Nelson, G., & Thornburgh, W. (2022)
The Hoosier Science Teacher, *45*(1)
DOI 10.14434/thst.v45i1.33577

Open Access

It's a Puzzle: Engaging Students in Plate Tectonics

George Nelson[1] and William Thornburgh[2]

Abstract

Plate tectonics is a topic where students are often not actively engaged and it can feel painfully slow as you are working through this unit. Through more opportunities for active engagement and a redesigned approach, make plate tectonics more engaging in your classroom and help your students build greater conceptual understanding.

Keywords: Plate tectonics, Unit planning, Conceptual understanding

It was almost a decade ago and I had been muddling through years of teaching a topic that I was interested in, but my students never really got excited about. I constantly asked myself, "Was it the way I was teaching?" "Was it just a boring topic?" "How can I teach plate tectonics differently and better?"

I needed help and thanks to seeking professional development (PD) opportunities - I got it! I attended PD where I learned more about A Framework for K-12 Science Education (NRC, 2012) and I learned Modeling Instruction™ (Hestenes, 2015) from the American Modeling Teachers Association (AMTA). Thanks to both, I was on my way to future success!

These professional development experiences helped me develop a plan to have my students 'act like' scientists, to 'do' science, and to engage more meaningfully in learning. I was able to restructure my class by using teaching strategies and by incorporating the three dimensions outlined in A Framework for K-12 Science Education. The results - my students were immediately more interested, they were gaining important foundational knowledge in plate tectonics, and they were more engaged in learning science.

If you struggle with this topic like I did and you are looking for new ways to teach your students, I have outlined a unit of activities and teaching strategies that are sure to captivate and transform your middle school classroom.

Full listing of authors and contacts can be found at the end of this article.

Unit Overview

1. Introduction "Why are there Fish Fossils High Up in The Himalayas?" (Khot, 2018)
2. Driving Question Board: Questions about the anchor activity
3. Core Samples worksheet
4. Plate Boundaries Data Analysis simulation (Concord Consortium)
5. Earth's Outer Layer reading annotation
6. Analyze Plate Boundaries simulation
7. Earth's Interior Research
8. **Convection Jar Activity**
9. Convection Jar simulation (ExploreLearning, n.d.)
10. Plate Tectonics simulation
11. Plate Boundaries reading annotation
12. Pangea simulation (ExploreLearning, n.d.)
13. Ancient Fossils reading annotation
14. Final Assessment

In this article I would like to focus on the connection with the Next Generation Science Standards [NGSS] (NGSS Lead States, 2013) (Table 1) and share my 5E learning cycle with the Convection Jar Activity in the Explore section. The intent of the convection activity is to introduce the driving force behind plate tectonics. What I have discovered over many years of

Published by the Hoosier Association of Science Teachers, Inc. (https://hasti.org/) ISSN 2475-451x

Table 1.
Connecting Instruction and NGSS

MS-ESS2 Earth's Systems *https://www.nextgenscience.org/dci-arrangement/ms-ess2-earths-systems*	
Performance Expectation	**Connections to Classroom Activity**
MS-ESS2-2: Construct an explanation based on evidencefor how geoscience processes have changed Earth's surface at varying times and spatial scales.	Students observe the convection jar and gather data on the motion of liquid when heated. These data help students make connections between motion on and below the Earth's surface, how it has shaped the Earth, and how it occurs on various scales.
MS-ESS2-3: Analyze and interpret data on the distribution of fossils and rocks, continentalshapes, and seafloor structures to provide evidence of the past plate motions.	Students complete readings, activities, and simulations to acquire data necessary for understanding the history of our planet.
Science and Engineering Practices	
Asking questions and defining problems	Students make predictions and ask questions before and during the convection current activity.
Developing and using models	They will make observations and use the data to develop a model.
Planning and carrying out investigations	Although they are given the investigation, students will carry it out and collect data.
Analyzing and interpreting data	Students will observe, record, analyze and interpret motion within the jar.
Constructing explanations and designing solutions	Upon recording data, students will collaborate and construct explanations for the observations they made.
Engaging in argument from evidence	Students will have an opportunity to engage in argument by using the evidence observed while conducting the activity.
Observing, evaluating, and communicating information	While collaborating in small groups and during the whole class whiteboard circle, students will communicate their findings and question others.
Disciplinary Core Ideas	
ESS1.C: The History of Planet Earth Tectonic processes continually generate new ocean sea floor at ridges and destroy old seafloor at trenches. *(HS.ESS1.C GBE),(secondary to MS-ESS2-3)*	Students observe and analyze two different simulations where they see seafloor spreading over the course of the unit. Additionally, students read articles about Iceland and Chile where they gather more information about seafloor spreading.
ESS2.A: Earth's Materials and Systems All Earth processes are result of energy flowing and matter cycling within and among the planet's systems. This energy is derived from sun and Earth's hot interior. The energy that flows and matter that cycles produce physical and chemical changes in Earth's materials and living organisms. (*MS-ESS2-1*)	Students observe convection cycles in the Convection Jar Lab and then apply it to the Convection Cycle Simulation. Students research the Earth's interior and observe that the mantle flows in a convection cycle.
ESS2.B: Plate Tectonics and Large-Scale System Interactions - Maps of ancient land and water patterns based on investigations of rocks and fossils, make clear how Earth's plates have moved great distances, collided, and spread apart (MS-ESS2-3)	Students read an article about fossils and discover that fossils of the same organism are found on different continents. Students then apply the reading to a simulation on Pangea. They use the simulation to find multiple pieces of evidence that the continents fit together.
Crosscutting Concepts	
Patterns	Students observe the flow of liquid in the convection jar while thinking about what is going on at the microscopic level. They then apply that to the macroscopic level of what is driving tectonic plate movement.
Cause and Effect	Plate Movement is caused by the Earth's interior, which affects the surface of the Earth.
Systems and System Models	Students develop a model of convection cycles at the microscopic level and then apply it to the macroscopic level of what causes plates to move.
Energy and Matter	Students apply how energy drives the convection cycle and how it moves matter through the process.
Stability and Change	Convection cycles drive the motion of plates, which cause earthquake and volcanic activity. Gradually, the plate moves, which causes the fossils to move apart over millions of years.

using this activity was that students still often found it challenging to explain why tectonic plates moved and what caused them to do so after completing it. This was a major missing concept in students' understanding of Plate Tectonics. Developing explicit connections to the Next Generation Science Standards (NGSS Lead States, 2013), using the 5E Learning Cycle as a framework, and incorporating teaching strategies from the professional development course, helped me improve my teaching.

In the upcoming 5E cycle, I will share how using the techniques learned from the Modeling Instruction™ professional development shaped my instructional practices and report how these changes lead to positive results for my students in 1) making sense of convection cycles and 2) understanding key unit objectives.

I have seen students becoming engaged while observing the convection currents during the Convection Jar Activity. Furthermore, they were able to build conceptual understanding, which carried forward and was able to be applied to other units throughout the school year.

Engage (45 min.)

This is an important decision for teachers, as it is often the first introduction to new concepts and we need to hook our students. Although there are many options, I use the article, Why are there Fish Fossils High Up in the Himalayas? (Khot, 2018). It is a short article that introduces students to continental drift and it creates a mystery about the location of fossils.

I use this introduction as an anchor activity to the unit and I challenge my students to solve this mystery. I begin by having students make a prediction about this event, then I place them into small groups (3-4 students) to share ideas. During small group discussion, I find it valuable to visit each group to hear their predictions and ask probing questions. This acts as a formative assessment for me as I gather insight into students' preconceptions and/or misconceptions about continental drift, fossils, and other topics that may come up.

Finally, the class comes back together for a whole-group discussion about how marine fossils could possibly be located high up in the mountains. As they report to the entire class, I record their ideas on the large whiteboard at the front of the classroom so we can revisit prior thinking later in the unit. Upon completion of the engage phase, students move through a series of exploration, explanation, and elaboration phases where they create and revise models to explain scientific phenomena. Eventually, we get to the Convection Jar Activity.

Over the previous weeks, students have explored a number of topics through readings, worksheets, discussions, simulations, and research. They build understanding of concepts such as: the Earth's surface, analyzing core samples and observing various locations on our planet, earthquakes and volcanic activity, the movement of plates and what happens at plate boundaries; and the composition of the Earth's interior. As we review what we have been learning, there are unanswered questions that remain. That is how I engage them for the upcoming activity.

Explore (30 min)

In this activity, I create small groups of 3-4 students. Some of the grouping strategies I use most often include randomly mixed and pre-assigned, gender mixed, and based on academic levels. Find what works best for you and your students by visiting teachhub.com (Kiser, 2019) or edutopia.org (Johnson, 2014) for more ideas on grouping strategies.

Before beginning the activity, it is important to provide assistance for setting up the convection jar. There are many ways to set up convection jars and it is important that you follow school and district policy for safety. I use the set-up as shown in Figure 1, with a rectangular-sided glass jar that fits nicely into wooden supports that hold the glass jar above the flame of the candle. The flame of the candle should not touch the jar. The jar should be high enough that the jar doesn't warm too quickly. I use Carolina Convection Fluid™. However, it is possible to make your own fluid with ground mica or rheoscopic fluid. Watch a 'how to' video here. Be sure to have students wear goggles, pull back hair, as well as clear the lab desk and surrounding area if they will be working with a flame.

Figure 1. *Student groups making observations*

Remind students not to touch the glass jar and use safe lab techniques. The observation should be timed to keep the temperature within controlled limits. The teacher should remove the jars after observation with oven mitts to model adherence to safety. [Refer to NSTA Heat Source Safety Guidelines](). Ways to build non-flame convection jars can be found by searching on-line.

Once groups have the activity set up and ignite their heat source, allow time to make observations on what is happening inside of the convection jar (Figure 1). Within minutes of heating the jar students will begin to observe that the liquid starts to flow up and in a circular pattern. It is common for students to express surprise and to be perplexed by the movement of the liquid. As they continue to observe and record data, groups should begin to formulate ideas for why the liquid behaves in this manner.

I ask my students to record their data on a whiteboard by drawing what they observe inside the jar in 3 phases - before, during, and after (Figure 2). This allows them to draw the system, record time, and write/draw observations. The collection and analysis of data are then used to compare with students' original predictions and to produce new ideas. The use of whiteboards is common practice in Modeling Instruction™, as they allow for small groups of students to team up and collaborate; they are large enough for groups to share with the entire class; and they provide students a way to represent their thinking (or models).

The goal of this exploration is for students to come up with an explanation of the liquid's movement within the convection jar. I encourage them to use multiple representations (e.g. written, pictorial, graphical) in order to describe the movement and explain why it flows the way it does. Although their explanations may not be completely accurate, this process has them gaining skills in collaboration, observation, data collection and analysis, using evidence for argumentation, and critical thinking.

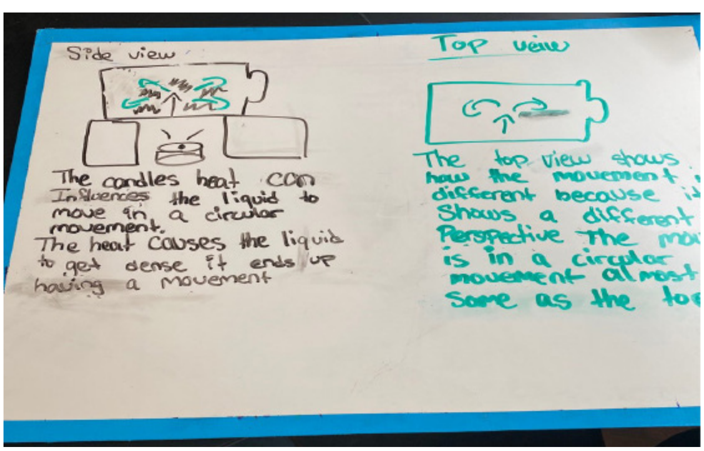

Figure 2. Group whiteboard

It is vital for the teacher to circulate through the room and listen to group discussions while focusing on what they are thinking, how they are depicting it on the whiteboard, if they are working off of each other's ideas, and if they are making any connections to previous content or activities.

Explain (40 min)

After students have collected their data and recorded observations and ideas on their whiteboards, the small groups return and we create a display of all group's whiteboards. This is called a whiteboard circle and it benefits students by allowing them to see and hear others' thinking. It is an opportunity for each group to share their findings with the class while the teacher facilitates the discussion. When using Modeling Instruction™, teachers need to create a student-centered experience, where students can construct and co-construct knowledge. It is vital to let students do the talking, compare whiteboards, ask questions, and explain their thinking.

During the whiteboard circle, I have a series of prompts that guide the discussion, but I also remain flexible to address students' questions and answers as they arise. Here are some prompts you may want to consider posing to your students to engage them in the activity and help them build a stronger conceptual understanding of convection currents:

- Do you notice similarities on any whiteboards?
- It looks like groups are representing motion in the jar - how did groups represent motion?
- Can you explain how or why this motion is happening?
- I see some boards mention that heat rises and that causes the motion. Can you elaborate on that?
- How could you explain the liquid's movement or heat rising by talking about these at the particle level?
- I notice that some groups included energy on their board. How is energy involved in this activity?

Elaborate (20-30 min)

After allowing ample time for rich, meaningful discourse where students are actively engaged, I ask students to make connections between the Convection Jar Activity and previous activities that we have completed. Although they may still need guidance, they are better able to explain things like volcanic activity and earthquakes than in previous years. In fact, I allow students to use the whiteboards or their iPads to represent their connections and knowledge if they choose to do so (Figure 3).

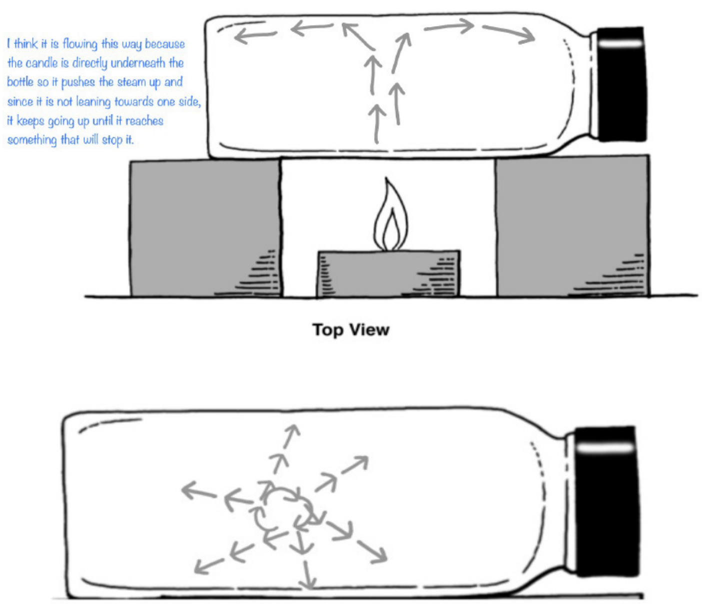

Figure 3. Sample Student Work (iPad) - arrows indicating movement with a written idea

Next, I ask students to use the activity to explain why tectonic plates move and how this activity ties into the unit's overarching question - "Why are fish fossils found so high in the Himalayas?". Through guidance and discussion, students eventually agree that the liquid in the jar flows in a circular motion (convection cycle) and some groups may notice that the liquid splits and forms two circular paths at the top of the jar. In order to solidify convection cycles, teachers could also show students a video. (Click for an example.)

Finally, to elaborate further on what students have observed and discussed, I have them complete a simulation to further their knowledge of convection cycles. Upon completion of a convection cycle Gizmo through-ExploreLearning (n.d.), groups reach a consensus on the flow pattern of the liquid in more detail, it helps students grasp convection cycles better, and they can link them to the tectonic model (Figure 4).

Evaluate

In total, this is a 6-week unit for my students, so the only evaluation I do at the completion of the Convection Jar Activity and simulation is formative in nature. Through visiting each group as they are making and recording observations - I evaluate their thinking. When we reconvene for our whole-class whiteboard circle, I evaluate each group's board, I listen to their questions and answers, and I am constantly evaluating the situation. Furthermore, when I move them from the activity into the simulation, I am able to work with them as needed and ask questions as I move throughout the room. All of these allow me to reflect on my teaching, evaluate student understanding, and make decisions on whether we move forward or spend more time learning a concept.

Within each formative assessment, teachers can evaluate individual students or small student groups depending on the structure of the classroom/activities they have created. Furthermore, if desired, this would be an acceptable place for teachers to do a short summative assessment to test students' knowledge of convection currents.

The use of questioning is an important feature of a Modeling Instruction™ classroom and an effective method to formatively assess students. They are free to express ideas, to ask questions, and work with their peers without 'fearing' a bad grade for being wrong. The questions should be designed to be higher on

4. Based on what you have seen in the jar, what effect do you think convection in the hot mantle might have on the earth's plates? What observations of the fluid inside the jar support your explanation?

I think that maybe it is what causes the plates to move. Like we learned yesterday, Earth's core is very very hot, so maybe the core heats up the mantle and pushes the liquid in it up towards the crust, and meanwhile the liquid near the crust gets cooler and sinks down, and this keeps repeating, and this is what causes plates to move and earthquakes and volcanoes to happen.

Figure 4. Sample student work

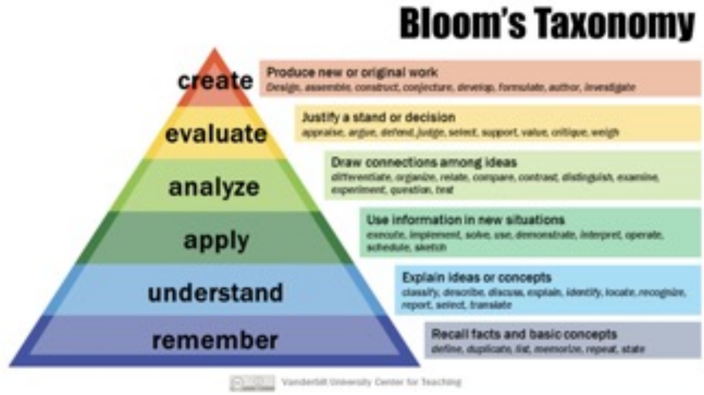

Figure 5. Bloom's Taxonomy (Armstrong, 2010)

the Bloom's Taxonomy scale (Figure 5) and improve students' critical thinking and problem-solving skills through Socratic questioning (figure 6).

At the conclusion of the unit, I evaluate students' models and I revisit the anchoring activity that was used on day one. In comparison to previous years, after I altered my instruction, the results have been nothing but positive. I have seen students forming more robust and elaborate explanations to the unit's objectives; the majority of students are able to bring concepts like convection currents into their reasoning; and they are able to explain what they have learned in much greater detail. I have included a writing prompt (figure 7) and rubric (figure 8) that I use, which is aligned with the NGSS framework.

There is a natural alignment between Modeling Instruction™ and the three dimensions of the NGSS (Figure 9). While attending the professional development, we (the teachers) participated in 'student mode' while deepening our content knowledge and having the teaching practices modeled by the workshop leader. This allowed us to experience the curriculum through the lens of students (known as student mode); to be immersed in a sequence of activities to build, test, and revise models just like scientists do; and to engage in equitable discourse just like their students will do.

Figure 6. Types of Socratic Questions (Paul & Elder, 2007)

Thanks to what I learned in these workshops, my classroom is truly student-centered and students are engaged in relevant learning experiences. The use of the Modeling Cycle (building, testing, and revising models) gives students opportunities to evolve their prior knowledge and develop greater conceptual understanding. Most importantly, my students work collaboratively through small group and whole class discussions, they collect and analyze data, they are able to construct explanations based on evidence, their communication has improved, and their critical thinking and problem-solving skills are better! Furthermore, my students have developed essential skills that will be useful in life (i.e. 21st Century Learning Skills, Fig. 10).

Plate Motion Final Assessment

1. Write a scientific argument about how is it possible that marine fossils have been found in multiple locations in the Himalayas? Some of the world's highest peaks are in the Himalayas, which is the highest mountain in the world. At this height, the air is thin, and the temperatures are extreme. The land is arid and brown, and it appears that it's been this way since the beginning of time. These mountains are hundreds of miles away from the closest ocean. Provide evidence and a detailed reason(s) supporting your evidence. This response should be no less than 5 sentences. Use your study guide to help construct your response.

Figure 7. Student writing prompt

Claims, Evidence and Reasoning – Scientific Explanations Rubric Linked to SBAC Argumentative Writing

	4	3	2	1	0
Claim – a conclusion that answers the original question	• Scientifically accurate • Completely answers the question • Common inaccurate claim(s) are clearly addressed.	• Scientifically accurate • Nearly completely answers the question • Inaccurate claim(s) are only generally addressed, no specifics	• Partially scientifically accurate • Partially answers the question • Inaccurate claim(s) are not addressed	• Is not scientifically accurate overall • Does not adequately answer the question	No claim
Evidence – scientific data that supports the claim	• The data are scientifically appropriate to support the claim. • The data are thorough and convincing – enough details and evidence provided. • Proper units are used in data • Shows with evidence why alternate claims do not work	• The data are scientifically appropriate to support the claim • The data are basically sufficient and convincing, but tend to be more general and not as specific and in depth • Does not address why alternate claims do not work • Evidence may be repetitive	• The data relate to the claim, but are not entirely scientifically appropriate • The data are not sufficient, though generally support the claim	• There is some evidence provided, but it is not logically linked to the claim or scientifically appropriate	No evidence provided
Reasoning – a justification that links the claim and evidence	• Reasoning clearly links evidence to claim • Shows why the data count as evidence by using appropriate scientific principles • There are sufficient scientific principles to make links clear between claim and evidence	• Reasoning adequately links claim to evidence • Includes related scientific principles, but only passably clarifies why this data count as evidence • Reasoning tends to be more general and shows only partial depth of content understanding	• Reasoning does not adequately link claim to evidence, or clarify why data count as evidence • Includes related and non-related scientific principles, and shows little depth of content understanding	• Reasoning is clearly insufficient and relates only tangentially to question and claim at hand • Scientific understanding is very limited	Does not provide reasoning
Language and Vocabulary	• Response clearly and effectively expresses ideas using precise, scientifically appropriate descriptions and vocabulary	• Response adequately expresses ideas and scientifically appropriate descriptions and vocabulary, but they are more general than specific	• Response inconsistently and sometimes inappropriately expresses ideas or scientific descriptions and vocabulary	• Scientific language and vocabulary are not precise or appropriate	Not under-standable
Focus and Organization	• Focus only on question at hand • Logical progression of ideas • Clearly stated and focused claim that is strongly maintained	• Focus mainly on question at hand, some loosely connected material present • Logical progression of ideas • Clearly stated and focused claim that is adequately maintained	• Focus not consistent on question at hand • Progression of ideas not entirely logical • Have a claim, but it's not entirely clear or maintained	• Focus not at all consistent • Progression of ideas not logical • Have an unclear claim that is not maintained	No clear focus or organiza-tion

Rubric adapted by Kevin J. B. Anderson from K. McNeill and J. Krajcik, NSTA, and SBAC Argumentative Writing Rubric for grades 6-11

Figure 8. Scoring rubric (McNeill & Krajcik, 2005)

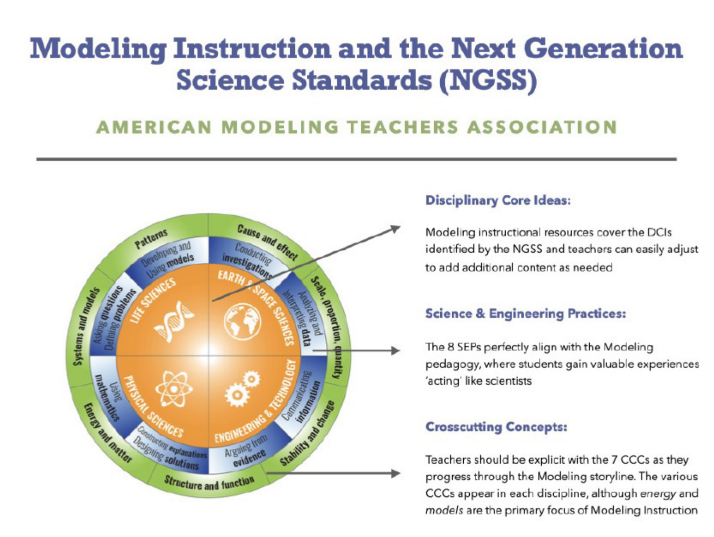

Figure 9. NGSS and Modeling Instruction™ (Thornburg, 2019)

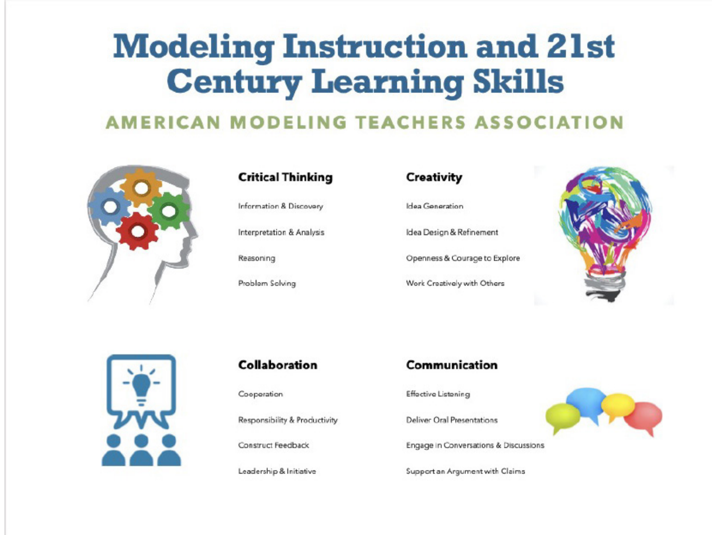

Figure 10. 21st Century Learning Skills and Modeling Instruction™ (Thornburg, 2019)

References

Armstrong, P. (2010). Bloom's Taxonomy. Vanderbilt University Center for Teaching.

ExploreLearning (n.d.) Building Pangaea Gizmo: Lesson Info. ExploreLearning.

ExploreLearning. (n.d.). Convection cells Gizmo: Lesson Info. ExploreLearning.

Hestenes, D. (2015). *Modeling theory and modeling instruction for STEM education*. In S. Chandrasekhara (Chair), *epiSTEME 6 international conference to review research on science, technology and mathematics education. Symposium conducted at the meeting of episteme* (Vol. 6).

Johnson, B. (2014, January 2). Student learning groups: Homogeneous or heterogeneous? Edutopia.

Khot, M. (2018). Why are there fish fossils high up in the Himalayas? WeatherNews.

Kiser, S. (2021, March 9). Ways to arrange students for Group Work. TeachHUB.

McNeill, K. and Krajcik, J. (2005). Scientific explanations: Characterizing and evaluating the effects of teachers' instructional practices on student learning. *Journal of Research in Science Teaching, 45*, 53-78.

National Research Council [NRC]. (2012). *A Framework for K–12 Science Education: Practices, crosscutting Concepts, and Core Ideas*. Washington, DC: National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, by States*. Washington, DC: National Academies Press.

Paul, R., & Elder, L. (2007). *The Thinker's Guide to the Art of Socratic Questioning.* Foundation for Critical Thinking.

Schmidt, W. (2018, September 2). DIY Rheoscopic Fluid. YouTube.

The Signing Zoologist. (2016, March 20). YouTube's best convection currents video! Science demonstration for your students.

Thornburgh, W. (2019). Modeling Instruction and The Next Generation Science Standards. American Modeling Teachers Association.

Thornburgh, W. (2019). Modeling Instruction and 21st Century Learning Skills. American Modeling Teachers Association.

William Thornburgh is employed by AMTA, which holds the MI trademark.

Authors

[1]George Nelson (nelsong@wilmette39.org) is a science teacher at Wilmette Junior High School, Wilmette, IL, USA.

[2]William Thornburgh (wthornbu@yahoo.com) is an Adjunct Professor at Eastern Kentucky University in Richmond, KY, and the Executive Director of the American Modeling Teachers Association.