Designing an Earthquake-Proof Art Museum: An Arts-and Engineering-Integrated Science Lesson

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Abstract

In this practical arts-integrated science and engineering lesson, an inquiry-based approach was adopted to teach a class of fourth graders in a Midwest elementary school about the scientific concepts of plate tectonics and earthquakes. Lessons were prepared following the 5 E instructional model. Next Generation Science Standards (4-ESS3-2) and the National Coalition for Core Arts Standards for fourth grade (Visual Arts: Creating 1.14a, Visual Arts: Creating 2.1.4a, and Visual Arts: Creating 3.1.4a) were addressed challenging students to create an earthquake-resistant structure to support a clay sculpture in a model of an art gallery for an earthquake-prone area. First, content knowledge was provided through videos and information texts that led to class discussion. Next, students collaboratively brainstormed ideas for the sculpture museum. In pairs, students drew sketches and planned what they would design. Natural, air-dry clay was used for the sculptures and the scaffolding supporting them was made of plastic straws, twist ties, and masking tape. Challenges to the task were introduced twice. Then, the structures were tested after completion at two different strengths of earthquake on a shake table with the help of the teacher. Information learned from the engineering challenge was used to investigate the world's tallest buildings. Students were very engaged in both the sculpting and the engineering challenges. They made generalizations about the structures by analyzing successful and unsuccessful designs. Students were very motivated to keep their artwork safe!

Key Words

Earthquake education, elementary students, structural design, Next Generation Science Standards, clay sculptures, engineering standards of the NGSS

Introduction

Children, like adults, habitually seek ways of explaining natural phenomena; often, these explanations are not congruent with accepted scientific principles (Tsai, 2001). Elementary students come to school with their own conceptions about the natural world when they are first introduced to the basic concepts of earth and space (Bulunuz & Jarret, 2009). For children and adults alike, the concepts of earth and space may pose challenges in understanding these scientific phenomena (Bulunuz & Jarret, 2009). People's prior knowledge may be scientifically correct, partially correct, or incorrect with misconceptions; teaching students about natural phenomena such as earthquake mechanisms and occurrence is frequently not as simple or straightforward as one might expect (Ross & Shuell, 1993).

Authors of a report on a seismographs-in-schools project (Kafka, Ebel, Barnett, Macherides-Moulis, Campbell, & Gordon, 2006) noted the problematic difference between elementary students who exhibit curiosity and their teachers who show reluctance to exhibit or model such curiosity. These authors attributed the teachers' attitudes to an absence of confidence and understanding of scientific content and inquiry. This lack of content knowledge appears in other situations. While trainee teachers have been found in their responses to questionnaires and interviews to hold Earth science misconceptions, anecdotal evidence indicates some science teachers to be dismissive of some Earth science misconceptions (King, 2012). Teachers' misconceptions may be a serious problem as indicated by the *National Science Education Standards* (National Research Council, 1996). Bulunuz and Jarrett (2010) observed that misconceptions among teachers teaching the concept of earthquakes and plate tectonics appear to be common. Results from their study on in-service teachers showed teachers had low conceptual understandings of the earth and space science concepts taught in elementary school. They cautioned that teachers lack an understanding of difficult scientific concepts they are required to teach and are unaware of their own misconceptions, they risk passing these incorrect ideas on to students.

Strategies applied to improve students' conceptual understandings include using a variety of textbooks, concept maps, computer simulations, conceptual change texts, field trips, and inquiry activities delivered through the learning cycle lesson plan approach (Bulunuz and Jarrett, 2010). This project was undertaken to explore and exemplify the use of hands-on inquiry activities using the 5E learning cycle on elementary school students' conceptual understandings about earthquakes and plate tectonics. A class of 24 fourth-graders at a Midwest elementary school were challenged to create an earthquake-resistant structure for an earthquake-prone area based on their newly-acquired content knowledge about plate tectonics and earthquakes provided through audio-visual input and text. In fulfilling the standards set by the Next Generation Science Standard (NGSS) 4-ESS3-2 for Engineering Design (NGSS Lead States, 2013, p. 36) for fourth grade students, the authors expected that challenging the students would help them understand the natural Earth processes on humans and lead them to generate ways and compare solutions to reduce the impacts of natural geological processes. Application of the STEAM (Science, Technology, Engineering, Arts, Mathematics) initiative can facilitate conceptual change and provide pathways for personal meaning-making, self-motivation, and construction of one's own learning (Land, 2013). Therefore, the National Coalition for Core Arts Standards for fourth grade were addressed through the project work described in this practical article.

Literature Review

In this brief review of pertinent professional literature, we first consider students' conceptions of earthquake phenomena. Then, we discuss ways of supporting science learning about earthquakes to motivate students and to prevent or resolve misconceptions.

Students' Conceptions of Earthquakes

The most common misconceptions among children, students, and teachers about earthquakes cited in the literature include "little understanding of the locations of earthquakes, little understanding of the causes of earthquakes, and poor knowledge of the structure of the Earth and of the state (solid, liquid, etc.) of its layers" (King, 2012, p.47). Studies have been conducted to explore students' preconceived notions about natural phenomena (e.g. Laçin-Şimşek, 2007; Buluş-Kırıkkaya, Çakın, İmalı, & Bozkurt, 2011; Savasci & Uludüz, 2013) and also ideas about causality of earthquakes after experiencing earthquakes in earthquake-prone zones (e.g. Ross & Shuell, 1993; Tsai, 2001). These studies indicate how prior knowledge influences children's ways of interpreting natural phenomena.

One of the earliest studies, Ross and Shuell's (1993) study, focused on elementary students' conceptions of earthquakes at two different locations in the United States. Students defined an earthquake as a shaking or trembling of the ground, noting it could be caused by volcanoes. Earthquake magnitude was regarded more in terms of property damage, deaths, or casualties it caused. Although in Tsai's (2001) study, conducted after a major earthquake in Taiwan, fifth and sixth graders received scientific information from the media and formal schooling, causes of earthquakes were attributed to myths and supernatural forces. In Buluş-Kırıkkaya and colleagues' (2011) study, Turkish fourth and fifth graders were unaware that they were living in an earthquake zone and simply described an earthquake as a natural disaster and quake. In the same geographical setting, Laçin-Şimşek (2007) investigated kindergarten to eighth graders' ideas about earthquakes and methods of protection. The causality of earthquakes could not be adequately or scientifically explained by anyone. Students also confused earthquakes with landslides, floods, and heavy rains. Turkish fifth graders in Savasci and Uludüz's (2013) study, like students in Ross and Shuell's study, described earthquakes as shaking of the ground, and a natural disaster rather than as a natural geologic process.

Supporting Science Learning about Earthquakes

Students' understandings of scientific concepts may be incorrect or they may develop misconceptions during their learning process. Therefore, it is important that students are exposed to activities that are based on scientific principles (Laçin-Şimşek, 2007; King, 2012) and are age-appropriate (Savasci & Uludüz, 2013) aimed to modify misconceptions. According to the *National Science Education Standards* (National Research Council, 1996), hands-on activities are not adequate for students' "active" science learning. Rather, they should have "minds-on" experiences. In fact, the emphasis is that "learning science is something students do, not something that is done to them" (p. 20). Therefore, if not addressed appropriately, students' misconceptions will persist. Students should be supported in their drive to achieve their goal of learning science content. Creative hands-on activities can motivate them towards science, technology, engineering, and math. In McConnell, Steer, and Owen's (2003) study, collaborative hands-on activities in inquiry-based classes were found to be more effective in clarifying conceptual understanding and preferred more by college students. Land (2013) suggests that the arts can facilitate the development of STEM skills for its more divergent approach. She explains that integrating the arts into core content areas helps a student to investigate a single concept from different vantage points and make use of different modalities of learning.

Davies (2012) suggested workshop activities in which practical demonstrations can help students see how science can reduce the damaging effects of an earthquake. He explained how a quick and easy illustration could involve using house bricks, varying their arrangement and number to produce different responses to earthquakes of different strengths; also, a short demonstration like shaking model buildings created with dry natural straw capped with modelling clay can indicate how resonance impacts the straw as the frequency differs. Furthermore, Hubenthal, Braile, and Taber (2008) advocated challenging students' misconceptions about earthquakes by introducing models such as the Earthquake Machine Lite (EML) along with an activity. The EML is a simple shake table designed to mimic an earthquake. This will not only increase student engagement but promote opportunities to participate in the scientific process.

Studies have indicated increased and higher levels of engagement in scientific inquiry through classroom projects (e.g. Purcell, Ponomarenko, & Brown, 2006; Kafka et al., 2006). Purcell et al. compared the effectiveness of using a Geographic-Information Systems (GIS)-based lesson to traditional text-based instruction on the same topic (plate tectonics) using 5E learning cycle lessons. Findings indicated the potentials of GIS technology in facilitating upper elementary students' understanding of abstract concepts; simultaneously, their inferential and problem-solving skills were strengthened. Kafka et al. (2006) implemented a seismographs-in-schools project to encourage scientific inquiry that required four levels of engagement: recording a distant earthquake using seismographs built by students, basic inquiry requiring exploration of earthquakes recorded, making systematic observations, and searching for and discovering patterns in seismograms. Although the researchers found some success in engaging the students in the world of scientific research, students needed to be prompted to actively engage in monitoring earthquakes.

The fact that students' scientific learning ought to involve "minds on" experiences implies that, as a strategy for teaching the scientific concept of earthquake, lessons should be prepared following the 5 E instructional model with a constructivist learning approach. This model includes the following phases: engagement, exploration, explanation, expansion, and evaluation (Bybee et al. 2006).

Standards Addressed by the Lessons

This lesson supported two Next Generation Science Standards (NGSS; NGSS Lead States, 2013) for fourth grade students. The first standard was 4-ESS3-2 Earth and Human Activity: Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans. This standard was addressed as students constructed different art museum rooms and tested them to determine which constructions best withstood simulated earthquakes while protecting delicate art sculptures. A second standard, an engineering-focused standard, was also supported by the lesson. This standard was 3-5-ETS1-1 Engineering Design: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. The students were given a limit on the type and amount of materials used. They were allowed a set number of large and small straws and twist ties. They could later trade some straws and twist ties for masking tape.

The National Coalition for Core Arts Standards (2014) for fourth grade were addressed, too, through the lesson. To create a structure for protecting art in a new sculpture museum students in the role of artists/architects had to "[C]ollaboratively set goals and create artwork that is meaningful and has purpose to the makers" (Visual Arts: Creating 1.2.4a) and "explore and invent art-making techniques and approaches" (Visual Arts: Creating 2.1.4a). This meant they had to "[b]rainstorm multiple approaches to a creative art or design problem" (Visual Arts: Creating 1.1.4a). They also reflected on their ideas for the sculptures and the successes and failures and decided they would "[r]evise artwork in progress on the basis of insights gained through peer discussion" (Visual Arts: Creating 3.1.4a).

Method

Students in a fourth grade class learned about plate tectonics and fault lines. They used their knowledge to create models of earthquake-resistant structures to safely display a piece of sculpture in a simulated art gallery room.

Participants and Setting

The elementary school at which this lesson took place is a kindergarten through grade four school in the Midwestern United States. The school has a middle class population with 18% of the students receiving free and reduced-price lunches. The school enrolls approximately 220 students of varying ethnic background, with the majority being Caucasian. The school has strong family and community partnerships. The class was made up of 24 students, twelve boys and twelve girls. The school is in the second year of incorporating the Next Generation Science Standards.

Materials

Two earth science videos, one on earthquakes (BrainPOP, 1999–2016a) and one on plate tectonics (BrainPOP, 1999–2016b), were used. Information from the book *Shattering Earthquakes* (Spilsbury & Spilsbury, 2010) was used to provide additional background knowledge. Material used for the sculptures was natural air dry clay purchased at an arts and crafts store, shaped with plastic utensils. Materials for the scaffolded structures that supported the sculptures during the simulated earthquake included plastic drinking straws, twist ties, and masking tape. A "shake table" was made using two cafeteria trays with four ping pong balls sandwiched in between them and held together by two large elastic bands. To simulate a strong earthquake, the teacher pulled the top tray horizontally about 4 inches (10 cm.) away from the bottom tray and released it, allowing the tray to shake back and forth, rolling on the ping pong balls. Paper and pencils were also needed during the work.

The Lesson

The lesson followed the 5 E Learning Cycle format. The five parts of the lesson are described in this section.

Engagement Activity

Students were shown two Brain Pop videos on plate tectonics and earthquakes. These appealing short videos captured student interest and focused their thoughts on the lesson. The class discussed the need for adequate building design to help protect people from earthquakes.

Exploration Phase

Students were told their role in the project. They were all artists who were working together to create a new sculpture museum. Unfortunately, the museum would be located in an earthquake-prone area, so the artists/architects would have to create a structure to protect their art. The structure would also have to allow the sculpture to be seen from all sides, and the sculpture could not rest on the floor. They would be tested against two strengths of earthquake (simulated by pulling on the shake table just a little (2 inches or 5 cm. displacement) or a lot (4 inches or 10 cm. displacement). Students would be supplied with straws, twist ties, and masking tape to make their structures.

Students discussed their ideas for the sculptures, many noting that a sculpture with more of its weight near the base would be more likely to withstand an earthquake. Some students chose design over earthquake resistance, deciding to sculpt a giraffe, for example. They also talked about the different geometric shapes and which ones were more structurally sound. Students remembered a challenge from the beginning of the year in which they had to construct a tower one meter tall using only three by five inch pieces of paper. They reminded each other that the triangular towers held up much longer and decided to base their designs on this geometric shape.

Explanation Phase

The students first made their clay sculptures in art class. See Figure 1 for example animal sculptures made by students. When they were dry, students began the design process for the structure that would support the sculpture and prevent damage during an earthquake. First, working in groups of two, they drew sketches and planned what they would design. To add a challenge to the task, the teacher informed the students that there had been a cut in funding and masking tape was no longer available. Students received ten large and ten small straws and twenty twist ties. After about ten minutes of work, the teacher added another challenge. She explained that limited extra supplies were available for a price. Students could purchase a length of masking tape by trading in a straw and could buy more straws by trading in five twist ties. Example student structures made with the straws, twist ties, and masking tape are shown in Figure 2.

When students' structures were complete, students had the opportunity to test them on the shake table and make adjustments as needed. All structures were tested at two different strengths of earthquake. The top of the shake table was pulled out three inches for the lesser earthquake and five inches for the stronger earthquake. Examples of student sculptures in their support structures on the shake table are shown in Figure 3. Students then were debriefed about the success of each structure and any general designs that seemed to work. They discovered that the pyramid shape was most successful in protecting the sculptures. One student even designed a hammock to place his sculpture on within the pyramid. The hammock swayed and protected the clay alligator.

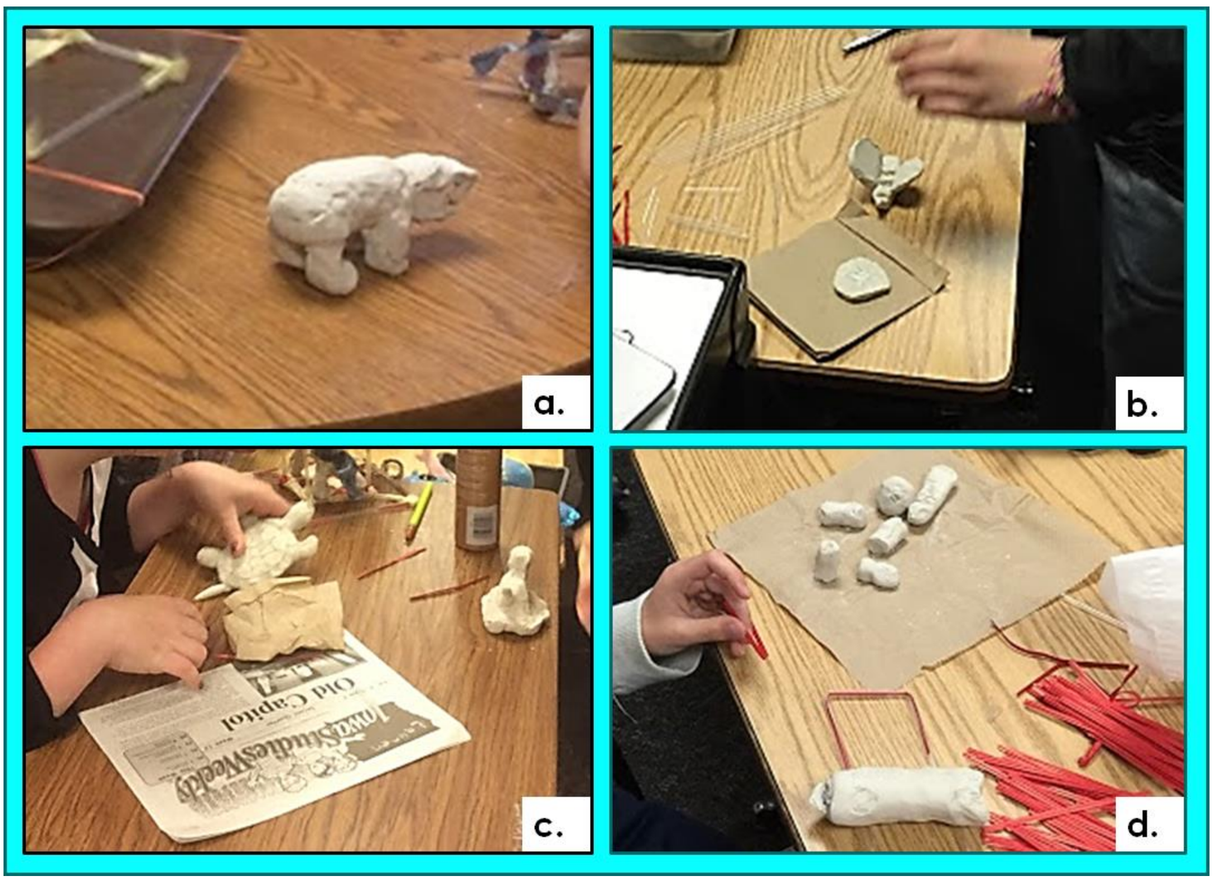

Figure 1. Example animal sculptures made by students. Figure 1a is a polar bear; 1b is a bee; 1c is a turtle; and 1d is the beginning of a red panda.

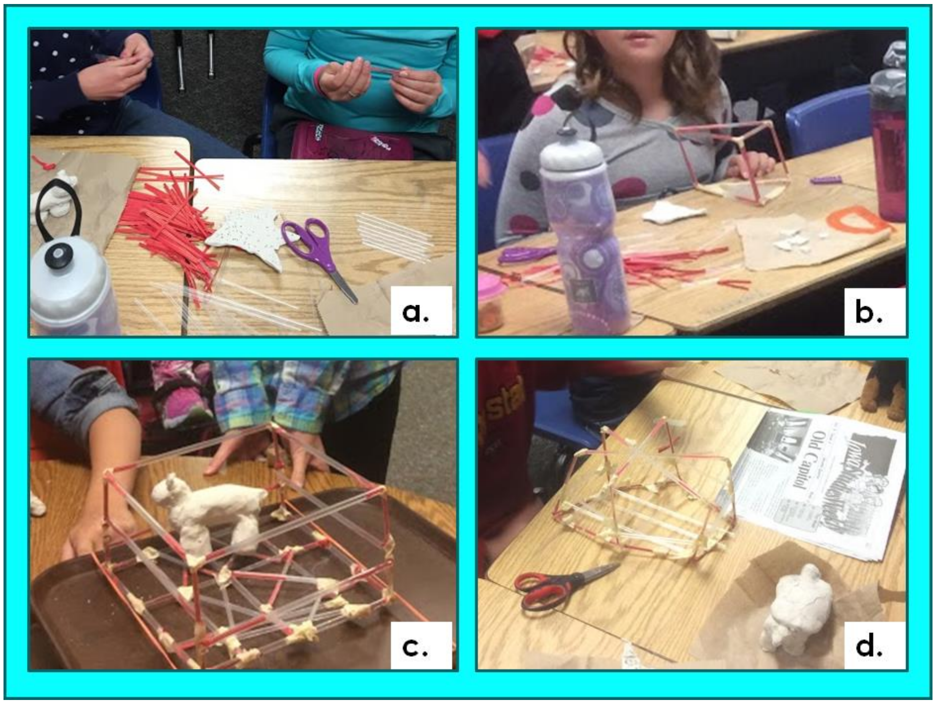

Figure 2. Making the support structures for the clay animal sculptures. Figure 2a shows students starting to make their structures; 2b shows the triangular structure many students identified as being stable; 2c shows an elaborate rectangular structure; 2d shows a structure with an interconnected top.

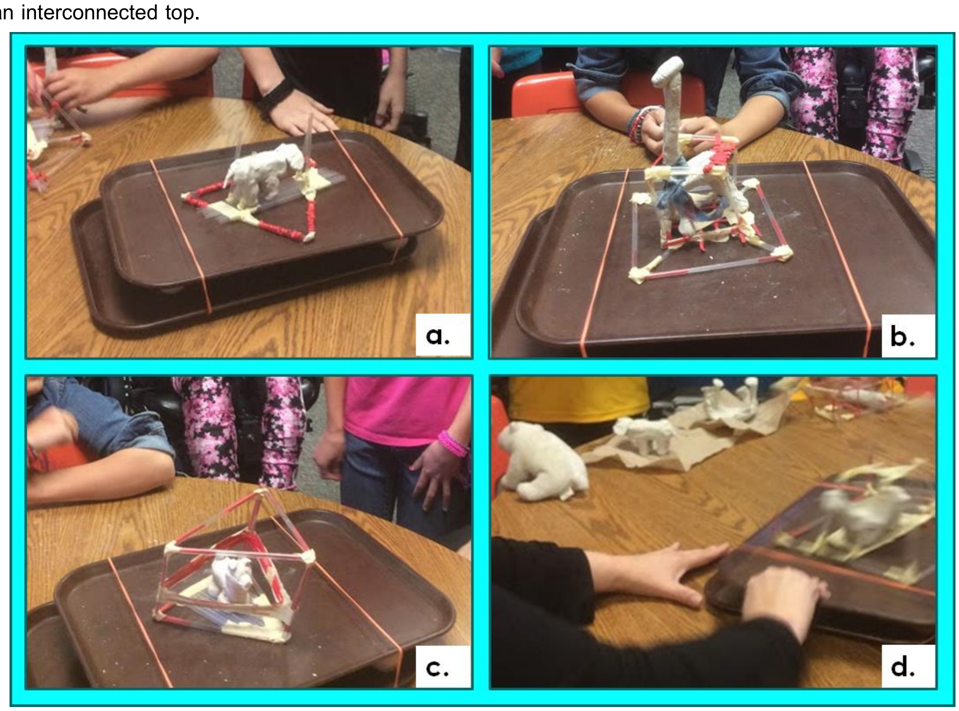

Figure 3. Student work being tested in support structures on the shake table. Figure 3a shows a puppy sculpture being tested; 3b shows the giraffe sculpture that broke apart during testing; 3c shows a pig sculpture that survived the simulation; 3d shows the table in motion.

Expansion Phase

Students took the information they learned from the engineering challenge to investigate some of the world's tallest buildings, such as the Willis Tower in Chicago, the Empire State Building in New York City, and the Petronas Towers 1 and 2 in Kuala Lumpur in Malaysia. They found explanations or inferred what architects had done to make them more stable and to be able to withstand earthquakes. They shared this information with the class. Some of the buildings, like the Dubai Tower in the United Arab Emirates, have a steel core that runs through all floors in the center of the building. Another technique to help a tall building during an earthquake is to have the building float on systems of ball bearings, springs and padded cylinders. These perform similar to shock absorbers in a car and isolate the building from the shaking of the ground.

Evaluation

Students evaluated their structures and wrote what they had learned about creating an earthquake resistant structure based on their own and their classmate's work. Students said they learned it is important to have a solid base in a structure to help with earthquake resistance. They reflected that design of the art is important too: more equant sculptures without long appendages fared better during testing. One student suggested that museums on fault lines should only have unbreakable art. Students reflected on what they could do differently if they faced this task again. Most students were very pleased with the design of their structures, as most structures had protected the art. They did write that if they were to do the task again, they would be sure to think about a "plan B" if constraints change during the project. The teacher evaluated the work by noting each student's reflection. If they had at least one idea of what they learned or what they would change, they received a proficient rating.

Conclusion

The students were very excited and engaged throughout the entire scope of the project. They were very involved in the design process and worked well in their groups. For the most part, the student structures held up, and only a few sculptures toppled. The structures that collapsed seemed to all be tall and lacking attachment points.

The teacher reflected on how the lessons might be improved in the future. Students might use a different medium to create the art for the museum. The clay was very heavy compared to the materials used to build the structures, and this weight may have had a positive impact on the resulting stability of the structures made to support the sculptures. Perhaps an Alexander Calder inspired sculpture with delicately-balanced moving parts or a Faberge-style egg would be more of an engineering challenge and yet still include an interesting art component.

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