehension*)
- Students will *predict* how a satellite is put into orbit and how gravity keeps it there. (*Comprehension*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slide 100-106**)
- Exit Ticket
- Driving Questions Worksheet

INTRODUCTION:

- Pass back the exit tickets from the previous class and go over the answers with the students. Answer key: 1. (3) 2. (4)
- Ask the students to take out their driving questions worksheet from the last few classes.

LESSON/ACTIVITY:

- Ask the students to share their finding on what would happen to the Earth if gravity were suddenly turned off. *They should have noticed that the Earth would continue off in a straight line*.
- Pose the questions:
    - Why would the Earth do that? *Objects in motion stay in motion at the same speed and in the same direction unless acted on by an unbalanced force. No gravity means no unbalanced force to change its motion*.
    - Which of Newton's Laws of Motion tells us this will happen? *1st*
- Remind the students that fortunately gravity is everywhere: pulling things to Earth, keeping the Moon orbiting the Earth and the Earth orbiting the Sun, and so much more.
- Pose the question: So if there's gravity everywhere, how can there be such a thing as zero gravity and how do astronauts float around in space like they are weightless?
- Explain that today they are going to discover the answer to these questions.
- Share the image of the cannon on the top of the Earth (**Slide 100**) with the students. The cannon is aimed horizontally to the ground.
- Pose the questions: If there were no gravity, what would happen to the cannon ball when we shot off the cannon? Why?

- Click the mouse/spacebar to play the animation to show the cannonball's path (**Slide 100**). Explain that Newton's 1st Law says that objects in motion stay in motion unless acted on by an unbalanced force. Because of this, the cannon ball would fly off horizontally and would keep moving at the same speed and in the same direction until something got in its way.
- Pose the question: Since there is gravity on Earth, what would actually happen to the cannonball when we shot it off? Why?
- Click the mouse/spacebar to play the animation to show the cannonball's path (**Slide 101**). Explain that the pull of gravity causes the cannonball's path to curve downward and eventually it hits the Earth's surface.
- Pose the question: What would happen if we used a more powerful charge to shoot the cannonball with a greater force? Why?
- Click the mouse/spacebar to play the animation to show the cannonball's path (**Slide 102**). Explain that Newton's 2nd Law tells us that if the mass of the cannonball stays the same and we increase the force, then it will have a greater acceleration. The greater acceleration would allow it to travel further horizontally before hitting the Earth.
- Pose the question: Is there any possible way that we could prevent the cannonball from hitting the Earth's surface?
- Explain that if we had a super powerful charge that could launch the cannonball with a great enough force we could actually get it so that as its path curved downward due to gravity, the Earth's surface would curve away too because of its spherical shape.
- Click the mouse/spacebar to play the animation to show the cannonball's path (**Slide 103**). Explain that if we got it so that gravity was pulling the cannonball downward at the same rate that Earth's surface was curving away from it we could keep it falling in a circular path around the Earth forever! We'd have to launch it at a speed of 18,000 mph but if we could do that the cannonball would go into orbit around the Earth.
- Explain that when one object orbits another, like the Moon orbiting the Earth or the Earth orbiting the Sun, the first object is really just falling unendingly towards the other object. So right now we are actually falling towards the Sun and the Moon is falling towards us.
- Recall the students' attention back to the earlier questions 'how can there be such a thing as zero gravity?' and 'how do astronauts float around in space like they are weightless?'.
- Pose the question: So why do you think astronauts, like these ones, float? (**Slide 104**)
- Explain that the International Space Station is in orbit around the Earth so really it is continuously falling. The astronauts on board it are also in orbit so they are continuously falling to the Earth too. Since the Space Station and the astronauts are falling at the same speed, the astronauts don't press down on the floor of the space station like you would here on Earth. There's nothing to stop their fall so they feel like they're floating.
- Explain that zero gravity doesn't really mean that there is no gravity. It's the apparent lack of gravity due to objects falling at the same rate, like the spaceship and the astronauts.

CLOSURE:

- Pose the question: What are some things that are orbiting the Earth right now besides the Moon? *International Space Station, Hubble, GPS satellites, etc…*
- Share the information on satellites (*Intro and Notable Satellites*) from National Geographic linked to the picture on **Slide 105** with the students.

- Ask the students to answer the following questions (**Slide 106**) on a separate sheet of paper and submit it as their ticket out the door:
    - *Predict: How are satellites put into orbit?*
    - *How does gravity keep a satellite moving in a curved orbit?*

ASSESSMENT:

- The students' ability to *explain* why the Earth would travel off in a straight line without gravity will be informally assessed through student responses during class discussion.
- The students' ability to *predict* how a satellite is put into orbit and how gravity keeps it there will be informally assessed through student responses to the exit ticket questions.

REFERENCES:

- *Is there gravity in space?* http://www.qrg.northwestern.edu/projects/vss/docs/space-environment/1-is-there-gravity-in-space.html
- The Origin and History of Life on Earth. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 30-31). Whitestone, New York: Barron's Educational Series.

DAY 5

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.1a** Most objects in the solar system are in regular and predictable motion.
  - Gravity influences the motions of celestial objects. The force of gravity between two objects in the universe depends on their masses and the distance between them.

OBJECTIVES:

- Students will *recall* the forces/motions that act on the Earth. (*Knowledge*)
- Students will *hypothesize* what characteristic of a celestial body determines the strength of its escape velocity. (*Synthesis*)
- Students will *discover* what a gravity assist is and how it helps spacecraft reach destinations throughout the solar system. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slide 107-113**)
- Exit Ticket
- Gravity and Orbits Notes **(p.130**)
- Gravity Assists Assignment (**p.131-133**)
- Computers

INTRODUCTION:

- Pass back the exit ticket from the previous class and go over the answers with the students.
  - *1. They are launched into space using rockets.*
  - *2. Gravity pulls it downward at the same rate that the Earth's surface curves away from it.*
- Play the 'How Do Satellites Get and Stay in Orbit?' video linked to the picture on **Slide 107** for the students. This video discusses how rockets are used to launch satellites into orbit and discusses how all satellites will eventually fall to Earth due to atmospheric drag.

LESSON/ACTIVITY:

- Pass out the **Gravity and Orbits Notes** to the students.
- Share the image of the Earth orbiting around the Sun (**Slide 108**) with the students.
- Pose the question: What forces/motions are acting on the Earth?
- Add arrows and labels to the image to show the forward velocity and the inward force of gravity. The students should add the arrows and labels to their notes as well.
- Explain to the students that it's the combination of these two forces that produces the circular motion of the orbit.
- Share the image of the forces acting on the Earth at multiple points in its orbit (**Slide 109**) with the students. Point out how the resultant force of the forward velocity and the inward force of gravity produces the curved motion.

- Explain that when an object, like the cannonball from last class, is launched with just enough speed to get it into orbit, the orbit will be circular.
- Pose the questions:
  - Are the orbits of all celestial bodies circular? *no, most are elliptical*
  - What do you think could be done with the cannonball to get it into an elliptical orbit?
- Explain that if the cannonball were launched at a speed greater than the 18,000 mph needed to get it into orbit, it would travel farther outward before being pulled back by gravity. This would produce the elliptical shape (**Slide 110**).
- Pose the question: Is it possible for a body to escape the gravity of another body around which it is orbiting? *yes*
- Share the definition of escape velocity (**Slide 111**) with the students. They should write the definition in their notes.
- Explain to the students that if we wanted to launch the our cannonball out of Earth's orbit, we would need to launch it at a speed of about 25,000 mph. This would give it just enough velocity to escape the pull of Earth's gravity.
- Pose the question: Do you think the escape velocity is the same for every body in our solar system? *no*
- Ask the students to order the bodies in our solar system from smallest to greatest escape velocity (**Slide 112**). They can write their answer on the back of their notes.
- Ask several students to share their thoughts on the order of the bodies and to explain their reasoning behind putting the planets in that order.
- Share the correct order of escape velocities (**Slide 113**) with the students.
- Explain that the more massive a body is, the stronger its gravity. The stronger the gravity, the more velocity needed to escape from it let alone put the object into orbit in the first place.
- Pose the question: Have you ever wondered how spacecraft get to other planets?
- Explain that gravity isn't just handy for putting satellites in orbit to study the Earth. It plays a big role our studies of the other bodies in the solar system as well.
- Pass out the **Gravity Assists Assignment**.
- Read the first three paragraphs with the students. These paragraphs provide an introduction to the concept of gravity assists. Explain that their task in this assignment will be to explore how they work even further.
- Go over the directions for the assignment with the students.
- Explain to the students that they have the rest of the class period to begin working on the assignment. Whatever they do not finish will be due the next class.

ASSESSMENT:

- The students' ability to *recall* the forces/motions that act on the Earth will be informally assessed through student responses during class discussion.
- The students' ability to *hypothesize* what characteristic of a celestial body determines the strength of its escape velocity will be informally assessed through student predictions on the back of their notes as well as student responses during class discussion.

- The students' ability to *discover* what a gravity assist is and how it helps spacecraft reach destinations throughout the solar system will be formally assessed through student responses to the Gravity Assists Assignment questions.

REFERENCES:

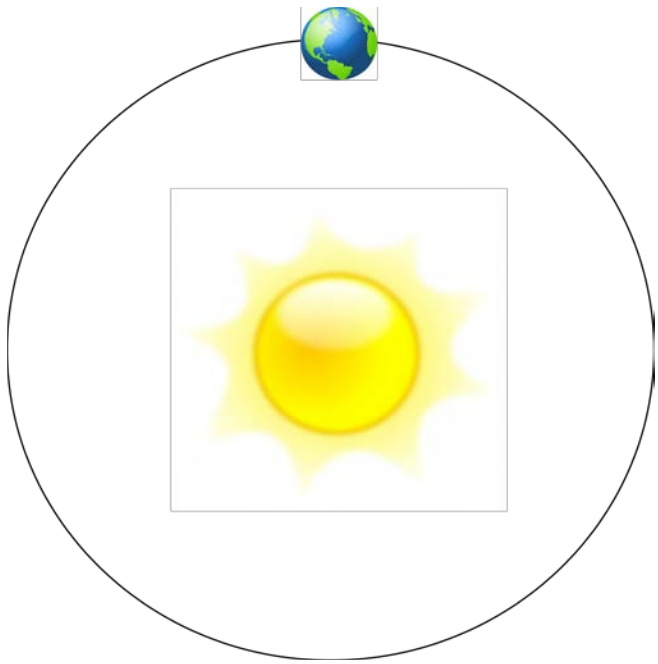
- ESA. *Let Gravity Assist You…* http://www.esa.int/Our_Activities/Space_Science/Exploring_space/Let_gravity_assist_you
- NASA (a). *Planetary Fact Sheet – U.S. Units*. http://nssdc.gsfc.nasa.gov/planetary/factsheet/planet_table_british.html
- NASA (b). *Sun Fact Sheet*. http://nssdc.gsfc.nasa.gov/planetary/factsheet/sunfact.html
- The Origin and History of Life on Earth. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 30-31). Whitestone, New York: Barron's Educational Series.

IMAGES:

- http://www.astro.ufl.edu/~guzman/ast1002/class_notes/Ch1/earth_orbits.gif
- http://thumb101.shutterstock.com/display_pic_with_logo/548344/151309757/stock-vector-wooden-slingshot-151309757.jpg
- http://nssdc.gsfc.nasa.gov/planetary/image/magellan_diagram.jpg

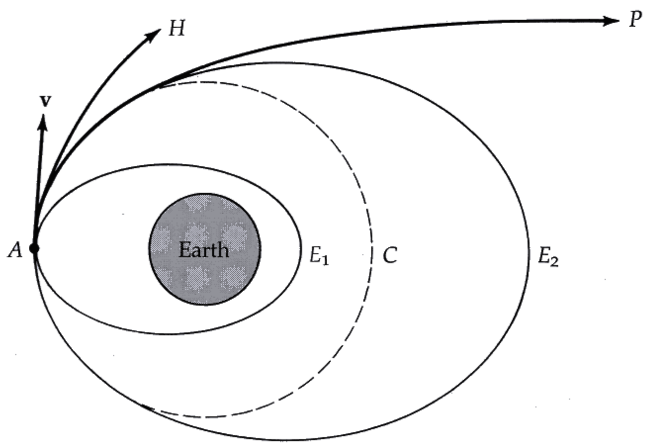
Name ____ Date _____________

Gravity and Orbits Notes Period ______



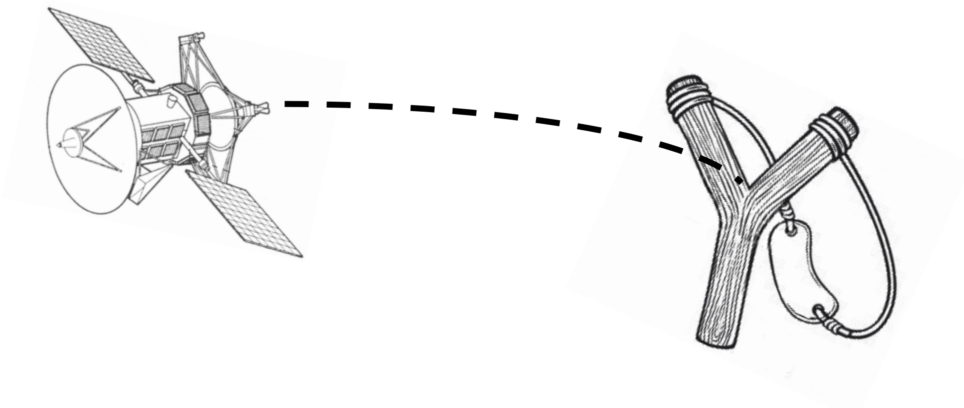
Escape Velocity: ____

____



Name ____________________________________ Date ______________
Gravity Assists Assignment Period ______

Let Gravity Assist You...



When a spacecraft launches on a mission to another planet it must first break free of the Earth's gravitational field. Once it has done that, it enters interplanetary space, where the dominant force is the gravitational field of the Sun.

The spacecraft begins to follow a curving orbit, around the Sun, which is similar to the orbit of a comet. When this orbit brings it close to its target destination the spacecraft must fire a retrograde rocket (fires in the opposite direction to the direction in which the spacecraft is travelling) to slow down and allow itself to be captured by the gravitational field of its target. The smaller the target, the more the spacecraft must slow down.

Sometimes passing a planet can result in the spacecraft being accelerated, even without the spacecraft firing any of its thrusters. This is known as the 'slingshot' effect. Such '**gravity assist**' maneuvers are now a standard part of spaceflight and are used by almost all European Space Agency interplanetary missions. They take advantage of the fact that the gravitational attraction of the planets can be used to change the trajectory and speed of a spacecraft.

YOUR TASK: Use various internet sources (just **NO WIKIPEDIA**) to help you answer the questions about 'Gravity Assists' on the next 2 pages**.** A great place to start is NASA's *Gravity Assist Primer* (http://www2.jpl.nasa.gov/basics/grav/primer.php).

1. **What is a ‘gravity assist’? (Define it)**

2. **How does a ‘gravity assist’ work?**
   Include a picture (one you draw or one you find on the internet) to help you explain.

3. **Select one of the following missions that utilized gravity assists to help the spacecraft reach its destination** (circle your choice) **and answer the questions:**

- Cassini
- Messenger
- New Horizons
- Rosetta

How many 'gravity assists' did the spacecraft need in order to reach its destination?

Which planets did the spacecraft receive these assists from? When did these assists occur (give specific dates)? How did these assists help the spacecraft reach its destination (speed up or slow down)?

How long did it take the spacecraft to reach its destination with the help of these assists?

BONUS QUESTION:

How much longer would it have taken the spacecraft to reach its destination without the 'gravity assists'?

RADIOMETRIC DATING UNIT

Overview of Computer Simulation

Title	**RADIOMETRIC DATING GAME**
Web Address	http://phet.colorado.edu/en/simulation/radioactive-dating-game
Description	This simulation contains four tabs. The first tab, *Half Life*, allows the user to manipulate the number of atoms in a decay sample to explore how half life is the amount of time it takes for half of a radioactive substance to decay. The second tab, *Decay Rate*, allows the user to explore a sample's decay through multiple half lives and the exponential nature of it. The third tab, *Measurement*, allows the user to explore why different elements are used for dating different objects. The final tab, *Dating Game*, allows the user to measure the percentage of the dating element present in an object and then to use that percentage to determine the age of the object.
Level of Implicit Scaffolding	High

Rationale

The concept of the radiometric dating traditionally presents a challenge for inquiry due to the equipment and time required to actually conduct the process. In addition, the radioactive decay of atoms is a very slow process occurring over thousands to billions of years and at the molecular level. The first two tabs of the simulation by PhET incorporated into this unit make these molecules visible and speed up the process of decay. The other two tabs eliminate the gritty and time consuming lab work by presenting the students with probes that allow the students to measure the amount of parent material remaining in a sample. From these measurements the age can then be determined by reading the decay curve for the element isotope.

DAY 1

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.2j** Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.
    - The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.

OBJECTIVES:

- Students will *identify* elements based on their numbers of protons and neutrons using the periodic table. (*Comprehension*)
- Students will *write* isotopes for several elements. (*Knowledge*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 115-125**)
- Radiometric Dating Vocabulary and Notes (**p.138-139**)
- Atom Cards (2 students per set) (**p.140**)
- Periodic Table (in student planners)

INTRODUCTION:

- Pose the question: How old is the Earth?
- Play the 'World's Most Asked Questions: How Old is the Earth?' video linked to the picture on **Slide 115** for the students. This video discusses how scientists have arrived at the 4.54 billion year age of the Earth.
- Explain to the students that scientists use a process called radiometric dating to essentially "read" a rock to determine its age. By "reading" the ages of rocks here on Earth and ones that came from space, scientists arrived at the 4.54 billion year age of the Earth. Over the next few days they will explore what radiometric dating is and how it can be used to "read" not only rocks but fossils and organic material as well.

LESSON/ACTIVITY:

- Pass out the **Radiometric Dating Vocabulary and Notes**.
- Explain to the students that there are two ways we can express the age of materials on the Earth or geologic events: as relative ages or absolute ages.
- Share the information on relative and absolute ages (**Slides 116-117**) with the students. They should write down the bold information in the appropriate box on their handout.
- Pose the question: What does the word radioactive mean?
- Share the definition of radioactive (**Slide 118**) with the students. They should write the definition in their notes.
- Share the information on elements (**Slide 119**) with the students. They should add the definition for element to their notes.

- Explain how to read the element squares on the periodic table to determine the number of protons, neutrons and electrons the atoms of a particular element have (**Slide 120**).
- Ask the students to get together with a partner and give each group a set of **Atom Cards**.
- Give the students several minutes to count the number of protons, neutrons and electrons for each atom and record them in the table in their notes. They should then use their periodic table to try to identify the element that is represented in the picture.
- Go over the number of protons, neutrons and electrons with the students and have them check their work. Then ask the students to share their thoughts on what the elements are. Answer key:

CARD #	# OF PROTONS	# OF NEUTRONS	# OF ELECTRONS	ELEMENT
1	3	4	3	Lithium-7
2	3	3	3	Lithium-6
3	6	6	6	Carbon-12
4	6	8	6	Carbon-14
5	8	8	8	Oxygen-16
6	8	10	8	Oxygen-18

- Explain to the students that elements are always identified by the number of protons that they have. Therefore the elements on cards 1 and 2 are both Lithium because they both have 3 protons.
- Share the definition of isotopes and the information on how to write them (**Slide 121**) with the students. They should add the definition for isotope to their notes.
- Ask the students to go back and write the elements in their table as isotopes. Then go over them (see key above).
- Explain that for some elements their isotopes with extra neutrons can be unstable or radioactive. These radioactive isotopes are particularly useful for the purpose of radiometric dating, especially Carbon-14, Potassium-40, Uranium-238 and Rubidium-87. The students should add these isotopes to their notes (**Slide 122**).
- Explain that unlike stable atoms which do not change, the atoms of unstable isotopes break apart in a process called radioactive decay.
- Share the information on radioactive decay (**Slides 123-124**) with the students. They should write down the definition for radioactive decay in their notes and any other bold information.
- Explain to the students that for the purpose of radiometric dating, the unstable isotope that we began with is called the parent and the stable isotope of the new element that it becomes is called the decay product or the daughter. They should add these words to the picture in their notes (**Slide 125**).

CLOSURE:

- Explain that radioactive decay takes place at a steady, constant rate. Nothing speeds it up or slows it down. Tomorrow they will use a computer simulation to explore more about this process and to discover how radiometric dating work.

ASSESSMENT:

- The students' ability to *identify* elements based on their numbers of protons and neutrons using the periodic table will be informally assessed through student responses on the chart in their notes and during class discussions.
- The students' ability to *write* isotopes for several elements will be informally assessed through student responses on the chart in their notes and during class discussions.

REFERENCES:

- *Isotopes and Atomic Mass Guided Inquiry Lesson*. http://www.teacherspayteachers.com/Product/CHemistry-Isotopes-Atomic-Mass-1324059
- The Origin and History of Life on Earth. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 249, 259-261). Whitestone, New York: Barron's Educational Series.
- *Radiometric or Absolute Dating of Fossils*. http://www.teacherspayteachers.com/Product/Radiometric-or-Absolute-Dating-of-Fossils-1041198

IMAGES:

- http://oceanexplorer.noaa.gov/edu/learning/15_seamounts/activities/media/decay_01.jpg

Name ____ Date ______________
Radiometric Dating Vocabulary and Notes Period ______

There are **two** ways of expressing the ages of Earth materials or geologic events:

RELATIVE AGE	ABSOLUTE AGE

Scientists have only been able to determine the absolute age of rocks and other objects since 1896. A.H. Becquerel's discovery of _____________________ made this possible.

Radioactive: ____

____

Element: ____

____

For each card count the number of protons, neutrons and electrons and record them in the table below. Then use your periodic table to determine which element the card represents.

CARD #	# OF PROTONS	# OF NEUTRONS	# OF ELECTRONS	ELEMENT
1				
2				
3				
4				
5				
6				

Isotope: ____

____

How to write isotopes:

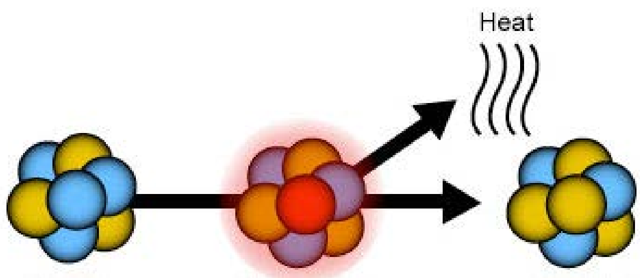
Name of element – mass of atom (aka. protons + neutrons)
Ex. Carbon-14

Some elements have isotopes that are unstable, or radioactive. These isotopes come in handy for radiometric dating. The most commonly used ones are:

-
-
-
-

Radioactive Decay: ____

____

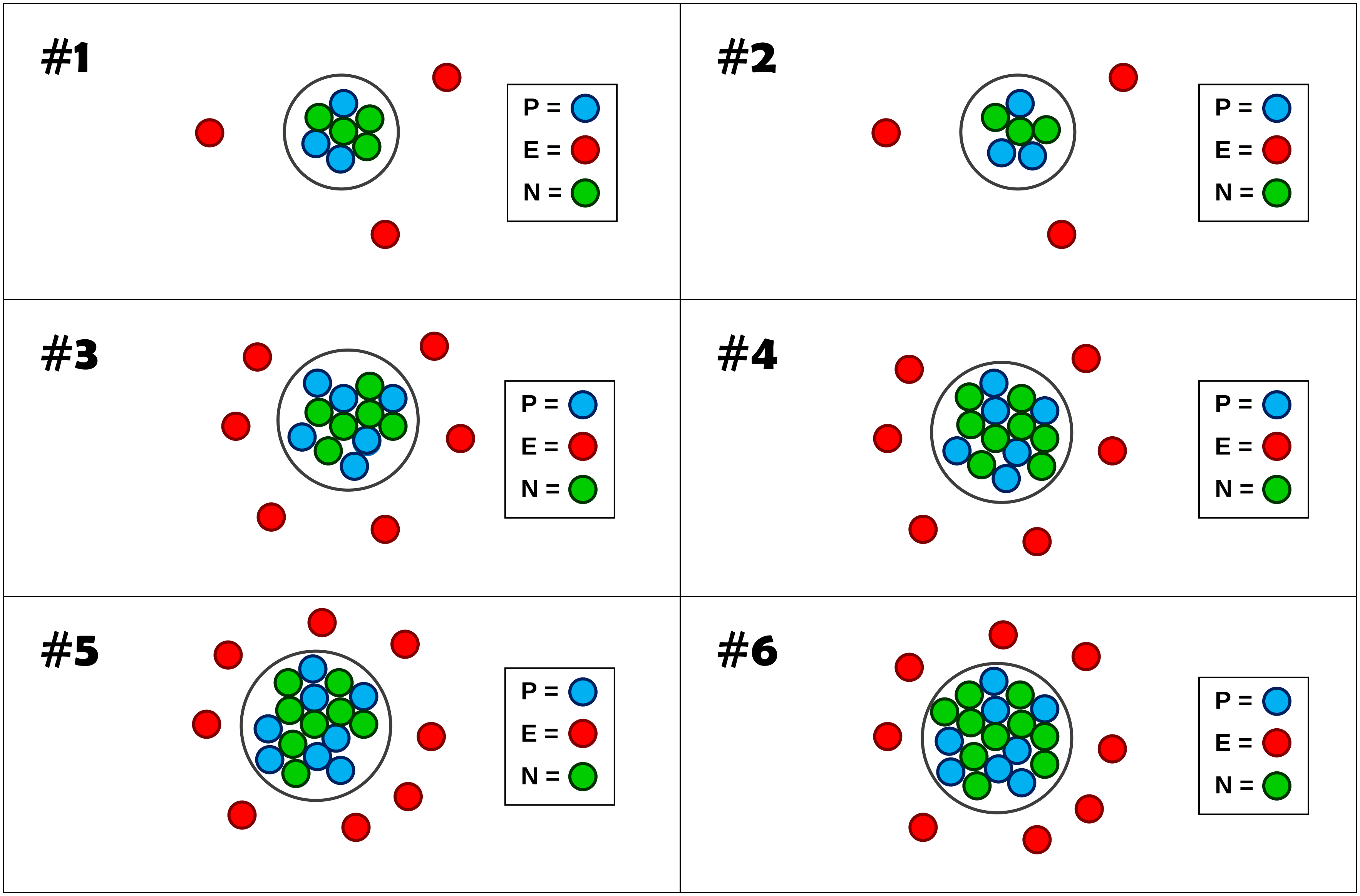


The end result of radioactive decay is ____

____

Ex. **Rubidium-87 (unstable)** → **Strontium-87 (stable)**

Rubidium-87 (unstable)	Strontium-87 (stable)
P = 37	P = 38
N = 50	N = 49



Atom Cards

DAY 2

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.2j** Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.
  - The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.

OBJECTIVES:

- Through the manipulation of the computer simulation, students will:
  - *Identify* parent isotopes and their corresponding daughters. (*Comprehension*)
  - *Interpret* the meaning of half life. (*Analysis*)
  - *Describe* the decay of a radioactive isotope based on a graph of its curve. (*Knowledge*)
  - *Analyze* why different elements are used for dating different objects. (*Analysis*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slide 126**)
- Computers
- Driving Questions Worksheet (**p.143-145**)
- PhET Radioactive Dating Game Simulation (http://phet.colorado.edu/en/simulation/radioactive-dating-game)

INTRODUCTION:

- To activate the students' background knowledge from the previous class, pose the following questions to the class:
  - What makes certain isotopes unstable/radioactive? e*xtra neutrons in their nucleus*
  - What happens to unstable isotopes? Give details. *they break apart through the process of radioactive decay – give off heat and/or subatomic particles to become a stable isotope of a completely different element*
- Explain to the students that today it will be their job to explore how radioactive decay works and how it can be used to date objects through the use of a computer simulation.

LESSON/ACTIVITY:

- Ask the students to get together with a partner and then log on to a computer. They should follow the directions on the board (**Slide 126**) to launch the simulation.
- Give the students 5 minutes to play around with the simulation on their own in order to familiarize themselves with it and to see what they can make it do.
- Once time is up, give each student a copy of the driving questions worksheet.
- Ask the students to make predictions about the answers to the questions based on what they already know and/or have discovered from their exploration with the simulation thus far.

- Give the students the remainder of the period to work on answering the driving questions with their partner using the simulation. Any groups that finish prior to the end of class may further explore with the simulation beyond what was addressed in the driving questions. The students should write down any further discoveries they make or questions that they have in the space provided on their worksheet.

CLOSURE:

- Ask the students to hold on to their worksheets as they will be used during the next class.

ASSESSMENT:

- The students' ability to *identify* parent isotopes and their corresponding daughters will be informally assessed through their responses to the driving questions (**#1**).
- The students' ability to i*nterpret* the meaning of half life will be informally assessed through their responses to the driving questions (**#2 and 3**).
- The students' ability to *describe* the decay of a radioactive isotope based on a graph of its curve will be informally assessed through their responses to the driving questions (**#4 and 5**).
- The students' ability to *analyze* why different elements are used for dating different objects will be informally assessed through their responses to the driving questions (**#6**).

REFERENCES:

- Fairchild, K. (2012). *Radioactive Dating Game*. http://phet.colorado.edu/en/contributions/view/3514

Name ____ Date ______________
Driving Questions – Radioactive Dating Period ______

PhET: Radioactive Dating

Click on the **Half Life** tab at the top of the screen if you're not already there.

1. What are the parent isotopes and their corresponding daughters in this simulation?

PARENT	DAUGHTER

2. How many radioactive atoms remain when the time on the graph reaches the half life? You need at least **4** predictions/findings for each element.

	PREDICTION	FINDINGS
Carbon-14	Ex. 7 out of 10	6 out of 10
Uranium-238		
[**HINT:** Pause the simulation when time reaches the half life; play around with the # of atoms]		

3. What is a **half life**?

PREDICTION	FINDINGS

Click on the **Decay Rates** tab at the top of the screen. To add parent atoms to the screen, drag the slider on the bucket.

4. How does the amount of original parent material change over time?

PREDICTION	FINDINGS

5. How does the decay of Carbon-14 compare to the decay of Uranium-238?

PREDICTION	FINDINGS

Click on the **Measurement** tab at the top of the screen.

6. Can any old parent isotope be used to date an object or do some work better for a particular object than others? Support your answer with evidence from the simulation.

PREDICTION	FINDINGS

FINISHED EARLY?

Freely explore with the simulation on your own. Write down any observations you make in the space below.

DAY 3

TIME: 40 minutes

NYS SCIENCE STANDARDS:
- **1.2j** Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.
  - The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.

OBJECTIVES:
- Students will *identify* the element represented in a decay curve based on its half life. (*Comprehension*)
- Students will *analyze* how the amount of the original element decreases with each half life. (*Analysis*)
- Students will *solve* half life problems. (*Application*)

MATERIALS:
- PowerPoint for Simulation Enhanced Units (**Slides 127-135**)
- Driving Questions Worksheet
- Radioactive Decay Notes/ Exit Ticket (**p.149-150**)
- Earth Science Reference Table

INTRODUCTION:
- Ask the students to pull out their driving questions worksheet from the previous class.
- Pass out the **Radioactive Decay Notes/Exit Ticket**.

LESSON/ACTIVITY:
- Ask the students to share their findings on the parent isotopes and their corresponding daughters presented in the simulation. *They should have noticed that carbon-14 decays to nitrogen-14 and uranium-238 decays to lead-206.*
- Share the 'Radioactive Decay Data' chart on page 1 of the NYS Earth Science Reference Tables (**Slide 127**) with the students. Explain that the middle column titled 'Disintegration' shows the four most commonly used radioactive isotopes and the daughter products that they decay to. Point out that potassium-40 decays to two different elements.
- Bring up the half life chart (**Slide 128**) on the board.
- Ask several students to share their findings on the number of radioactive atoms that remained when the time on the graph reached the half life mark for Carbon-14. Record the numbers they share on the board, then repeat for Uranium-238.
- Pose the question: Do you notice any similarities between the numbers on the board? *They should notice that they are all close to half or 50%.*
- Pose the question: With that in mind, what do you think a half life is?

- Share the definition of half life (**Slide 129**) with the students. They should write the definition in their notes.
- Recall the students' attention to the numbers they shared earlier. At the half life mark, many of them show more or less than 50% of the radioactive atoms decayed.
- Pose the question: Why didn't exactly 50% of the radioactive atoms decay every time?
- Explain to the students that radioactive decay is a random process. Each individual atom can decay at any time so the amount of time it takes for half a mass to decay varies from sample to sample. The half lives indicated by the simulation are averages of the times it took for half the radioactive atoms to decay in a large collection of samples.
- Share the 'Radioactive Decay Data' chart from the Reference Tables (**Slide 130**) with the students again. Explain that the last column titled 'Half Life' shows the half life times for the four radioactive isotopes.
- Ask the students to share their findings on how the amount of original parent material changed over time. *They may have noticed details such as: the decay slowed down over time, at the 2nd half life only 25% of the parent material remained, the decay was curved not linear, etc.*
- Explain to the students that a mass of radioactive atoms decays exponentially – that's why the graph was curved (**Slide 131**). The students should add the bold information to their notes.
- Bring up the half life curve and table (**Slide 132**) on the board.
- Demonstrate how to find the half life for Element X from the curve – locate 50% and follow the line over until it hits the curve, then follow it down.
- Knowing that the half life is 1.3 billion years, ask the students to use their Earth Science Reference Tables to determine which element's decay is shown by the curve. *Potassium-40*
- Explain to the students that as a mass of radioactive atoms decays it will go through more than one half life. The length of time it takes for a half life to occur always remains the same: in the case of potassium-40 it will be 1.3 billion years.
- Use the graph to complete the chart as a class (**Slide 132**). The students should fill in the chart in their notes as they go. Answer key:

HALF LIFE	AMOUNT OF ORIGINAL ELEMENT REMAINING	TIME (in billions of years)
0	100% or 1	0
1	50% or $\frac{1}{2}$	1.3
2	25% or $\frac{1}{4}$	2.6
3	12.5 or $\frac{1}{8}$	3.9
4	6.25% or $\frac{1}{16}$	5.2
5	3.125% or $\frac{1}{32}$	6.5

- Draw the students' attention to the middle column and pose the question: What pattern do you see? *They should notice that each value is half of the value before it*.
- Explain that the amount of the original element decreases by half with each half life (**Slide 133**). The students should add the bold information to their notes.
- Share the practice problems (**Slides 134-135**) with the students and walk them through how to solve them.
- Ask the students to share their findings on how the decay of Carbon-14 compares to the decay of Uranium-238. *They should have noticed that the shape of the curve was similar but uranium-238 took a longer time to decay*.
- Remind the students that while radioactive isotopes of different elements have different half lives, they still decay in the same manner. The decay is always exponential; it's just the time that varies.

CLOSURE:
- Ask the students to flip over their notes to the exit ticket.
- Ask the students to answer the practice regents' questions and submit their work as their ticket out the door.

ASSESSMENT:
- The students' ability to *identify* the element represented in a decay curve based on its half life will be informally assessed through student responses during class discussion.
- The students' ability to *analyze* how the amount of the original element decreases with each half life will be informally assessed through student responses during class discussion.
- The students' ability to *solve* half life problems will be informally assessed through student responses to the exit ticket questions.

REFERENCES:

- The Origin and History of Life on Earth. (2007). In *Let's Review: Earth Science the Physical Setting* (3rd ed., pp. 259-261, 273, 278). Whitestone, New York: Barron's Educational Series.
- Syvum. *Earth Science - New York Regents June 2005 Exam*. http://www.syvum.com/cgi/online/mult.cgi/exam/regents/earth_science/regents_earth_jun_2005.tdf?2
- EduSolutions. *Regents Quiz*. http://www.edusolution.com/edusolution2/regentsquiz/earthscience/quiz2/frame4.htm

IMAGES:

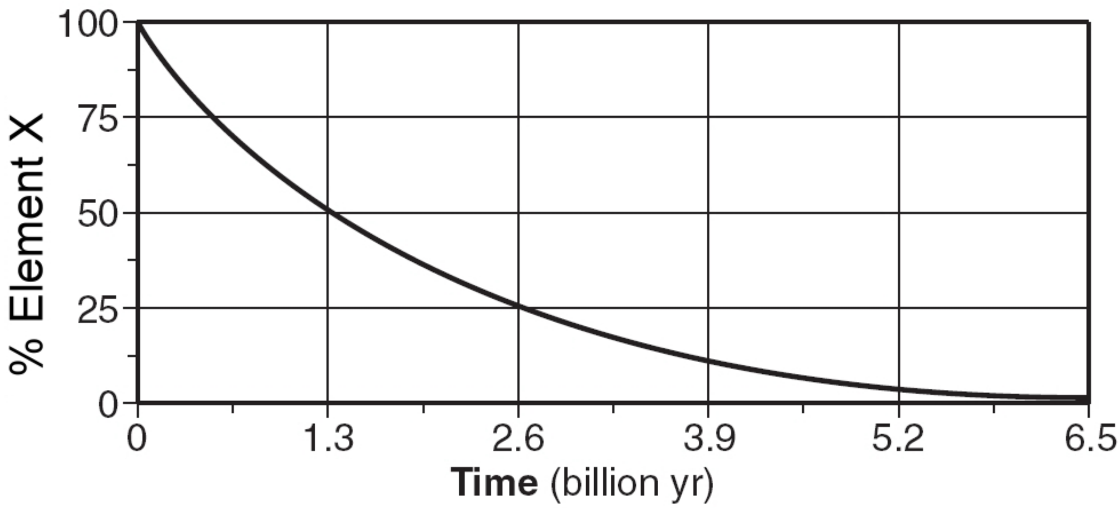
- http://www.regentsearth.com/Illustrated%20ESRT/Page%201%20(Radioactive%20Decay)/Clips/GeoHist40a.jpg

Name ______________________________________ Date _____________
Radioactive Decay Notes/ Exit Ticket Period ______

Half Life: ____

____

Radioactive decay occurs ____________________________.



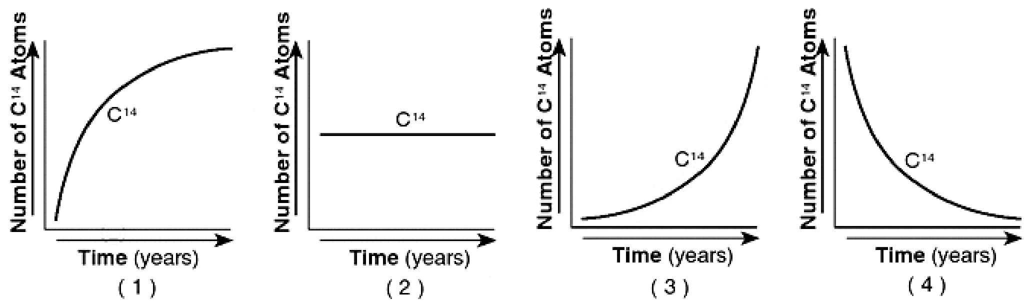
HALF LIFE	AMOUNT OF ORIGINAL ELEMENT REMAINING	TIME (in billions of years)
0		
1		
2		
3		
4		
5		

From one half life to the next ____

____

Exit Ticket:

1. Which graph best shows the radioactive decay of carbon-14?



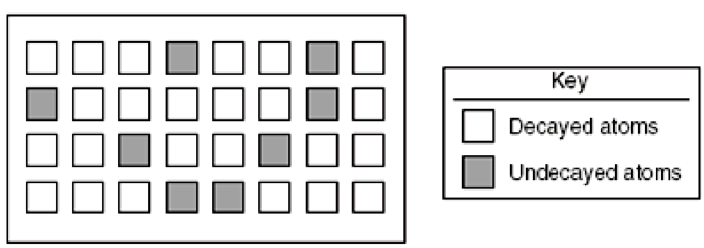
2. A rock sample contained 8 grams of potassium-40 (K^{40}) when it was formed, but now contains only 4 grams because of radioactive decay. Based on the Earth Science Reference Tables, what is the approximate age of this rock?

   (1) 0.7×10^9 years (3) 2.8×10^9 years
   (2) 1.4×10^9 years (4) 5.6×10^9 years

3. A rock sample containing the radioactive isotope potassium-40 is calculated to be 4.2×10^9 years old. According to the information in the Earth Science Reference Tables, how much of the original potassium-40 is left in this rock sample?

   (1) 0 (3) 1/8
   (2) 1/4 (4) 1/2

4. The diagram below represents the present number of decayed and undecayed atoms in a sample that was originally 100% radioactive material.



   If the half-life of the radioactive material is 1,000 years, what is the age of the sample represented by the diagram?

   (1) 1,000 yrs (3) 3,000 yrs
   (2) 2,000 yrs (4) 4,000 yrs

DAY 4

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.2j** Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.
  - The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.

OBJECTIVES:

- Students will *determine* the ages of different objects using radioactive decay rate and original-daughter element ratios of Carbon-14 and Uranium-238. (*Application*)
- Students will *explain* why different elements are used for dating different objects. (*Comprehension*)

MATERIALS:

- PowerPoint for Simulation Enhanced Units (**Slides 136-140**)
- Computers
- PhET Radioactive Dating Game Simulation (http://phet.colorado.edu/en/simulation/radioactive-dating-game)
- Radioactive Dating Game Activity Sheet (**p.153-154**)

INTRODUCTION:

- Pass back and go over the exit ticket question from the previous class with the students. Answer key: 1. **(4)** 2. **(2)** 3. **(3)** 4. **(2)**
- Ask the students to pull out their driving questions worksheet from the previous classes.

LESSON/ACTIVITY:

- Ask the students to share their findings on whether any old isotope can be used to date an object or if some work better for a particular object than others. *They should have noticed that the tree could be dated with carbon-14 but not uranium-238 and that the rock could be dated with uranium-238 but not carbon-14.*
- Pose the question: Why do you think you can't just use any isotope to date an object?
- Share the 'Six Radioisotopes Used in Dating' chart (**Slide 136**) with the students.
- Explain that the composition of an object is a big factor in determining which isotope to use to date it. An object can only be dated using isotopes that it contains…duh!
- Draw the students' attention to the materials that can be carbon-14 dated (**Slide 136**).
- Explain that carbon-14 is particularly useful for dating things that were once living because all living things contain carbon (**Slide 137**). As long as an organism is alive, the amount of carbon-14 in its body remains constant – like when the tree was alive in the simulation, the carbon-14 remained at 100%. Any carbon in a living organism's body that decays is quickly replaced by its surroundings (air, water and food). It's not until an organism dies that the carbon-14 stops being replaced and can be used for dating.

- Explain that the only problem with carbon-14 is that because its half life is so short, it can only date objects up to 70,000 years old. After that the amount of carbon-14 is just too small to measure.
- Share the image of the dinosaurs (**Slide 138**) with the students.
- Pose the question: If dinosaurs lived over 65 million years ago, can we use carbon-14 to date their bones? *no*
- Explain that in order to date objects, particularly rocks, which are older than 70,000 years other isotopes like uranium-238 and potassium-40 must be used.
- Share the image of the lava flow (**Slide 139**) with the students.
- Explain that within the lava there are minerals that contain radioactive isotopes. These isotopes are basically like mini clocks. Once the lava solidifies into a rock, the unstable isotopes start ticking or decaying that is. So the age calculated for any igneous rock through radiometric dating really just gives a measure of how long it's been since the rock solidified. It doesn't tell you how long the material that makes up the rock has been around.
- Explain that if the rock were to be melted and cooled again, the clock would reset and all the previous information provided by the rock would be destroyed.
- Pass out the **Radioactive Dating Game Activity Sheet**.
- Ask the students to log on to a computer and follow the directions on the board (**Slide 140**) to launch the simulation.
- Give the students the remainder of the period to work independently on filling in the chart and answering the questions on the activity sheet.

CLOSURE:

- Collect the Radioactive Dating Game Activity Sheets from the students that are done. Anyone who is not should finish the activity for homework.

ASSESSMENT:

- The students' ability to *determine* the ages of different objects using radioactive decay rate and original-daughter element ratios of Carbon-14 and Uranium-238 will be formally assessed through student responses in the chart on the activity sheet.
- The students' ability to *explain* why different elements are used for dating different objects will be formally assessed through student responses to questions on the activity sheet.

REFERENCES:

- Loeblein, T. (2013). Radioactive Dating Game Inquiry. http://phet-downloads.colorado.edu/files/activities/3636/Radioactive_Dating_Student_directions.pdf
- Smith, T. (2009). *Astronomy 150: Radioactive Dating.* http://www.astro.washington.edu/users/smith/Astro150/Labs/RadioDating/

Name ____ Date ____________

Radioactive Dating Game Activity Period _____

Click on the **Dating Game** tab at the top of the screen.

For each object, determine which isotope to use and then use the probe to determine the percentage of the original dating element that remains. Then use the graph to determine the age of the object (**HINT:** the green arrows slide). Record your findings in the chart below.

OBJECT	ELEMENT	% REMAINING	AGE
Living Tree			
Animal Skull			
Bone			
Rock 2			
Rock 3			
Distant Living Tree			
House			
Wooden Cup			
Rock 1			
Rock 4			
Dead Tree			
Large Human Skull			
Fish Bones			
Rock 5			

Bonus: See if you can determine the ages of the objects below.

OBJECT	HALF LIFE	% REMAINING	AGE
Small Human Skull			
Fish Fossil			
Dinosaur Skull			
Trilobite			

Answer the following questions.

1. How did you decide which isotope to use for each object?

2. How does the percent remaining (ex. 98.2%) help you determine the age of the object?

3. Why do scientists used more than one type of isotope for radiometric dating?

DAY 5

TIME: 40 minutes

NYS SCIENCE STANDARDS:

- **1.2j** Geologic history can be reconstructed by observing sequences of rock types and fossils to correlate bedrock at various locations.
    - The regular rate of nuclear decay (half-life time period) of radioactive isotopes allows geologists to determine the absolute age of materials found in some rocks.

OBJECTIVES:

- Students will *summarize* the actual process through which scientists radiometrically date rocks. (*Analysis*)

MATERIALS:

- Radioactive Dating Game Activity Sheet
- "Reading" a Rock to Get Its Age (**p.157-161**)

INTRODUCTION:

- Pass back the Radioactive Dating Game Activity Sheets from the previous class to the students and go over the three questions on the back.

LESSON/ACTIVITY:

- Pose the question: How do you think scientists calculate the percent of parent and daughter isotopes in a sample? They definitely don't have probes like in the simulation that simply tell them.
- Explain to the students radiometric dating isn't as easy as it might look. Today they're going to read an article that describes just how scientists conduct this process.
- Pass out the **"Reading" a Rock to Get Its Age** article to the students and ask them to get together with a partner.
- Give the students the remainder of the period to read the article with their partner and answer the comprehension questions that go along with it.

CLOSURE:

- Collect the students' answers to the comprehension questions at the end of the period.

ASSESSMENT:

- The students' ability to *summarize* the actual process through which scientists radiometrically date rocks will be formally assessed through student responses to the comprehension questions that accompany the reading article.

REFERENCES:

- Kinzler, R. *"Reading" a Rock to Get Its Age.* http://amnh.mrooms.net/mod/page/view.php?id=14332

IMAGES:

- Acasta Gneiss. http://www.crystal-world.com/html/Crystal-world%20graphics/Canada/Tom-CanadaTrip%20small75.jpg
- Rock Cycle. http://www.exploringnature.org/graphics/ecology/rock_cycle_color72.jpg
- Zircon. http://cbsnews1.cbsistatic.com/hub/i/r/2014/02/24/3cefd136-fb3e-46e5-85b2-03e7db7808b2/thumbnail/620x350/8ad4585e33b9f1c3a294a12d5953719b/crystal1.jpg

Name ____ Date ______________
‘Reading’ a Rock to Get Its Age Period ______

“Reading” a Rock to Get Its Age

By Dr. Ro Kinzler

Nearly everything we know about Earth has been learned from rocks. Geologists:

- map the distribution of rocks
- record how rocks have been contorted over the ages
- study thin sections (slivers of rock cut thin enough for light to pass through)
- determine the composition of rocks as well as the composition of the minerals they contain
- determine rock age using both relative and radiometric techniques

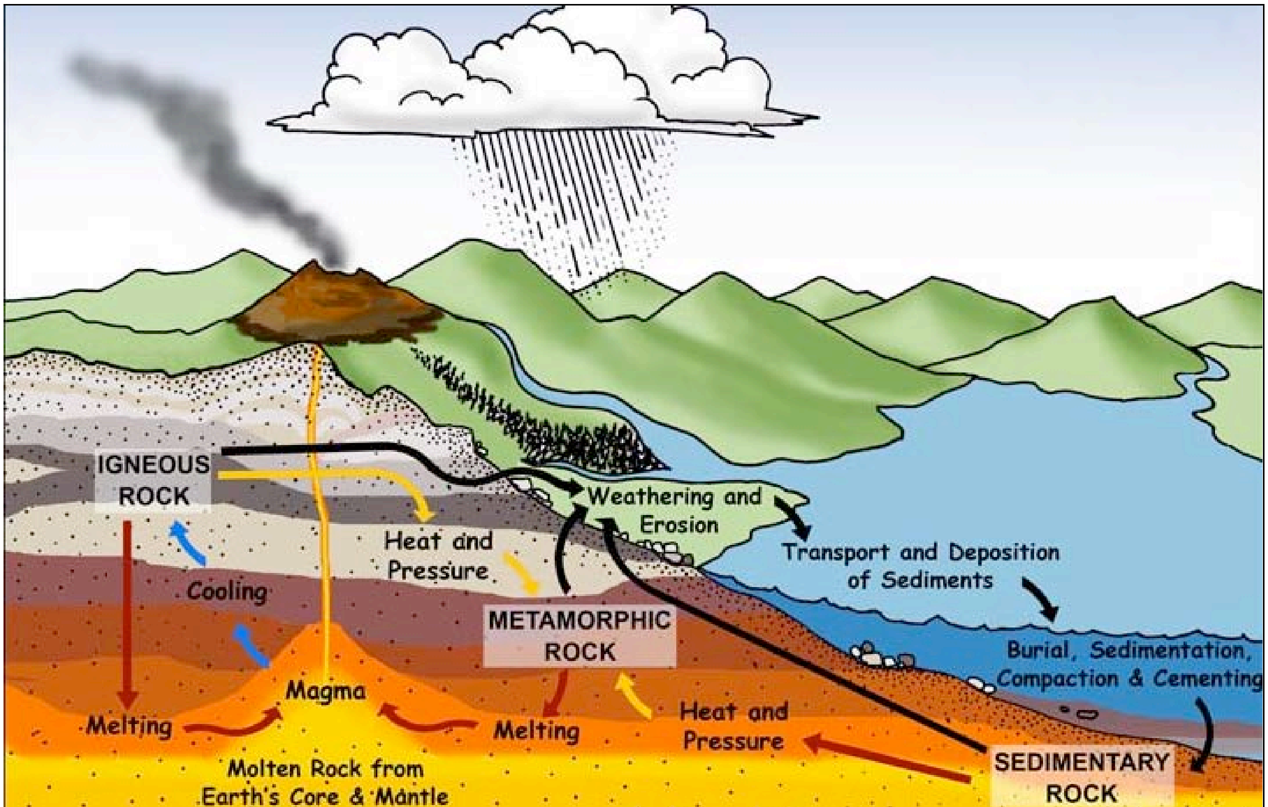
In other words, geologists "read" rocks in order to deduce the processes that formed them and the history they reveal. Then they piece together histories from various sources to arrive at a history of that part of Earth.

Radioactive dating is the most common method by which geologists determine the precise ages of rocks, and it’s key to our current understanding of Earth and our solar system. British geologist Arthur Holmes was a pioneer in the development of radioactive dating. His extensive work dating rocks and minerals during the first half of the 20th century formed the basis for the modern geologic time scale.

Acasta Gneiss
By dating the zircons embedded within the Acasta gneiss, geologists have determined its age to be 4.03 billion years. This rock’s composition establishes it as part of a continent, indicating that continents existed nearly four billion years ago.

Geologists used radioactive dating of Earth materials and meteorites to estimate the age of Earth at 4.56 billion years. An apparent paradox is that the planet itself is older than any material it contains. The oldest rock identified thus far, the Acasta Gneiss (from the Northwest Territories in Canada), has been dated at approximately 4.03 billion years using the uranium-lead isotopic system (although rock found in northern Québec’s Nuvvuagittuq Greenstone Belt may be even older). The fact that evidence from meteorites has established that Earth is older than any known Earth materials means that about 500 million years of its early history has not been preserved in the geologic record—or perhaps has not yet been discovered!

This is not entirely surprising given the nature of the rock cycle: the set of continuous geologic processes such as melting, crystallization, erosion, burial, heating and deformation (i.e. metamorphism) that transform rocks into new rock types. Rocks formed very early in Earth's history are very likely to have been transformed into new rocks, which date back only to their most recent transformation. In fact, the Acasta Gneiss is a metamorphic rock, so it formed from a pre-existing (and thus older) rock.



Rock Cycle
The rock cycle takes eons. It strongly affects the carbon and other geochemical cycles by locking up critical elements for tens to hundreds of millions of years. Processes driven by plate tectonics—volcanism, uplift, erosion, and burial—recycle rocks. Over the age of the Earth, some rocks have passed many times through the complete cycle.

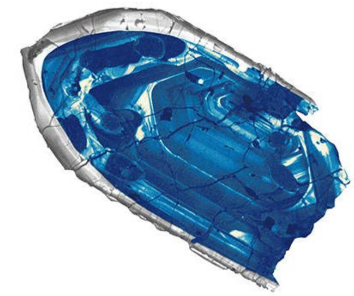
Some minerals in rocks have been identified that are even older than the oldest rock! The oldest Earth material identified so far are zircon crystals that were separated from a 3 billion year old metamorphosed conglomerate from Australia and that are over 4.3 billion years old. Zircon is a common mineral, but one that exists only in miniscule amounts in most rocks. Once formed, zircons are so hard they are almost impossible to destroy. So a single zircon crystal that originally formed in the deep core of a mountain may survive, and even record, several episodes of erosion, sedimentation, and mountain formation.

Radioactive dating requires knowing the compositions of different isotopes of a specific pair of elements that are related by radioactive decay. How are those isotopic compositions determined? It's a time-consuming process, but worth the effort.

Radioactive Dating: The Laboratory Process

The story of the Earth is written in the rocks, but they don't yield their secrets easily. Reading rocks by radioactive dating is a very laborious process, as I had the opportunity to experience firsthand in graduate school.

Step 1: Physically Preparing the Rock Sample



Zircon Crystal
Zircon contains the radioactive element uranium, which the University of Florida's Dr. Paul Mueller calls "the clock within the zircon" because it converts to the element lead at a specific rate over a long span of time. "It makes the zircon the most reliable natural chronometer that we have when we want to look at the earliest part of the Earth's history," says Mueller.

First you have to obtain a very clean chunk of the rock. How big a chunk? That depends on the grain size of the rock. Rocks with very big grain sizes require big chunks; rocks with very small grain sizes require smaller chunks. The important thing is that the chunk must be a good representation of the whole rock. Obtaining the sample is usually the fun part, because that's when you get to go into the field. But geologists also work in the laboratory.

You use a big hammer to crush the chunk into fine gravel against a steel plate, then a mill of some kind to crush it into even finer gravel. This very fine gravel is mostly made up of pieces of the different minerals that make up the rock. The next step is to separate these minerals from each other. The two major techniques are magnetic separation (which distinguishes between minerals based on how magnetic they are), and separation with heavy liquids (which distinguishes between minerals according to their density). These mineral separates, as they are called, are then turned into powder in what was called a "shatterbox" when I was in graduate school (which had as much to do with what it did to your eardrums as to the minerals). If all goes well, this part of the process takes about eight to ten hours per rock sample.

Step 2: Chemically Preparing the Rock Sample

Once you have the mineral powders, you move into the "chemistry" phase. This phase, which takes a couple of days, is carried out in a "clean lab": a series of linked rooms that are environmentally controlled to minimize contamination (the addition of foreign material). The elements necessary for radioactive dating are usually present in very small amounts, so contamination can throw off your findings.

You may have seen clean labs depicted in movies or on TV shows with high-tech or medical themes. You need to be well trained in how to avoid contamination and injury from acids, particularly hydrofluoric acid. After training, you don your "bunny suit"—a white jacket and pants, white booties, and a white hat to cover your clothing and hair (potential sources of contamination). You enter the clean lab through a hallway covered with a sticky mat to remove any residue outside on your shoes. Once inside, you begin to work with acids of various degrees of causticity and danger to dissolve your powders, being careful not to get any acid on your skin or clothing. This series of dissolution steps takes days to complete, by which time the solutions from your rock chunk have become very precious.

Now you pass your mineral solutions through chromatographic columns that contain material similar to that found in a water filter. This separates the dissolved ions from each other because some pass through the columns faster than others. You can collect your desired ions because they move through the solution at known rates, but often you can't avoid collecting other elements that move at a similar rate. Ions of similar size, like calcium and strontium, move through the column at similar rates. So you actually discard most of what comes out of the bottom of the column, just retaining the portion that contains the dissolved ions of interest – in this case, elements related to each other as parents and daughters in the radioactive decay process—with as little extraneous material as possible. Then you repeat this process with columns that contain material that's slightly better at differentiating between ions of similar size, until you're left with just the mineral solutions you desire.

These solutions—one for each mineral and probably one for the whole rock – are then placed on a hot plate and evaporated. (The only thing worse than dealing with acids is dealing with hot acids!) This leaves a little tannish-white speck in the bottom of a Teflon beaker. That's what you're going to measure on the mass spectrometer.

But wait—first you need to make a final dissolution in a tiny drop of acid. This droplet is then painstakingly sucked into a small pipette and dropped with extreme care onto a tiny metal filament. There it is once again evaporated to form a tiny, tannish-white spot. This last step is a killer. I can't tell you how many times it gave me trouble, and my tiny drop of acid landed somewhere other than on the metal filament. When this happens, you start practically from scratch, at the beginning of the chemistry step. That's assuming you had enough of your mineral powder left (which you try very hard to do – after you've made this mistake once).

Step 3: Collecting Your Data

The metal filament is then loaded into a mass spectrometer, an instrument that uses a combination of electric and magnetic fields to separate isotopes of different masses in order to determine their relative concentrations. Needless to say, the age information you get at the end of this process is extremely precious.

You've probably guessed that I decided not to become an isotope geochemist! Instead, I became an experimental igneous petrologist. I still spent a lot of time in the laboratory, but instead of dissolving rocks in acids, I use furnaces and high-pressure devices to conduct experiments that replicate conditions deep within the Earth. These experiments help us understand how rocks melt, how magma (molten rock) moves within the Earth, and what happens to this magma as it nears the surface, erupts, and cools to form rock.

Name ____ Period ______

Directions: Answer the following questions based on the reading.

1. What effect did the radiometric dating work done by Arthur Holmes have on the scientific community?

2. What radioactive isotope was used to determine the age of the Acasta Gneiss?

   How old did it show the rock to be?

3. Make an inference: Why is there a 500 million year gap between the age of the Earth (4.56 billion years) and the oldest known rocks on Earth (4.03 billion years)?

4. What most likely happened to rocks formed very early in Earth's history?

   How does that effect radiometric dating?

5. What is the oldest Earth material discovered so far? How old is it?

6. Why is contamination bad for the process of radiometric dating?

7. Summarize the process through which scientists radiometrically date rocks.

8. How long does this process take assuming you don't mess up?

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Appendix F Science and Engineering Practices in the NGSS - FINAL 060513.pdf. (n.d.). Retrieved from http://www.nextgenscience.org/sites/ngss/files/Appendix%20F%20%20Science%20and%20Engineering%20Practices%20in%20the%20NGSS%20-%20FINAL%20060513.pdf

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