# Benefits of a STEAM Collaboration in Newark, New Jersey: Volcano Simulation Through a Glass-Making Experience

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## ABSTRACT

A simulated physical model of volcanic processes using a glass art studio greatly enhanced enthusiasm and learning among urban, middle- to high-school aged, largely underrepresented minority students in Newark, New Jersey. The collaboration of a geoscience department with a glass art studio to create a science, technology, engineering, arts, and mathematics (STEAM) educational experience increased strong interest in learning about volcanoes by 40.7% and learning of volcanic concepts by up to 92% across four major topic areas. In particular, using hands-on, interactive experiences, activities effectively informed and enthused students about the heat of a volcano and lava, lava flows and the dangers they pose, forms of falling volcanic bombs, volatiles in lava, and interaction of lava with water. Teachers found that students remained highly motivated by the experience even after their return to school. The Glass Volcano Experience has the potential to constitute a critical incident in encouraging students to pursue geoscience as an interest and/or profession. Such innovative collaborations of unlikely partners has the potential of creating new and innovative learning experiences for urban students who might not otherwise have the opportunity to witness geologic phenomena in situ. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/16-188.1]


*Key words:* STEAM education, analog models, urban youth

## INTRODUCTION

Place-based education has been found to be effective in Earth and Environmental Science education because it relates theory to geographic and geologic features that are familiar to the students (Semken, 2005; Semken and Butler Friedman, 2008; Apple et al., 2014). There is a stronger interest in science if it can be related to features that are important to students, their families, and their communities. This is especially beneficial in urban areas where students are not as familiar with the features of natural settings where geologic features are more commonly found. As such, place-based education has been found to be effective in encouraging underrepresented minority students to take an interest in Earth and Environmental Sciences, and even consider pursuing the discipline as a college major and career (Boger et al., 2014; DeFelice et al., 2014; Blake et al., 2015). Such place-based education has been applied to studying river systems that flow through many cities and the drainage systems that feed them (O'Connell et al., 2004; Apple et al., 2014). It has also worked well in coastal communities (Blake et al., 2015). The problem is that not all cities have rivers and relatively few are situated in coastal areas. Earth processes demonstrating many fundamental principles of Earth and Environmental Science are not widely available or occur at times where they might be useful for educational purposes.

Volcanism is a fundamental topic for any geoscience course, part of the Next Generation Science Standards (Next Generation Science Standards [NGSS] Lead States, 2013) and considered a "big idea" in Earth Science literacy principles (Wysession et al., 2009). It is also regularly chosen as a topic of study for education and outreach projects because of the hazards, the impact in history, the spectacular visual effects, and the grandeur of eruptions (Parham et al., 2010; Nunn and Braud, 2013; Jolley and Ayala, 2015). However, in the United States, several areas have volcanic deposits but only the Cascade Range from northern California through Washington, Hawaii, and the Aleutian chain in Alaska contain active volcanoes. The only continuously active of these that are relatively conveniently located and safe to approach are in Hawaii.

In an attempt to capture at least part of the enthusiasm for Earth Science generated by place-based education, it is possible to construct analog models for experience (Gates and Kalczynski, 2016), but such a model for a volcano experience would be impossible or prohibitively expensive to construct. However, an innovative collaboration between unlikely partners of a faculty member and students from the Department of Earth and Environmental Sciences at Rutgers University–Newark for science, technology, engineering, and mathematics (STEM) and GlassRoots, a nonprofit glass art studio, for true science, technology, engineering, arts, and mathematics (STEAM) education (Crayton and Svihla, 2015; Radziwill et al., 2015), produced an affordable Glass Volcano Experience for K–12 students from the Newark, New Jersey area. This paper reports on the program and results of this educational experiment between these partners, which was conducted in the 2014–2015 academic year.

STEAM educational opportunities in the geosciences are uncommon. Several efforts have involved combining video production with explaining geoscience concepts (Rooney-Varga et al., 2014) or using popular movies as teaching tools in science classes (Yow, 2014) but these types of collaborations are not uncommon in most academic fields. The use of digital globes to explain deep ocean bathymetry and

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processes to the general public (Beaulieu et al., 2015) has also been employed as a natural STEAM application. More distant and obscure partnerships for STEAM education are underway but less commonly reported at this time.

## PURPOSE AND LEARNING GOALS

The purpose of the Glass Volcano Experience is to give students from urban areas first-hand experience with volcanic processes in their hometown. It is designed to give students an appreciation of the heat involved in igneous processes and an understanding of the properties of molten glass as a proxy for magma and lava, as well as solid and solidifying volcanic rocks. Specifically, the learning goals are to give students an understanding of the fluidity and mechanical properties of lava, the results of interactions between lava with gases and lava with water, the mechanical properties and processes of hardening and crystallizing lava, and the geologic formations produced during a volcanic eruption. The program is also designed to teach students about heat capacity of volcanic rocks and the volcanic hazards of the processes.

## EDUCATIONAL PROGRAM

The visiting school groups were recruited by GlassRoots, primarily through their art education network. Most participants were charter schools from Newark, but public and parochial schools also participated. Participants ranged in age from mid grammar school through high school. Groups were a maximum of 25 students overseen by two to three attending teachers and limited by the size of the facilities at GlassRoots. The program consisted of an introduction and activities in three standard glass facility shops: the torch shop, the furnace shop, and the cold shop. The torch shop consists of individual stations where artists work with glass using acetylene torches. Larger quantities of molten glass are worked in the furnace shop, and solid glass is worked in the cold shop.

### Orientation

Each group was given a 20-min multimedia presentation upon arrival. A professor or a student assistant gave a PowerPoint presentation to the entire group, with photos and embedded videos illustrating the features of volcanoes that would be simulated in the glass shop. The presentation included many of the topics of the InVEST volcanic concept survey (Parham et al., 2010) such as:

- Different types of eruptions, especially Strombolian (video)
- Volcanic bombs: Pele's tears and hair
- Lava flows: transition from magma (video)
- Heat: enough to melt rock
- Destruction of buildings: contact with lava (video)
- Water and explosions: phreatic explosions (video)
- Lava in water: pillow lavas (video)
- Volcanic glass: obsidian
- Gases in lava: vesicles
- Cooling of lava: columnar joints

Students were shown images or videos of the features and they were described and placed into context, and the processes were described using common analogs (Jee et al., 2010), such as soda bubbles to illustrate vesicles in lava. They were also encouraged to interpret what they observed. For example, the phreatic explosion produced white smoke for water vapor and gray smoke for particulate material. Students were encouraged to identify the composition during the program on this basis. Finally, where appropriate, local familiar features were referenced to involve place-based connections, a best practice to engage urban youth (DeFelice et al., 2014). The Watchung Mountains formation is a flood basalt that was extruded during the break up of Pangea 200 million years ago. Columnar joints are ubiquitous in the unit, which occurs in three extensive ridges in northern New Jersey. The Turtle Back Zoo is a popular family destination in the area and named because the polygonal tops of the basalt columns upon which it sits resemble the plates on a turtle's back. After the orientation, the group was divided in two, half in the torch shop and half in the furnace shop.

### Torch Shop

The objective of the torch shop exercise was to learn the mechanics and form of falling volcanic bombs by producing Pele's tears (also known as Apache's tears in geology and Prince Rupert's drop in glass art), and Pele's hair out of glass. Twelve students sat at the studio table of 12 stations mounted with acetylene torches. After a brief safety introduction, the instructor explained and demonstrated how the acetylene torch can heat the end of a glass rod enough to melt it. Once the glass melts, it drips downward in a teardrop shape with a trailing, thread-like tail of glass while hardening (Fig. 1a and 1b). As the glass rod is pulled away from the flame, the thread connects the droplet with the rod and must be detached. The instructor explained that the liquid glass droplet falls like a volcanic bomb in response to gravity and takes on its raindrop-like shape as the result of the physics of falling liquid. Photos of actual volcanic Pele's tears and hair were shown to the students for comparison. The size and texture of the glass drop are similar to Pele's tears, which are composed of volcanic glass.

After the demonstration, the students chose a glass rod in the color of their liking, turned on their torch, and lit it with a striker. With the help of several assistants, each student made two Pele's hairs and tears using the techniques that they observed (Fig. 1a). This gave them firsthand experience with the melting and dripping of glass. Once the glass drop cooled, they cut the hair from it (Fig. 1b). They then chose the best drop to be mounted as a necklace, which they kept.

### Furnace Shop

The furnace shop contains two glass furnaces operating at temperatures of about 1400°C (2000°F), similar to that of a volcano. The students walked in front of each furnace to experience the heat and sight of yellow-orange molten material. Noting that the larger furnace feels much hotter than the smaller furnace, the factor of volume of the hot material was explained. This concept was then extended as students were asked to consider how hot a volcano must feel and appear.

The next activity built upon the video showing lava flows destroying a town in Hawaii. Students were given a box full of simple paper houses and trees and asked to build a small town on a steel table. The glass worker scooped approx-

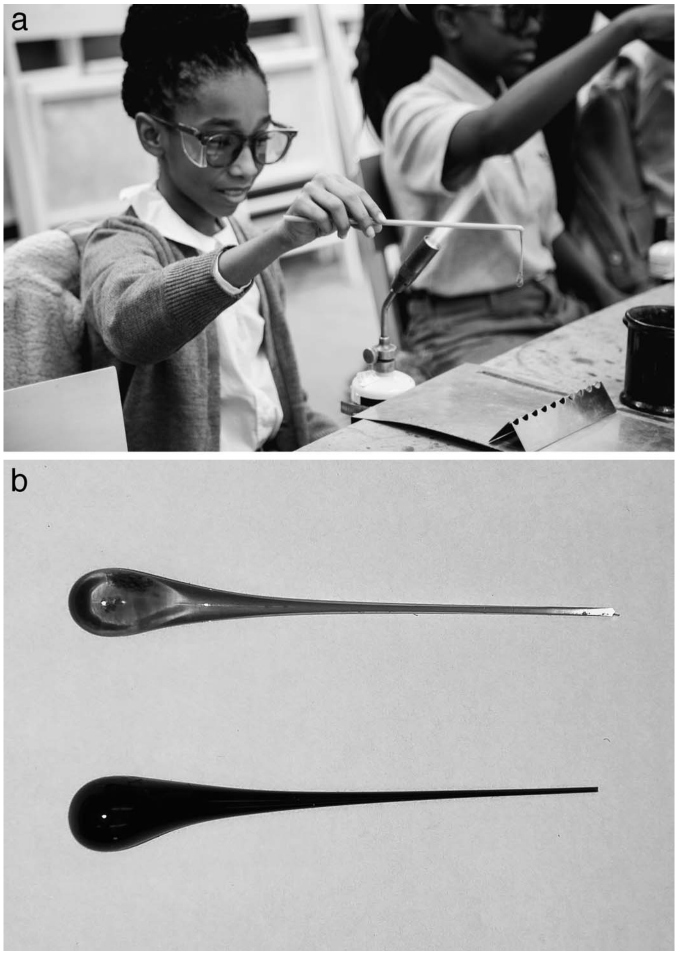


**FIGURE 1: Making Pele's tears from glass in the torch shop. (a) A student makes Pele's hair and a tear from glass using an acetylene torch. (b) Finished Pele's tears with Pele's hair removed. Tears are 4 cm in length.**

imately 0.5 L of molten glass from the furnace and poured it on the table within the town where it slowly spread into circular pancake about 25 cm in diameter (Fig. 2a). Many of the houses and trees burst into flames even if they were not directly in contact with the glass flow (Fig. 2b), and many other nearby houses were blackened but did not ignite. The students were asked to put their hands over the flow to feel the heat and asked how long they thought it would take to cool. They were told that real lava flows can take 10 y or more to cool.

Baking soda was then sprinkled on the glass flow and a second scoop of molten glass was poured on top. The baking soda vaporized and bubbled through the molten glass where bubbles were trapped, forming vesicles. The students understood the purpose of baking soda in baking, and were reminded of the soda analog.

Molten glass was poured into a glass bowl of cold water. It flowed for a short distance before hardening and the exterior began cracking and spalling off of the body. The interior of the glass continued to glow orange. The glass looked very similar to the analog pillow lava from the video and students were asked to recall the process.

Molten glass was then poured into a pot of hot water, which flash boiled upon contact. The mixture hissed loudly and clouds of white steam were emitted. Students were asked to recall the video of the phreatic explosion and to determine whether the smoke was water vapor or pulverized glass based upon the color.

The final activity was to determine how far an approximate 0.5-L scoop of molten glass could be stretched. Students were given chalk and marked the floor where they thought the glass would stretch. The glass workers then stretched the molten glass to a surprisingly long and thin strand that hardened into a glass rod. This was related to a lava flow to show how far they could extend as well as the physical properties of the lava in terms of viscosity and cohesion. These properties were related to how a fiber optic cable could be produced.

During these later activities, the glass flow in the student-built town began to cool and shrink. Loud pops and cracks were heard throughout this time. Upon returning to the flow, cracks and breaks formed clear polygonal patterns in the glass similar to columnar joints to which they were compared.

### Cold Shop

The students entered the cold shop and sat on chairs in a circle. They passed around samples of obsidian and glass for comparison, along with a sample of a columnar joint. The semicircular surfaces in both the obsidian and glass were identified and described as conchoidal fracture. Students could feel these smooth surfaces, and volunteers were permitted to strike the bulk glass samples with a hammer to generate their own conchoidal fractures.

## EVALUATION

The evaluation was conducted by Partnerships for Creative Action educational consultants. Surveys were administered to participating students on site prior to the beginning of the program (presurvey) and immediately following its completion (postsurvey). The student survey was designed to assess participant outcomes in four specific areas: interest in the topic of volcanoes, perception/experience regarding molten glass, knowledge and understanding of volcanoes and volcanic behavior, and the students' assessment of the program's effects. Additional data collection included a follow-up survey that was emailed to teachers of the participating students and administered a minimum of two weeks after the session.

A total of 140 6th–12th grade students from seven schools in the Newark, New Jersey area participated in eight Glass Volcano Experiences. By observation rather than survey, it is estimated that 94% of the students were from underrepresented minority groups, either African American or Hispanic American. This is a similar demographic to that of Newark Public Schools, which has 95% underrepresented minority students (51% African American, 40% Hispanic/Latino American; Newark Public Schools, 2013), though four of the schools were 100% underrepresented minority students. Gender was split evenly between male and female, and student selection for participation varied from school to school. In some cases, a teacher brought an entire class and in others, students were chosen from a variety of classes and grades. In some cases, participation was considered a privilege offered to students who were trusted to behave well and benefit from the experience. The largest number of


**FIGURE 2: Simulating a lava flow using molten glass in the furnace shop. (a) Students watching a glass artist pour molten glass from the furnace onto a metal table containing the town of paper figures assembled by the students. (b) Closer view of glass flow on the table and the town in flames.**

participating students were in the 6th grade (52), followed by 8th grade (42), and 12th grade (19). Smaller numbers of 7th, 10th, and 11th graders also participated. There were no 9th graders in these groups.

## Enthusiasm and Interest

The students were asked to rate their interest in learning more about volcanoes in a Likert scale. They were offered a choice of four responses: *very interested*, *somewhat interested*, *a little interested*, and *not interested at all*.

Table I shows a marked increase in interest in learning about volcanoes between the students' pre- and postsurveys. This is particularly the case with the *very interested* category, which increased 40.7% (from 27.9% to 68.6%). There were corresponding decreases in the *somewhat interested* and *a little interested* ratings (22.1% and 18.6% decreases, respectively). There was no change in the *not at all interested* category.

Table II shows the interest in learning about volcanoes within the 6th–8th grade and the 10th–12th grade level groupings. There was a dramatic increase in interest among

TABLE I: Pre–post interest in learning about volcanoes.

| | % (Frequency) Response | |
|---|---|---|
| Level of Interest | Pre | Post |
| Very interested | 27.9 (39) | 68.6 (96) |
| Somewhat interested | 40.0 (56) | 17.9 (25) |
| A little interested | 30.0 (42) | 11.4 (16) |
| Not at all interested | 2.1 (3) | 2.1 (3) |
| | 100.0 (140) | 100.0 (140) |

6th–8th grade students of 49% among those who described themselves as *very interested*, with decreases among those who were *somewhat interested* and *a little interested*. The changes in the 10th–12th grade responses were less dramatic, with students who were *very interested* increasing by 20%, and a 5.7% decrease in those who were *somewhat interested* compared with the presurvey. There was sizeable 14.3% decrease in the *a little interested* category.

Table III cross-tabulates the pre- and postsurvey responses by individual to show how the changes in each category took place. It shows that 76 of the survey respondents did not change their level of interest in learning about volcanoes by participating in the volcano program. Of those who did not change, 39 remained *very interested*, 21 remained *somewhat interested*, 13 remained *a little interested*, and 3 remained *not interested at all*. Most of the changes were from responses of either *somewhat interested* ($n = 32$) or *a little interested* ($n = 25$) to postsurvey responses of *very interested*. Four individuals who had been *a little interested* in the presurvey, changed to being *somewhat interested* in the postsurvey. Three individuals, who changed from being *somewhat interested* to *a little interested* were the only participants indicating decreased interest in learning more about volcanoes.

## Enhanced Knowledge About Volcanoes

Seven questions were included in the pre- and postsurveys that were designed to measure how much the students learned about volcanoes and volcanic activity. Table IV provides a comparison of correct responses to these questions in the pre- and postsurveys. In addition, the table includes the percentage of change in correct responses.

The most dramatic increase in correct responses to the questions was about the temperature inside a volcano, followed by that "there is an explosion when lava hits water." These are marked changes in levels of knowledge. Notably larger percentages of the participating students began the workshop with some knowledge about the other questions (ranging from 35% to 64.3%), so the changes in percentage of correct responses are less dramatic. The only question that saw a decrease in correct responses was that "lava changes texture when it cools."

## Perceived Effects

The postsurvey included a section asking students to assess their perception of their experience with the workshop in a variety of ways. Table V presents their responses as a whole and by grade level. A majority of the students (69.9%) felt that they "learned things about volcanoes they never knew before"; the percentage was largest among 6th–8th graders (73.5%). A large number of participating students (66.9%) also felt that they had "learned things about molten glass that they never knew before," with the largest percentage (71.4%) among 10th–12th graders. The largest percentage of 10th–12th graders also indicated that "working with molten glass made learning about volcanoes fun" (60%), and that the Glass Volcano Experience "made me want to visit a volcano in person" (28.6%). In addition, 10th–12th graders (51.4%) were more likely to indicate that "combining science and art is a good way for me to learn," and 6th–8th graders (43.1%) were more likely to write that "working with molten glass helped me to understand how volcanoes function." The one category with relatively equal response rates among all of the subgroups was "experiencing molten glass in the context of learning about volcanoes helped me to understand the properties of molten glass," with which 38.2% of all participants agreed.

The students were specifically asked to rate the extent to which the introductory presentation improved the experience. Their responses were as follows ($N = 137$):

- A great deal: 44.5% (61 students)
- Somewhat: 38% (52)
- A little: 15.3% (21)
- Not at all: 2.2% (3)

Students were asked to comment on their experience by identifying their most and least favorite parts. Based on their comments, the hands-on making of Pele's tears was the favorite part of the experience for more than one-half of the participants. This was the case for both 6th–8th grade and 10th–12th grade students, but most other activities were also listed as favorites in fewer numbers. Several students wrote that they enjoyed everything about the Glass Volcano Experience and relatively few identified least-favorite parts.

The teachers were also asked to assess the program's effects on their students. All four of the teacher respondents agreed that it was age- and grade-level appropriate for their students. They all also agreed that the art-making and

TABLE II: Interest in learning about volcanoes by grade level.

| % (Frequency) Response | Grade Level | | | |
|---|---|---|---|---|
| | 6th–8th Grade ($n = 102$) | | 10th–12th Grade ($n = 35$) | |
| Level of Interest | Pre | Post | Pre | Post |
| Very interested | 29.4 (30) | 78.4 (80) | 22.9 (8) | 42.9 (15) |
| Somewhat interested | 37.3 (38) | 8.8 (9) | 45.7 (16) | 40.0 (14) |
| A little interested | 33.3 (34) | 12.7 (13) | 22.9 (8) | 8.6 (3) |
| Not at all interested | 0 | 0 | 8.6 (3) | 8.6 (3) |

**TABLE III: Specific pre–post changes in interest in learning about volcanoes.**

| Presurvey Interest | Postsurvey Interest (% choosing) | | | |
|---|---|---|---|---|
| | Very Interested ($n = 96$) | Somewhat Interested ($n = 25$) | A Little Interested ($n = 16$) | Not Interested at All ($n = 3$) |
| Very interested ($n = 39$) | 39 (100.0) | 0 | 0 | 0 |
| Somewhat interested ($n = 56$) | 32 (57.1) | 21 (37.5) | 3 (5.4) | 0 |
| A little interested ($n = 42$) | 25 (59.5) | 4 (9.5) | 13 (31.0) | 0 |
| Not interested at all ($n = 3$) | 0 | 0 | 0 | 3 (100.0) |

hands-on aspects of the Glass Volcano Experience helped the students to better understand the scientific principles being presented, for example:

> *"It lent itself very well to interdisciplinary teaching, specifically Pele's tears. Students were excited to get some desired output (a necklace) so it forced them to build it effectively using what they knew about the heat and science behind making it."*

> *"The hands-on part was really crucial for students' understanding and retaining the scientific principles because it gave them something concrete and tangible to connect information to."*

> *"When students have to manipulate the molten glass they are able to get a sense of how melted or molten rock behaves. Working with the torches helped them to get a small idea of the amount of heat needed to melt solid rocks, as well as seeing how rocks cool from the outside in. They even experienced that, even if it looks like it has cooled and solidified, it doesn't mean it is actually cool to the touch, it takes time for rocks or glass to cool."*

The teachers also commented on the ways in which the experience affected their students' interest in science.

> *"Many of my students are interested in some field of science (and I think this experience added to their already interested minds). I did find that a student who was interested in art was able to make a connection between art and science, which I think came about from this experience."*

> *"My students really loved being able to work with the glass and see all the demos of glass as lava. They were talking about it for days afterward!"*

## DISCUSSION

The increase in strong interest in learning about volcanoes of the 140 students by 40.7%–78.4% of the total clearly demonstrates that the Glass Volcano Experience was successful in generating enthusiasm among K–12 students in Newark, New Jersey. The quantitative results support anecdotal observations. For example, one teacher reported that they had taken a field trip to the Statue of Liberty several weeks earlier and the students were far more excited about the Glass Volcano Experience, and that their school wanted to make the experience a regular fieldtrip. Although the charter schools and parochial schools forbade cell phone use, most of the students from the public schools captured images and videos of the experience, especially the simulated lava flow through the town. In one group, every student recorded the simulations to view later and to show their family and friends. One student even announced to his group that he thought the trip was going to be boring but that it was really cool.

As far as learning from the experience, in general, the factual questions showed marked increase in knowledge. Virtually all of the students appreciated the amount of heat involved in the process and similarity of lava and glass. These and the interaction of water and lava and factors controlling speed of a lava flow showed marked gains in knowledge. Lesser gains were realized in the danger of lava flows and that eruption styles can vary, though the latter still had one of the higher average scores because of a high level of previous knowledge. The only area that saw a decrease in knowledge was the texture of cooling lava but there was no direct observation of this in the activities, only in observed samples of volcanic rock and in the video. This implies that students learned best in dynamic activities though this would need to be explored in greater detail to be definitive.

Student perceptions of learning were also positive. The students felt most strongly that they learned a lot of new

**TABLE IV: Pre–post comparison of correct responses to factual questions about volcanoes and volcanic activity.**

| Facts About Volcanoes | % (Frequency) of Correct Responses ($N = 140$) | | |
|---|---|---|---|
| | Pre | Post | % Change |
| It is 2000°F inside a volcano. | 9.3 (13) | 96.4 (135) | 87.1 |
| There is an explosion when lava hits water. | 2.1 (3) | 62.9 (43) | 60.8 |
| Lava can take on the properties of glass. | 50.7 (71) | 92.1 (129) | 41.4 |
| Lava flow speed varies depending on a variety of factors. | 41.4 (58) | 66.4 (93) | 25 |
| Lava flow is only dangerous to things in its path. | 35.0 (49) | 42.1 (59) | 7.1 |
| Lava can come out of a volcano in different ways. | 64.3 (90) | 70.7 (99) | 6.4 |
| Lava changes texture when it cools. | 58.6 (82) | 35.7 (50) | –22.9 |

TABLE V: Participating student self-assessment of the Glass Volcano Experience and its effects.

| Effects | All ($N$ = 137) | 6th–8th Grade ($n$ = 102) | 10th–12th Grade ($n$ = 35) |
|---|---|---|---|
| Learned things about volcanoes never knew before. | **69.9 (95)** | 73.5 (75) | 51.4 (18) |
| Learned things about molten glass never knew before. | **66.9 (91)** | 63.7 (65) | 71.4 (25) |
| Working with molten glass made learning about volcanoes fun. | **52.9 (72)** | 50.0 (51) | 60.0 (21) |
| Combining science and art is a good way for me to learn. | **47.8 (65)** | 44.1 (45) | 51.4 (18) |
| Working with molten glass helped me to understand how volcanoes function. | **41.9 (57)** | 43.1 (44) | 34.3 (12) |
| Experiencing molten glass in the context of learning about volcanoes helped me to understand the properties of molten glass. | **38.2 (52)** | 37.3 (38) | 37.1 (13) |
| Made me want to visit a volcano in person. | **26.5 (36)** | 24.5 (25) | 28.6 (10) |

things about volcanoes from the experience, particularly the younger students who may not have attended Earth Science courses yet. This result helps to target the age group for maximum impact. The older students seemed more impressed with working with glass and the analog of glass and lava. The direct question about the STEAM aspect of the experience was appreciated but not to the degree of the STEM results, even though it was partly incorporated in several of the other questions. Teacher perceptions were equally positive emphasizing the hands-on activities and support of STEM interest among the students.

This was not the first formal introduction of STEAM into the geosciences. Recently, geology and cave art were related in a STEAM study (Battles and Hudak, 2005). However, constructing a physical model from existing art resources for STEAM education is not common. Considering that the students had no knowledge or experience with glass art or volcanoes, this construction was a mutual alignment analogy (Gentner, 2005) in which both the target and vehicle had to be appreciated for understanding. Even though this analog seemed to function well for the goal of the study, as cautioned by Jee et al. (2010), volcanoes and lava have many factors that are difficult to account for. For example, the viscosity of the glass tends to be very high and small volumes tend to harden quickly, which greatly reduces the flow and prevent surface textures like the ropy surface of pahoehoe lava. The columnar joints form in an instant, which may not reflect nature either. For that reason, the planned learning must be thought through carefully to avoid giving misinformation or the wrong impression through a poor analogy. In the current study, the heat and effects thereof, the shape and character of a falling liquid, the interaction of liquid glass/lava with water, and the character of solid glass, whether volcanic or not, were emphasized without emphasizing details of volcanic features. This is why the exercise was apparently more effective with the younger students.

The vast majority of the participating students were from underrepresented minority groups. They clearly enjoyed the experience and learned about processes of a fundamental topic in geoscience. Considering that the geosciences are the least diverse of the sciences, graduating only about 9% or fewer underrepresented minority students with Bachelor's degrees per year (American Geological Institute, 2014), such experiences might be beneficial in addressing this problem. The exercise certainly falls within the general recommendations for best practices of hands-on, active, and authentic experiences (Karsten, 2003; Huntoon et al., 2005; Huntoon and Lane, 2007). Stokes et al. (2015) found that minority interest and persistence in the geosciences was commonly sparked by a critical incident in their lives that drew them to the study. The Glass Volcano Experience could serve as such a positive critical incident to encourage these students to pursue geosciences.

The next step in this analysis would be to form a longitudinal study on the students who participated in the Glass Volcano Experience. It would be important to determine whether it actually qualified as a critical incident and if it encouraged any of the participating students to pursue geoscience as a college major or profession. If the students performed better in their science classes, engaged in other extracurricular activities in science, or pursued science as a college major, this would also be considered a positive outcome. There is no plan to conduct such an analysis at this time.

## Recommendations for Innovative Partnerships

Innovative collaboration of less than obvious partners like this has the potential to provide new educational experiences that could be more effective than current practices in both learning and encouraging students to pursue geosciences. In general, STEAM efforts require innovative collaborations and, as a result, are increasing in many STEM areas. Other opportunities, however, also exist at many levels from combining techniques from different sciences to industry. They have the potential to form the critical incidents that encourage students to pursue geosciences (Stokes et al., 2015) and other STEM disciplines. This may be especially effective in areas where students may not have the resources to visit geological phenomena in their natural state.

Other unusual collaborations have yielded effective geoscience educational resources. For example, a collaboration of multiple agencies in New York to evaluate the safety of subway ventilation during terrorist attacks was used as an educational opportunity for geoscience students (Blake et al., 2015). This unusual collaboration encouraged student interest through the practical value of the results in protecting city residents. In another example, an annual tradition of thousands of students jumping into an artificial pond on a university campus in support of a football rivalry game was used to teach students about water quality and the effects of human activities on the environment (Goldsmith et al., 2013). These and other examples require a willingness of collaborators to operate outside of their normal comfort zones. It requires significant effort to smooth the transition between incompatible educational and outreach practices on many levels of science, but also addresses differences as basic as understanding and using new vocabulary. In many cases, STEAM collaborations might be the most difficult of these because the areas are so disparate. As this study demonstrates, making the effort to explore such unusual partnerships can have outstanding benefits to expanding and improving geoscience education.

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