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Building and Using a Hydrology Experiment for Place-Based Learning With Native American Students

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BUILDING AND USING A HYDROLOGY EXPERIMENT FOR PLACE-BASED LEARNING WITH NATIVE AMERICAN STUDENTS

by

Michaela Shallue

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ABSTRACT

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by

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Geoscience has a known diversity problem, which is partially manifested as a participation gap of ethnic minority representation. This participation gap is especially severe regarding Native American representation. To address this participation gap, an identity gap first needs to be bridged. This is where Native students need to first be able to visualize themselves as geoscientists before they can commit to geoscience programs and careers. This project uses a hands-on, place-based learning activity as an opportunity for Native students to better see themselves as geoscientists.

Portable rainfall simulators have been used to investigate the relationships between infiltration, runoff, and erosion since its invention in the 1950's. Here, we use a portable rainfall simulator to help teach these concepts to Native American students through place-based learning, where concepts are tied to specific locations. Native students were from the Four Corners region of the southwestern United States, where infiltration-excess overland flow is commonplace in the landscape due to low infiltration rates and intense monsoonal storms. Over a year and a half of using the rainfall simulator, improvements to the design and calibrations were made for more accurate data collection and better use in teaching.

The rainfall-simulator activity was used in learning settings at Utah State University (USU) that develop pathways for Native Students to pursue STEM degrees – the Native American Summer Mentorship Program (NASMP) and USU's Blanding campus College Launch and Upward Bound programs. I investigated whether hands-on learning experiences connected practically to Native homelands increased attitudes towards geoscience. Before and after each implementation of the rainfall-simulator activity, student volunteers completed a pre- and post-survey to rank and assess their attitudes and motivations toward geoscience. A follow-up group interview was used for further qualitative analysis on the activity. Main takeaways are that learning science is more likeable when hands-on, that making connections between STEM learning and students' lives does create more meaningful experiences, and that the hydrological-analysis portion of the learning activity needs to be improved. These main takeaways apply to all students, but in this project, we focus on how they specifically apply to Native students.

(69 pages)

PUBLIC ABSTRACT

Building and Using a Hydrology Experiment for Place-Based Learning
with Native American Students

Michaela Shallue

Geoscience has a known diversity problem, specifically a participation gap of ethnic minority representation, and it is especially severe regarding Native American representation. To address this participation gap, an identity gap needs to be addressed first. Native students need to visualize themselves as geoscientists before they can commit to geoscience programs and careers. This project uses a hands-on, place-based learning activity as an opportunity for Native students to better see themselves as geoscientists.

A portable rainfall simulator was constructed, calibrated, and refined for use in teaching concepts about rainfall, runoff, and erosion. It was employed in place-based learning exercises with Native students from the Four Corners region of the southwestern United States. Students who volunteered to complete surveys and participate in a group interview provided results indicating they could indeed see themselves as scientists better after the exercise.

ACKNOWLEDGMENTS

I would like to especially thank my major advisor, Dr. Joel Pederson, for taking me on as a graduate student to work on this project in geoscience education, as well as letting me explore geomorphology beyond my project to collect and process luminescence samples. I am most grateful for Joel's patience in my writing. I am also appreciative of my committee members Dr. Kristin Searle and Dr. Katie Potter. My independent study with Kristin was valuable in gaining the background necessary for this project, and she provided highly constructive feedback on my proposal, research, and thesis draft. Katie not only has provided feedback on my project, but as given advice on what to expect during my experiences in Blanding, and has been great listener and person to bounce ideas off of for my project, the department's DEI working group, and beyond. I'd also like to thank Colter Davis for letting me take a day away from his intro class to implement my project, as well as helping me with the activity. I'd also like to thank Joel, Katie, Matt Rossi, and Yuval Shmilovich for assisting with the activity in Blanding.

This research was made possible by financial support from the National Science Foundation (EAR- 2100753; 1633756), USU's Climate Adaptation Science Program, and USU's Geosciences Department. Additional support was provided by the Geological Society of America and the Four Corners Geological Society. I would like to the thank the USU Geosciences Department for awarding me the J. Steward Williams Graduate Fellowship twice.

I'd also like to acknowledge the land this project was completed on. Utah State University Blanding, where I completed my fieldwork, resides on the ancestral, traditional, and contemporary lands of the Navajo Nation, San Juan Southern Paiute

Tribe, and the White Mesa Ute peoples. Participation in the Native American Summer Mentorship Program, this project's analysis, and my graduate experience was completed on the ancestral, traditional, and contemporary lands in the Sihivigoi (Willow Valley) of the Northwestern Band of the Shoshone Nation.

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CHAPTER I

INTRODUCTION

The field of geoscience has had a long-lasting issue of diversity. Of physical science programs, geoscience has ranked worst for ethnic diversity, especially with Native peoples (AGI, 2010; Bernard & Cooperdock, 2018). While other minority ethnic groups see an increase in number of awarded undergraduate degrees in geoscience over the past decade, this number has remained stagnant for Native peoples (AGI, 2020). To address this participation gap, we need to first address an identity gap, where underrepresented groups need to be able to visualize themselves in STEM fields (Searle and Kafai, 2015). A potential solution to bridging the identity gap is to incorporate place-based education, where taught concepts are tied to specific places.

To explore the effectiveness of a hands-on, place-based exercise in helping Native students better visualize themselves as geoscientists, this study built and utilized a portable rainfall simulator to learning hillslope hydrology concepts. The construction and calibration of the device is outlined in Chapter 2 of this Thesis. This includes a narrative of iterative improvements to the rainfall simulator to better fit the needs of teaching runoff processes as well as research data collection.

Chapter 3 assesses whether the rainfall simulator activity is a useful tool for motivating Native students about geoscience, where students can understand the importance of geoscience, and see themselves becoming geoscientists. This is explored in changes between a pre- and post- surveys from student volunteers inquiring about self-concepts and tribal identities in regard to science. In addition, a group interview was conducted to better understand students' responses to the rainfall-simulator activity. The rainfall-simulator exercise was employed in three programs hosted by Utah State University (USU), that offer pathways for Native Students to explore STEM fields, including the Native American Summer Mentorship Program (NASMP) and the Upward Bound and College Launch programs at the USU Blanding campus.

I recognize that the findings in this study might not apply to all Native students. I am a cis-gendered, white woman, and I approached this project through that lens and recognize that not all biases can be eliminated.

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CHAPTER II

DESIGN AND CALIBRATION OF A RAINFALL-RUNOFF SIMULATOR FOR USE IN GEOSCIENCE RESEARCH, TEACHING, AND OUTREACH

ABSTRACT

Portable rainfall simulators have been used to investigate the relationships between infiltration, runoff, and erosion since their invention in 1950's. Here, we use a portable rainfall simulator to teach these concepts to Native American students through place-based learning. In particular, we used the rainfall simulator to teach infiltration-excess overland flow and its associated erosion to Native students from the Four Corners region of the southwestern United States, where these processes are commonplace due to low infiltration rates and intense monsoonal storms. The rainfall simulator we used to teach these processes was constructed based on a design by Iserloh et al. (2012). The rainfall simulator was calibrated with three Lechler nozzles (model numbers: 460 608, 460 606, and 460 486). As recommended by Iserloh et al. (2012), we found 460 608 to be the best nozzle for our rainfall simulator. This nozzle was used for place-based teaching instruction in an introductory geology class consisting of mostly Native students at USU Blanding, in the Four Corners region, as well as an upper-level geomorphology course at USU Logan. After a year and a half of using the rainfall simulator, improvements to the design must be made for more accurate data collection, but the instrument is still useful in teaching infiltration-excess overland flow.

2.1 INTRODUCTION

The interactions between rainfall, infiltration of moisture into soil, and runoff dictate flooding and erosion, particularly in dryland environments where soil-infiltration rates are low. The drylands of the southwestern United States are subject to convective monsoonal storms and frontal storms that cause flooding and erosion. Our goal is to improve learning about these geomorphic processes with students, especially Native students whose homelands are marked by infiltration-excess overland flow and its erosion. To work with students and understand how these processes play out in a single storm, we built and tested a portable rainfall-runoff experimental setup that simulates a rainstorm of known intensity and allows the measurement of runoff. After calibration and testing, we conducted field-experiments as learning exercises to better engage Native students in geoscience.

Infiltration-excess overland flow occurs when the rate of precipitation exceeds the changing rate of water infiltration into soil over the length of a storm. Also known as Hortonian overland flow, this type of runoff commonly occurs in semi-arid and arid regions, where infiltration capacity is low. To explore these processes with the rainfall-runoff setup, we have the advantage of setting a known precipitation rate, and then being able to observe the time and amount of runoff from a plot of known size. We also task students with measuring infiltration rates as they change through time and differ among substrate types using mini-disk infiltrometers for comparison to the experimental observations. These infiltration data provide an estimate of when the precipitation rate should exceed the incrementally decreasing infiltration rate and when runoff should occur.

The advantage of using a rainfall-runoff experiment for learning about these processes is that it provides hands-on learning. In comparison to conventional, lecture-style teaching, experiential learning creates a more enriching experience, and students are better able to understand and remember learned concepts. Also, the simulator is portable, so it's easy to transport to different test locations. It can be used to teach students about the hillslope hydrology of different places and soil conditions through place-based learning. This is advantageous for outreach with Native students located at the USU Blanding campus in southeastern Utah, nearly 400 miles away from USU's main campus in Logan, UT.

2.2 BACKGROUND

Portable rainfall simulators have been used in multiple disciplines, including soil science, agriculture, and engineering, and in a wide variety of settings to conduct runoff and erosion experiments. The first portable rainfall simulator experiment was used by Adams et al. (1957) to conduct erosion and infiltration experiments beyond a single, set location. Today, researchers constructing rainfall simulators strive to make them more portable in order to access remote locations and use less water (e.g., Cerdà et al., 1997; Clarke and Walsh, 2007). For example, to investigate runoff and erosion in drylands, portable rainfall simulators have been used to study terrace erosion (Martínez-Hernández et al., 2017), erodibility of calcareous soils (Ayoubi et al., 2018), and tillage effects on runoff and erosion in semi-arid to arid regions (Jones et al., 1994; Wang et al., 2017).

As part of broader research on the evolution of desert escarpments (Shmilovitz et al., 2023), we had the goal of quantifying rainfall and runoff thresholds for erosion at multiple field sites. To meet this goal, we designed a portable rainfall simulator based on the design of Iserloh et al. (2012) (Figure 2.1), because their study and design share our observational goals. The Iserloh et al. (2012) portable rainfall simulator is relatively simple to assemble, and parts are easy to obtain. Iserloh et al. (2012) also tested specific nozzles, specifically investigating drop size and distribution, allowing us to build upon their recommendations.

Figure 2.1. Portable rainfall simulator schematic from Iserloh et al. (2012). Design shows the main components of the portable rainfall simulator, including a water pump, needle valve flow meter, nozzle, and plot.

2.3 CONSTRUCTION AND TESTING OF SIMULATOR

2.3.1 Rainfall Simulator Construction

Our rainfall-runoff experimental setup includes Lechler-brand spray nozzles identified in Iserloh et al. (2012), as well as a needle valve, a flow pressure meter, and a pump purchased commercially (Figure 2.2). Three Lechler nozzles were chosen to test which is the most useful for the rainfall simulator: models 460 608, 460 606, and 460 486. They were chosen based on differences in how wide the nozzles spray laterally.

Other key components were custom-designed and fabricated by the Geosciences Department technician, Kenneth Kehoe. This includes the stainless-steel frame that holds the nozzle, the legs that extend downward from it, and the aluminum circular plot with funnel to divert runoff. The circular plot is notable (Figure 2.2C) for being made of lightweight aluminum and more portable, with an exit chute set at a shallow downward angle with a cover piece to shield it from receiving direct rainfall input to the chute area. The circular plot was widened to incorporate more soil variability and has a diameter of 0.74 meters, which gives the interior of the test-plot an area of 0.43 square meters. An additional aluminum ring extending 1 cm below the base of the circular plot was added early during our study to better inset the plot into the ground. However, it was found that this interfered with rocks and uneven ground and added an unwanted exit route for water; therefore, the basal ring was removed.

Finally, the setup is completed by the addition of a shower curtain and a top ring to hold the curtain. The shower curtain prevents interference from wind while also protecting nearby scientists and students from getting wet. The curtain is made from a tarpaulin, which is heavy enough that isn't easily moved by wind and is long enough to be held down by heavy objects to avoid slack interfering with the simulated rain. The curtain does get hit by laterally directed spray, which then runs down the inside of the tarp and outside of the circular plot.

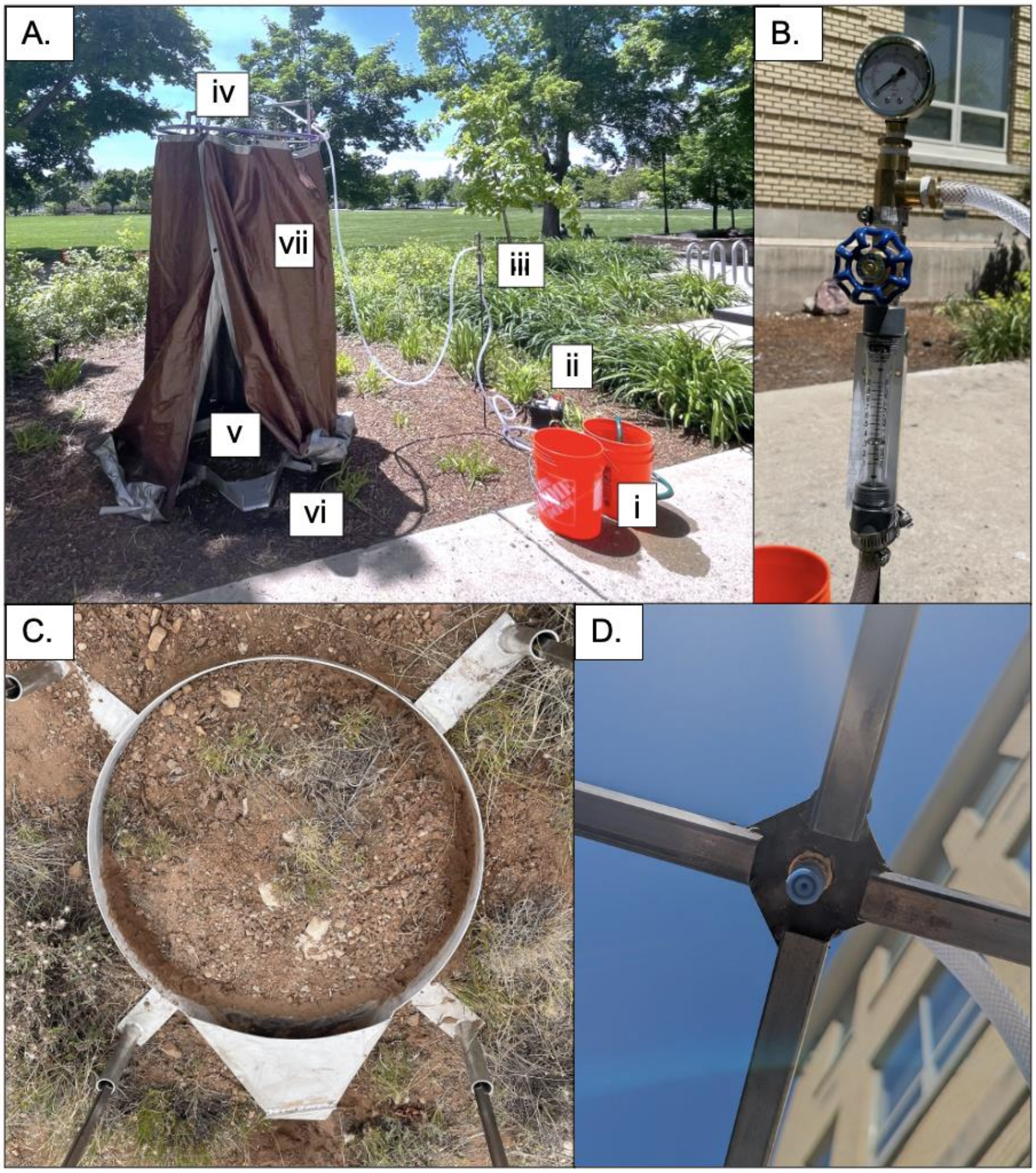

Figure 2.2. Rainfall-runoff experimental set up: A) i. buckets where water is held and the pump uptakes water from; ii. battery and water pump that pushes water through the hose and nozzles; iii. flowmeter that controls the rate of flow through the hose; iv. location where water comes out from the nozzle, pointing down at the ground toward the circular plot; v. circular plot used for rainfall simulator trial observations; vi. spout where water is directed for runoff collection. This is placed at the downhill location of the plot so water will naturally flow. vii. The shower curtain is used for wind protection and to protect observers from spray. It is weighed down at the bottom to prevent sagging and interference from wind. B) Flow meter used to control flow rate of water coming out of the nozzle; C) overhead image of circular plot used for rainfall simulator trial observations for ponding, runoff, and erosion; and D) close image of nozzle, where water is expelled from the top of the rainfall simulator.

2.3.2. Testing and Calibration Narrative

The rainfall simulator was first used in a flower bed at the USU Logan campus in May 2022 with Lechler nozzle 460 608. Fifteen-minute calibrations were completed to measure rainfall rates. This involved running the simulator at set flow rates for fifteen minutes and collecting rainwater in a Nalgene beaker from within the plot. The rainwater collected was used to convert to flow rate. For each flow rate, at least one measurement was taken from the center, and a second measurement was taken along the inside edge of the cylinder.

In this first trial, the rainfall simulator used a light-weight shower curtain for wind protection. The shower curtain didn’t reach the ground completely, making it difficult to keep taught and prevent wind from interfering with water reaching the circular plot. After the first round of 15-minute rainfall rate calibrations, it was found that the battery running the pump for the simulator would last only 45 to 60 minutes. The battery required an overnight charge, so we determined a second battery was necessary to conduct a full experiment. A final lesson from the first trail was that the hole dug for collecting samples below the exit chute for runoff from the circular plot needed to have a drainage outlet. By digging a trench from the hole, the water doesn’t overfill the hole, and runoff collection is possible.

The simulator was next set up and used for the Native American Summer Mentorship Program (NASMP), where we continued to work on calibrations and construction with a visiting undergraduate student. The rainfall simulator was used at four locations: 1) in a flowerbed on the USU Logan campus; 2) on a hillslope along the valley floor above the mouth of Green Canyon in Logan, UT; 3) on a low-sloping terrace along the Blacksmith

Fork River near Hyrum, UT; and 4) on a dirt lot on the USU Logan campus near the Surplus Property Sales building (USU Surplus). Nozzle 460 608 flow-calibrations were continued in the flowerbed where it was determined that flow rate has an inverse relationship with precipitation rates, so that when low flow rates are used for water input, higher rainfall rates come out of the nozzle, due to the spray being more direct at lower flow rates. At Green Canyon, it was very windy when attempting to use the simulator. The interference of wind altered the rainfall rate over the plot, greatly reducing the precipitation rate and runoff was not achieved. As a result, we upgraded the shower curtain to tarpaulin, which improved the wind protection. A hula hoop was added to hang the tarp. Then, the simulator was taken to a location in the Blacksmith Fork River Canyon floor, where it was set up on a sloping, grassy river terrace. No runoff was produced here, possibly due to errors in set up and the fact that the substrate has naturally high infiltration rates. Finally, to gain observable runoff more readily, we conducted a trial on a compacted surface with hypothesized low infiltration rates – a dirt lot near USU Surplus. Runoff occurred after two minutes at a rainfall rate of 4.3 cm/hr.

Following the initial set up and adjustments made with the NASMP student, the rainfall simulator was used during an activity with 22 students enrolled in an introductory geology class at USU's Blanding campus in June 2022. This class is taught through USU Blanding's Upward Bound and College Launch programs. Here, the rainfall simulator was set up on ground that is a mixture of exposed bedrock, gravel, and sand cover right at the west edge of USU's Blanding Campus. This was the first activity where students also measured infiltration rates with mini-disk infiltrometers. We ran the rainfall simulator at a rainfall rate of 4.3 cm/hr for 10 minutes, then increased it to 5.1 cm/hr for the remainder of the experiment. Runoff was successfully produced after 14 minutes. The time of observed runoff was compared to the predicted time from the infiltrometer measurements, which didn't predict runoff to occur. We elected to not collect runoff volume, as we were not confident with this step yet.

Immediately after using the rainfall simulator with the Upward Bound and College Launch students, the device was used for research-data collection at a site in the Book Cliffs near Woodside, UT. Based on this experience with other research collaborators, we removed the extended metal ring at the base, and learned to use mud made in the field to seal gaps between the ring and the soil. The mud barrier can be added on the inside and outside, all the way around the ring to ensure that water ponding and running off from the circular plot is diverted to the funnel.

In October 2022, the experimental setup was used in a laboratory exercise for a geomorphology class at USU Logan. Two separate lab classes worked with the simulator and mini-disk infiltrometers at the dirt lot located by USU Surplus. However, the spot chosen was not as compact as in the prior trial at this location. Runoff wasn't observed until 25 minutes after running the rainfall simulator at a rainfall rate of 5.1 cm/hr.

Up until this time, only nozzle 460 608 had been used. Our observations indicated that we could only simulate relatively high rainfall rates with this nozzle, and that small changes in flow rates resulted in large changes in rainfall. For example, the high end of rainfall rates might double with just a 0.05 gal/min change in flow rate. We wanted to see whether other nozzles could fine-tune rainfall rates over a larger range of flows. To explore two other nozzle models and to gain a more complete calibration of rainfall rates that could be simulated in the plot, calibration runs of the rainfall simulator were conducted indoors in the Geology Building at USU Logan in February 2023. Full results are described in the next section, but in summary, original nozzle 460 608 was found to have the widest range in precipitation rates given flows ranging from 0.2 to 0.3 gal/min. Nozzle 460 606 had a more limited range in average rainfall rate, while nozzle 460 468 was even less useful.

In late May and early June 2023, the rainfall simulator was used for a second iteration with two NASMP students at the USU Logan campus and then with introductory geology students in the Upward Bound and College Launch programs at the USU Blanding campus. During the USU Logan experiments, the NASMP students worked with the rainfall simulator and mini-disk infiltrometers. Two trials were run, the first at the USU Surplus location, and the second at the Blacksmith Fork Canyon location. Runoff data were collected at both sites. The USU Blanding experiment was held at the same field location as the previous year. Runoff was successfully produced for each of these trials, but it became increasingly clear that the mini-disk infiltrometers failed to validate the runoff time. Because runoff volume was also collected, students got to plot runoff as a hydrograph. This part was added in 2023 to enhance students understanding of the rainfall-runoff relationship and how runoff behaves over time.

2.3.3. Calibration of flowmeter for rainfall rate

Once the experimental setup was complete and refined, we conducted systematic testing and calibration to explore the rainfall rates produced by each of the three spray nozzle models over different flow rates set by the needle valve. Each rainfall rate calibration has at least one calibration measurement taken with the 2 L Nalgene beaker from the center of the plot as well as at least one measurement from the interior edge of the circular plot. Collected rainfall in the beaker was transferred to a 500 mL graduated cylinder for measurement at regular time intervals. Taking the measurements from both the center and the edge is important because rainfall rate is observably different across the area of the plot.

Spray nozzle model 460 608 is recommended in Iserloh et al. (2012). Yet, we recognized that the range of rainfall rates the nozzle could simulate is limited by the fact that, after a point, increased flow does not produce significantly different rainfall rates on the ground. Thus, we explored whether other spray-nozzle models may be better suited to model rainfall rates.

Nozzle 460 608 calibration runs were set at flow rates ranging from 0.2 gal/min to 0.4 gal/min. This produced rainfall rates measured in the circular plot ranging from 10.1 cm/hr at 0.2 gal/min, down to 2.6 cm/hr at 0.4 gal/min. There is greater difference in simulated rainfall rate at lower flows but more precise or reproduceable rainfall rates at larger flows ranging from 0.275 gal/min to 0.4 gal/min (Figure 2.3A.). The rainfall rates plateau at around 3 cm/hr. Any flows above 0.4 gal/min sprayed mist rather than droplets, and the nozzles increasingly sprayed water laterally. A least-squares best-fit function through the datapoints results in the decaying power function:

$$y = (0.00002x^{-7.9}) + 2.9 \qquad \text{Eq. 3.1}$$

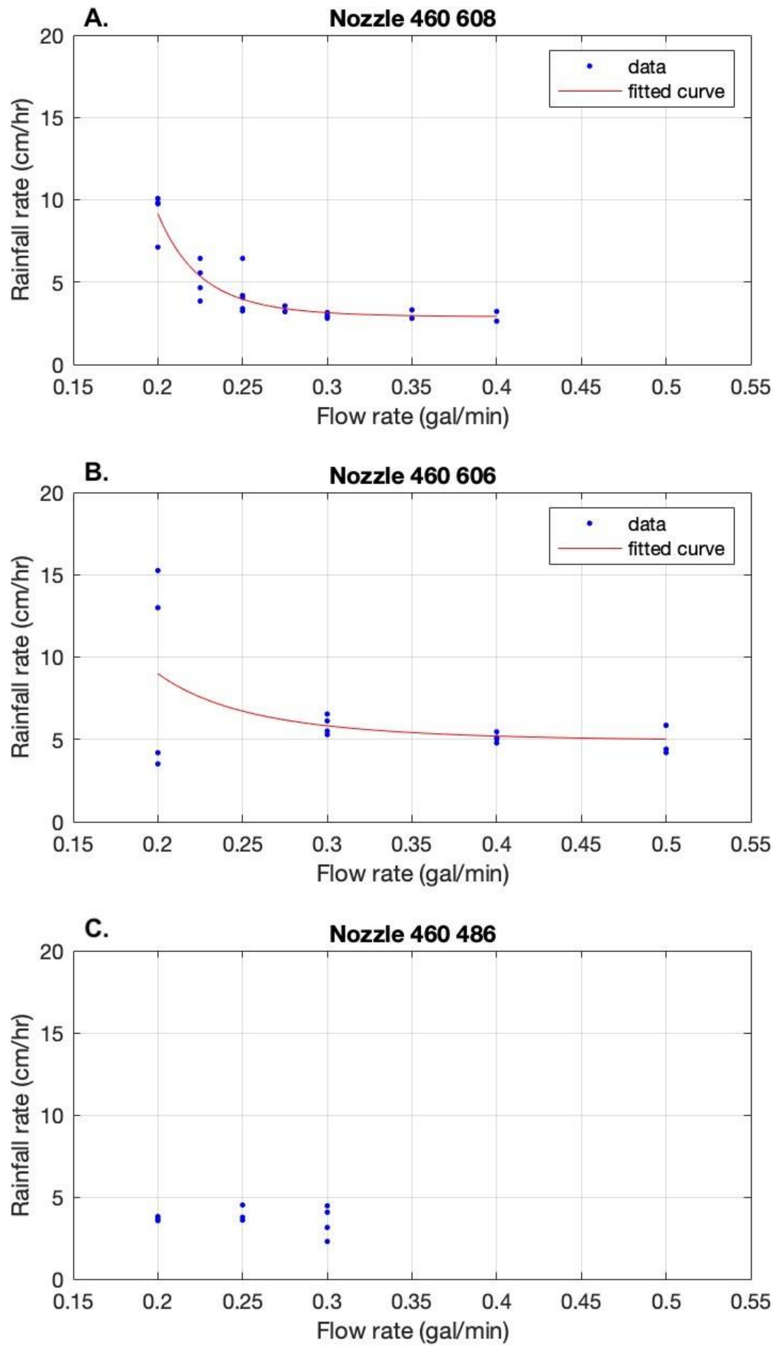

Figure 2.3. Plots of calibration data and fitted-exponential trends for the first two nozzles: A) Nozzle 460 608 (R^2=0.8637); B) Nozzle 460 606 (R^2=0.2697). C) Nozzle 460 486 (the trendline result is not statistically valid).

Nozzle 460 606 calibration runs were conducted from 0.2 to 0.5 gal/min (Figure 2.3B.). At the lowest flow of 0.2 gal/min, there is greater variability in measured rainfall rates from 3.5 cm/hr, collected at the edge of the circular plot, to 15.3 cm/hr collected at the center. This nozzle directs most of its water directly down and is more uniform in the center with less flow being diverted laterally. This was confirmed in observation and was expected because its spray angle is 90°, which is smaller than nozzle 460 608, which is 120°. At 0.3 gal/min and higher, the rainfall rates become more uniform across the area of the plot and the average varies less, simulating rainfall of around 5 cm/hr regardless of increased flow. Nozzle 460 606 data, with relatively low significance, results with the following power function:

$$y = (0.013x^{-3.6}) + 4.8 \qquad \text{Eq. 3.2}$$

Nozzle 460 486 calibration runs were limited to flows between 0.2 and 0.3 gal/min (Figure 2.3C). Slower flows did not produce droplets spanning the full circular plot, while flows higher than 0.3 gal/min did not work at all, because the nozzle seemingly prevented water exiting under high pressures. These limited results did not produce a valid functional relationship between flow and simulated rainfall rate.

In summary, despite our effort to explore other available spray nozzles, model 460 608 performs the best for experimentation as suggested by Iserloh et al. (2012). The nozzle's average rainfall rates vary from 2.9 to 9.2 cm/hr across 4 useful valve settings, providing the best range to work with. It produces rainfall at low flow rates, so using the simulator doesn't require as much attention as rainfall rates that require higher flow rates. However, this nozzle shouldn't be used above 0.4 gal/min, because then the nozzle sprays mist, rather than droplets. Average rainfall rates calculated from the calibrations of the three nozzles are summarized in Table 2.1.

TABLE 2.1. RAINFALL RATE CALIBRATION AVERAGES

Nozzle model number	Flow rate (gal/min)	Rainfall rate (cm/hr)
460 608*		
	0.2	9.2
	0.225	5.1
	0.25	4.3
	0.275	3.3
	0.3	3.0
	0.35	3.1
	0.4	2.9
460 606**		
	9.2	9.0
	0.3	5.9
	0.4	5.1
	0.5	5.1
460 486***		
	0.2	3.7
	0.25	4.0
	0.3	3.5

* N = 24
** N = 16
*** N = 13

2.3.4 Example Experiment Conducted with Students

During the Fall 2022 Geomorphology lab exercise, we visited the USU Surplus location and used the setup where the ground was disturbed but not compacted. Two classes of twelve students conducted the exercise on different days. For each class, the students were further divided into two groups of six. One group would collect two mini-disk infiltrometers trials, and the other group would work directly with the simulator. The group with the simulator would observe what was happening in the plot and note down if/when ponding and runoff would start. After fifteen minutes, the groups swapped and completed the other task. If ponding and runoff was already occurring by the time the second group shifted to the rainfall simulator, they were briefed on what was happening and instructed to observe the runoff and erosion occurring in the plot. By the end of the activity, students were able to identify erosional features in the plot, specifically micro-channels in the soil. The students completed a follow-up assignment to plot infiltration rate measured from the mini-disk infiltrometers against rainfall rate, and then answered questions related to the activity.

Student results from one lab section are summarized in Figure 2.3. In this example, it took 23 minutes between observing ponding and runoff. Ponding occurred in two minutes and runoff occurred in 25 minutes. Ideally, ponding and runoff would occur within seconds of each other. This unexpected result might be evidence of water flowing below the funnel and edge of the metal ring, rather than through the runoff chute as intended.

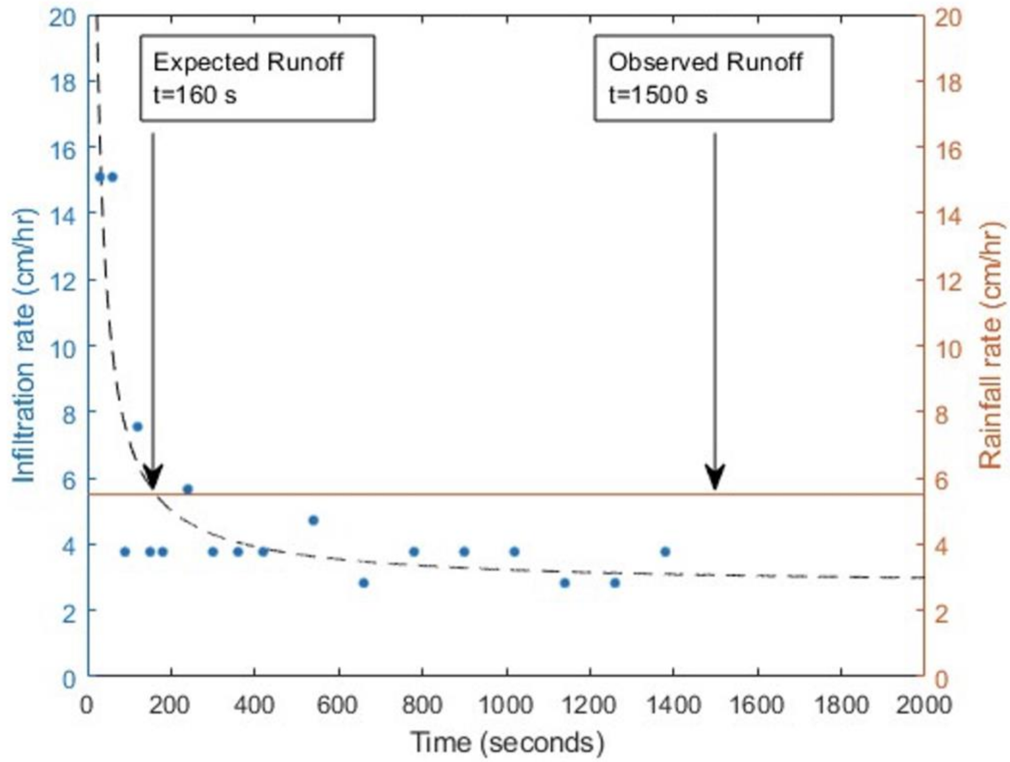

Figure 2.3. Infiltration and rainfall-simulator example run with USU's geomorphology class Fall 2022. For the trial run, nozzle 460 608 was used. The flow rate was set to 0.225 gal/min, producing a calibrated rainfall rate of 5.1 cm/hr. The infiltration rate started at 15.3 cm/hr, and dropped to a plateau at 4 cm/hr. The intersection where the rainfall rate exceeds infiltration rate is at ~160 seconds. During this experiment, ponding was observed starting at 120 seconds. Runoff wasn't confidently observed until the rainfall simulator was running for 1500 seconds (25 minutes).

2.4 DISCUSSION

Our modified version of the Iserloh et al. (2012) portable rainfall simulator can still be improved upon. Our main suggestion is to be able to position the nozzle so it's centered over the plot, so water can spray out of nozzle consistently over the circular plot when level. As it is currently designed, the rainfall simulator up-down axis will always be perpendicular to the ground, but the nozzle face is parallel to the ground. If the ground is sloped, then the nozzle will likewise be sloped parallel to the circular plot, and will disproportionately spray water at the downslope portion of the circular plot while the upslope part receives less rain. The improvement needed could be made through adjustable legs. Levels could be added to the top frame that holds the nozzle, so the nozzle can be adjusted horizontally and centered above the plot. To better improve mobility with the rainfall simulator, a lithium battery would be better than a lead-acid battery. Lithium batteries are lighter, so they'd be easier to transport, and they last several-times longer than lead-acid batteries.

In terms of improving the exercise with students, we eventually gave up on reconciling the mini-disk infiltrometer measurements with the rainfall simulator observations. The fact is, the mini-disks are not intended to provide values of instantaneous, changing infiltration rate through time, which is how we tried to use them. Instead, the infiltrometers are designed to estimate the eventual, steady-state, saturated hydraulic conductivity of soils. However, when we used the infiltrometers this way, our estimated time when rainfall rate exceeds declining infiltration rate did generally coincide with observed ponding on the soil surface.

Although the infiltrometer measurements could not be reconciled with the runoff observations, this added activity was an opportunity to get more students involved in the hands-on experience. The exercise is visual, and students can learn concepts from observations with the rainfall simulator and infiltrometer, even though the data don't align perfectly. Therefore, we recommend including infiltrometer measurements in future student activities. We also recommend collecting runoff from the plot's chute when it happens, so students can generate hydrographs.

Using the rainfall simulator for teaching purposes is more successful in semi-arid to arid regions, where infiltration-excess overland flow is more easily obtainable. This activity would not work as well in humid regions where infiltration rates are high, and saturation excess overland flow may be the dominant runoff mechanism.

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CHAPTER III

PLACE-BASED LEARNING OF STORM HYDROLOGY TO INCREASE NATIVE AMERICAN STUDENT MOTIVATION TOWARD GEOSCIENCE

ABSTRACT

Geoscience has a history of underrepresentation of minority groups. For ethnic diversity, higher-education geoscience programs rank lowest among physical sciences, and this is most critical with Native American students. My project used a place-based, hands-on learning activity, so Native students could have an opportunity to visualize themselves as geoscientists. This activity was used in learning settings that develop pathways for Native Students to pursue STEM degrees, the Native American Summer Mentorship Program (NASMP) and Utah State University's Blanding campus College Launch and Upward Bound programs. I investigated whether hands-on learning experiences that connect practically to Native homelands would increase learning and motivation towards geoscience. This activity used a portable rainfall simulator to teach concepts relating to dryland hydrology, where students made connections between weather, flash flooding, and runoff. Before and after each implementation of the rainfall simulator activity, students took a pre- and post-survey to rank and assess their attitudes and motivations toward geoscience. A group interview was used for further qualitative analysis on the activity.

3.1 INTRODUCTION

Higher-education geoscience programs rank lowest for ethnic diversity among all physical sciences (AGI, 2010; Bernard & Cooperdock, 2018; Beane et al., 2021). This problem is the most severe with respect to Native American students (AGI, 2010; NSF, 2017). In undergraduate geoscience programs, degrees awarded to underrepresented ethnic groups have increased from 9% to 15.7% between 2010 and 2019, yet degrees awarded to Native students have remained stagnant, with students receiving around 1% (AGI, 2020). While this participation gap of ethnic minorities in science is very real, recent research suggests that a bigger problem is an identity gap where ethnic minority students do not see themselves in STEM fields (Searle & Kafai, 2015).

To address both the underrepresentation of Native students and the identity gap where Native students do not see themselves belonging in geoscience programs, my project uses hands-on experiences, place-based learning, and integration of Indigenous and Western ways of knowing to introduce Native American students to geology. By connecting geology to students' lived experiences and the places where they live, the hope is that Native students will begin to visualize themselves as geoscientists.

Increasing the diversity of students to be representative of ethnic minority groups is of fundamental importance for the future of geoscience. The breadth of impact of geoscience increases as a result of increased diversity. One aspect of this is how higher education approaches increasing diversity from a business stance, where diversity is framed as benefiting institutions and programs from diverse perspectives. For example, diverse backgrounds bring in different perspectives and approaches to problem solving and researching different foci and generate new findings (Battiste, 2002; Huntoon & Kane, 2007; Medin and Lee, 2012). Inclusion of diverse groups brings in research relevant to them. For example, the majority of STEM research revolves around issues relevant to white people; increasing diversity will increase research on issues relevant to underrepresented groups (Medin and Lee, 2012). The business stance is countered by a moral stance to increase diversity that focuses on equity. A second important rationale for increasing diversity is because it’s the ethical thing to do (Haacker et al., 2022). This stance aims to attract and retain diverse scientists by valuing them without justification for their inclusion.

Increasing diversity in STEM, specifically with Indigenous Peoples, can be used to fill in knowledge gaps in Western science and has larger implications for environmental management. Battiste (2002) explains that Indigenous Knowledge helps identify the limitations of Eurocentric theory and fill its ethical and knowledge gaps. For example, in climate science, Indigenous Knowledge is a reliable source for historical and regional knowledge and reduces uncertainties about regional weather patterns and climate (Ankrah et al., 2021). The use of Indigenous Knowledge also has been successful for Native land restoration, including wetlands and forests (e.g., Turner et al., 2000; Zedler and Stevens, 2018). Native land management success stories have generated calls for the use of Indigenous Knowledge at the federal level (Maldonado et al., 2016). Increasing Indigenous Peoples’ representation in STEM is necessary to gain these benefits for science and management. Alternatively, Indigenous Peoples participating in science can provide opportunities for employment and have self-determination with tribes having the ability to manage their own natural resources.

This study examines hands-on experiences that connect practically to Native homelands, and if they increase learning and motivation towards geoscience. The project was guided by the following question: How do field and lab experiments that relate to surface processes in Native homelands effectively teach and increase motivation toward geosciences? The purpose of this project was to develop and evaluate a learning exercise that engages Native students in geoscience. A dryland hydrology exercise was used with students, which was designed around hands-on experiences, Indigenous Knowledge Systems (IKS), and place-based learning. Through this, there was an underlying goal that students might better visualize themselves as geoscientists. Further, Native students engaged in an experience similar to what practicing geoscientists do, allowing them to see and understand the contribution that geoscience can make to the ongoing survival of Native communities.

The hands-on activity for this project explores aspects of introductory-level geomorphology focused on dryland hydrology and was implemented in pre-existing Utah State University (USU) programs designed for Native students. These concepts are linked to the Four Corners region, where most of the Native students participating in the USU programs are from.

3.1.1 Positionality Statement

I approach this project as a cis-gendered, white woman. This gives me a certain lens in how I view the world and ultimately approach this study. My background is in geoscience, so I must rely on IKS and their scholars to fill in my gaps in knowledge. I use data interpretation techniques, such as creating a qualitative analysis memo, to limit the effect of my positionality on the results and discussion of this study. However, not all biases can be eliminated.

3.2 BACKGROUND

3.2.1 Opportunities at Utah State University

There are three programs designed to develop pathways for Native American students at USU, including the Native American Summer Mentorship Program (NAMSP) and the

USU Blanding campus College Launch and Upward Bound programs. The purpose of NASMP is to provide research opportunities and experiences at USU Logan for Native students from the USU Blanding campus. Students from the USU Blanding campus participate in a month-long program, rotating through different labs and completing a series of week-long learning and/or research experiences in various STEM fields. The following goals guide each NASMP learning experience: (1) participate in hands-on research in STEM fields; (2) develop communication skills in academic environments; and (3) form connections between research areas and foster personally-motivated curiosity. The College Launch and Upward Bound programs at USU Blanding were designed to assist Native American, first-generation and/or low-income students as they transition from high school to higher education. Recent high-school graduates enroll in college classes, including Introduction to Geology, before beginning their fall semester to earn college credit and gain skills and experience. Other undergraduate students can enroll in these classes too. The hands-on activity lasted only three hours, but it still included practical hands-on experiences and place-based learning to motivate Native students to engage in geoscience. Like NASMP, students had a hands-on experience of how scientists conduct research. This venue was more applicable to students' communities, as it took place within or near students' homelands.

3.2.2 Indigenous Knowledge Systems and Research Methodologies

The curriculum designed for the hands-on exercise took into consideration IKS, comprised of epistemologies (ways of knowing), ontologies (ways of being), and axiologies (ways of valuing), specifically in reference to the relationships between knowledge, place, and connections to one's community (Barnhardt & Kawagley, 2005).

In Western ideology, “knowledge” is a noun and it’s considered as something acquired through learning. In IKS, knowledge is a verb, it’s acquired through experience and rooted in its own ontology (Smith, 1999). Due to the close relationship between knowledge and ontology, Indigenous students may prefer to make connections that are circular and holistic, so they can understand the bigger picture of how science fits in with their community (Brayboy and Maughan, 2009).

Knowledge is considered a basis of power because it can be used for a greater goal and is necessary for cultural survival. This stems from Indigenous Knowledge being tied to community and an expression of sovereignty, where the needs of the past, present, and future are used for tribal decisions (Battiste, 2005). Indigenous Peoples may prefer to carefully think and act upon decisions to achieve larger objectives relevant to their community and culture (Brayboy and Maughan, 2009). When teaching science, it is important to remember that Indigenous students may want to know all components, and, more importantly, their representation and relevance to their communities, before diving into an experiment. Every decision may need to be thought out before being acted upon so it has purpose and significance, especially as it can be applied to one’s culture (Brayboy and Maughan, 2009). Research isn’t just about the science, but about associations with traditional stories, place, and culture. Eurocentric education is refined to a point where it’s detached from Indigenous Peoples’ life experiences (Deloria and Wildcat, p.42, 2001).

For many Indigenous students, it is important to situate scientific experiments within the context of a particular place and community. As Maori scholar Linda Smith observes, Indigenous Knowledge is tied to land, not just specifically, but to landforms, landscapes, and biomes. This is where knowledge is transferred (Smith, 1999). By this, she means land is culturally significant because stories are tied to it, and it’s where stories are passed onto future generations (Battiste, 2005). Similarly, Basso (1996) discusses how Western Apache stories are tied to landforms and are used for knowledge transmission and the survival of culture. In these ways, science becomes a practical tool that can be used for community survival rather than an abstract discipline (Brayboy and Maughan, 2009).

3.2.3 Place-Based Learning in Geoscience

Place-based learning contextualizes concepts with a connection to a local place and practical relevance, usually integrating cross-cultural content and outreach to community (Semken et al., 2009). In geoscience education, place-based pedagogies connect what students already know through cultural experiences to geoscience concepts (Semken et al., 2017). Place-based learning has gained traction due to its ability to engage Indigenous Peoples in science (Semken et al., 2017). When teaching geoscience with place-based learning, educators need to be conscientious of potential cultural discontinuities with geoscience (Semken, 2005; Semken et al., 2009). For example, place-based learning may turn Native students away from science, especially if pre-existing place attachments are discussed in terms of natural resource extraction. Educators should be aware of pre-existing attachments that Native students may have, due to cultural meanings and the sacredness of the place (Semken et al., 2009).

3.2.4 Native-Focused STEM Programs and Geoscience Education

While numbers of Native students in higher education remain stagnant, there have been several efforts to attract Native students to geoscience. These approaches emphasize cultural relevance, place-based education, and the relationship between science and self-concepts. For example, Unsworth et al. (2012) evaluated culturally grounded, field-based geoscience and understanding factors that motivate high school students to pursue higher education in geoscience. They taught a culturally grounded and field-based geoscience curriculum in a STEM program geared towards Native students, using a pre- and post-survey assessment for the effectiveness with high school students. They found that students understood how science is relevant to their communities and were also able to make connections between their culture and geoscience. They also found that students were able to make connections between science and their self-identity. The survey created by Unsworth et al. (2012) was adopted for this study.

3.2 METHODS

3.3.1 Design Approach

This project follows a design-based research approach (Design-Based Research Collective, 2003; Cobb et al., 2003). Rather than testing curriculum and other educational innovations in a controlled lab setting, this project tests curriculum in a real-world context, which is a primary characteristic of a designed-based experiment. The design-based approach uses context and iterative design, where there are cycles of intervention and revision. For this project, the rainfall simulator exercise was implemented in summer 2022, then reimplemented with revisions in summer 2023.

3.3.2 Rainfall Simulator Exercise

The learning objective for the exercise was that students be able to quantitatively connect the pathways of rainfall and water runoff on land. To achieve this learning objective, students participated in a field exercise with a rainfall simulator. The rainfall simulator is modelled from Iserloh et al. (2012), which is used for soil erosion experiments. The rainfall simulator has a spray nozzle pointing toward the ground from a frame at 2 meters height. Flow from the nozzle is driven by a battery-operated bilge pump drawing from a bucket of water and adjusted by a needle valve to simulate varying rainfall intensities. By using the rainfall simulator, students could learn the basic pathways of water, including how water is directed downslope over land as runoff (infiltration-excess overland flow) versus how much water infiltrates to become subsurface runoff or groundwater. Infiltration-excess overland flow generated by the rainfall simulator is collected from the area of the study plot defined by a metal ring, which has an outlet funnel for a sample bottle. Rainfall that is not running off at the surface is assumed to be infiltrating into the soil, and this infiltration rate is estimated by the difference between the rainfall rate expelled from the nozzle and the rate of runoff measured from the plot. In addition, a separate, miniature infiltrometer was used to independently measure infiltration rates over time for the same soil type to compare to the indirect estimates from the experimental setup. The overland-flow measured over time from the simulator is used to create a hydrograph. Students identified an initial threshold amount of rainfall intensity and/or duration that creates overland flow, then a pattern or trend of changing discharge over time, simulating runoff during a rainstorm. Overall, students should have been able to quantitatively understand the pathways of water that lead from storms to floods in streams. For the analysis portion of the exercise, students demonstrated their understanding of dryland hydrology by constructing and labelling a plot of infiltration rate vs rainfall rate. Students were able to predict when runoff should occur, which is when rainfall rate is greater than infiltration rate, and they compared this to the observed timing of runoff. In 2023's NASMP and Blanding geology course, students collected runoff at one-minute time intervals and produced a hydrograph.

In both 2022 and 2023, trial runs with the rainfall simulator exercise were completed with NASMP students prior to instruction for the USU Blanding introductory geology course during the College Launch and Upward Bound programs. For implementation during NASMP, the exercise was conducted with one student over a week in 2022 and two students over a day in 2023. The rainfall simulator was calibrated during these trial runs, and the students explored hydrologic processes in settings around the Logan area. For the College Launch and Upward Bound programs at USU Blanding, students were taken to a location on the USU Blanding campus for three hours to observe, collect, and interpret data from one trial run with the rainfall simulator. The Blanding area is a prime dryland locality for this exercise, with sandstone, mudstone, and cryptobiotic soil substrates.

3.3.3 Data Collection and Analysis

3.3.3.1 Pre- and post- assessment ranking of motivation toward geoscience

Before and after each implementation of the learning exercise, students took a pre- and post-assessment to rank their attitudes and motivations toward science based on a series of statements (Appendix A). College Launch and Upward Bound students took the survey at the beginning and end of the three-hour course. Survey statements were pulled from Unsworth et al. (2012) which asked Native high school students to rank motivation and self-concepts of science. Although our exercise is specifically geared toward hydrology and geoscience, the survey questions inquire about science more generally. We did not adjust the previously validated survey statements to be more specific, because that would have required an additional validation effort. Statements 1 through 5 were answered by all participants. These statements relate to students' concepts of science. Statements 6 through 9 were only answered by Native students, and these statements asked about connections between science and tribal livelihood. In Blanding, the rainfall simulator activity was given to Upward Bound and College Launch students in the introductory geology course. In Summer 2022, there were 22 students in the class, 11 students participated in the survey. In Summer 2022, there were 15 students in the class, and 11 students participated in the survey. The surveys and group interviews (see below) underwent USU's Institutional Review Board process for human subjects review and they were approved with an "exempt" status.

These data are used to answer our research question of whether our experimental learning modules are effective at increasing Native students' motivation toward geoscience. Changes in student rankings between pre- and post- survey semi-quantitatively record success and/or failure of module implementation. No change in rankings indicates the learning experience had no impact on motivation toward geoscience.

The post-survey has two open-ended questions asking students: (1) How does what you've learned apply to your community? and (2) What processes and scientific concepts are you still confused about? Data from these questions tell us if the students form connections between science and their communities. The question asking students about what they are still confused about provided feedback on what needs to be improved upon in future iterations of the exercise

3.3.3.2 Classroom observations

An observation protocol was followed in the classroom to record how students participated in the learning exercises. This protocol outlined to note about students' use of scientific terminology, whether students discussed how geoscience was relevant to their communities, when students appeared engaged vs. disengaged based on their level of participation, and how students worked together. Observations were documented as written field notes in the classroom during teaching instruction (Emerson, Fretz, & Shaw, 2011). Interpretations and conclusions drawn from classroom observations were verified with others, due to potential validity threats caused by researcher bias.

3.3.3.3 Student interviews

To gain insight into possible reasons for students' rankings and changes, a group interview was conducted after the 2023 rainfall-simulator exercise at the USU Blanding campus. The interview was voluntary, and three students participated. The group interview followed the exercise and occurred the same day, so students' experiences with the rainfall simulator were fresh in their minds. The interview was held over dinner, to promote a more comfortable and laid-back environment for students. The interview protocol consisted of ten questions, which inquired into students' previous experiences with geoscience and their thoughts on the rainfall simulator exercise (Appendix B).

The interview took forty minutes to complete and was audio-recorded. The audio recording was then transcribed using a speech-to-text API transcribing service. The transcription was then corrected for errors by the researcher. The interview was listened to, and the transcript was read through multiple times to identify key themes or codes. From these themes, an analytic memo was created to better refine the codes (Saldaña, 2021). There were multiple iterations of the analytic memo to further refine the code and produce the qualitative analysis of interview data, which is explored in greater detail in the results.

3.4 RESULTS

3.4.1 Pre- and Post-Surveys

In the surveys conducted before and after the rainfall-simulator experiment, students ranked their agreement to nine statements (Table 3.1A). Most statements asked students to rank their agreement from a scale of 1-10, except for statement 5, "Western Science and Native American views overlap", where students selected from a series of four Venn diagrams the one that best represented their perception. For that case, the data reflect a ranking from only 1-4. In Table 3.1B, results for this statement are multiplied by 2.5 to normalize them to the 1-10 scale of the other statements. Also, statement #2, "Science is something we only learn in the classroom" is inversely scored, with lower values being more positive. In Table 3.1B, the scores for this statement are inverted so that they match the scale and can be directly compared to the other statements.

TABLE 3.1A. SURVEY RESULTS IN ORDER OF QUESTIONING

Pre-Test	2022*		2023**		2022 & 2023***	
Question	Mean	Std Dev	Mean	St Dev	Mean	Std Dev
1. I like science	7.9	1.6	7.8	1.3	7.9	1.4
2. Science is something we only learn in a classroom	3.5	2.3	4.7	2.9	4.1	2.6
3. It would be easy for me to be a scientist	4.6	2.1	4.6	1.4	4.6	1.8
4. It's a strong possibility that I will be a scientist	5.3	2.1	4.6	2.3	5.0	2.2
5. Western Science and Native American views overlap (1-4)	2.2	0.9	2.3	0.5	2.2	0.7
6. My tribe has been doing science for a long time	5.6	2.1	5.3	2.5	5.5	2.2
7. Scientists and people in my tribe think about nature the same way	6.0	2.6	4.5	2.3	5.3	2.5
8. I could be a scientist and live my cultural way of life	8.2	1.8	5.2	3.4	6.7	3.0
9. The things I can learn are important to my tribe	7.7	1.9	6.4	2.9	7.1	2.5
Post-Test	2022		2023		2022 & 2023	
Question	Mean	Std Dev	Mean	St Dev	Mean	Std Dev
1. I like science	8.5	1.6	7.5	1.3	8.0	1.5
2. Science is something we only learn in a classroom	3.9	2.3	5.0	3.0	4.5	2.7
3. It would be easy for me to be a scientist	5.8	2.7	4.9	1.6	5.3	2.2
4. It's a strong possibility that I will be a scientist	5.9	2.7	4.3	2.1	5.1	2.5
5. Western Science and Native American views overlap (1-4)	2.2	0.9	2.3	0.5	2.3	0.7
6. My tribe has been doing science for a long time	6.1	2.3	5.3	3.1	5.7	2.7
7. Scientists and people in my tribe think about nature the same way	6.5	2.5	4.5	2.2	5.5	2.5
8. I could be a scientist and live my cultural way of life	8.5	1.8	4.9	3.0	6.6	3.0
9. The things I can learn are important to my tribe	7.8	2.3	5.8	3.1	6.8	2.9

* *n* = 11
** *n* = 11
*** *N* = 22

TABLE 3.1B. SURVEY RESULTS IN ORDER OF MEAN SCORES

Pre-Test	2022*		2023**		2022 & 2023***	
Question	Mean	Std Dev	Mean	St Dev	Mean	Std Dev
I like science	7.9	1.6	7.8	1.3	7.9	1.4
The things I can learn are important to my tribe	7.7	1.9	6.4	2.9	7.1	2.5
I could be a scientist and live my cultural way of life	8.2	1.8	5.2	3.4	6.7	3.0
Science is something we only learn in a classroom (inverse)	6.5	2.3	5.3	2.9	5.9	2.6
Western Science and Native American views overlap (normalized)	5.5	2.2	5.7	1.2	5.6	1.7
My tribe has been doing science for a long time	5.6	2.1	5.3	2.5	5.5	2.2
Scientists and people in my tribe think about nature the same way	6.0	2.6	4.5	2.3	5.3	2.5
It's a strong possibility that I will be a scientist	5.3	2.1	4.6	2.3	5.0	2.2
It would be easy for me to be a scientist	4.6	2.1	4.6	1.4	4.6	1.8
Post-Test	2022		2023		2022 & 2023	
Question	Mean	Std Dev	Mean	St Dev	Mean	Std Dev
I like science	8.5	1.6	7.5	1.3	8.0	1.5
The things I can learn are important to my tribe	7.8	2.3	5.8	3.1	6.8	2.9
I could be a scientist and live my cultural way of life	8.5	1.8	4.9	3.0	6.6	3.0
My tribe has been doing science for a long time	6.1	2.3	5.3	3.1	5.7	2.7
Western Science and Native American views overlap (normalized)	5.5	2.2	5.8	1.2	5.7	1.7
Science is something we only learn in a classroom (inverse)	6.1	2.3	5.0	3.0	5.5	2.7
Scientists and people in my tribe think about nature the same way	6.5	2.5	4.5	2.2	5.5	2.5
It would be easy for me to be a scientist	5.8	2.7	4.9	1.6	5.3	2.2
It's a strong possibility that I will be a scientist	5.9	2.7	4.3	2.1	5.1	2.5

* *n* = 11
** *n* = 11
*** *N* = 22

Table 3.1A lists statements in the order they were asked. There is no apparent pattern in responses related to the order of questioning. The highest scores were with the first and the last statements, and the lowest score with statement 5 in the middle. Therefore, the order of the statements did not have a systematic effect on the responses.

In Table 3.1B, showing statements in order of score, mean values are neutral to positive, ranging from 4.6 to 7.9 for the pre-survey, and a slight improvement to 5.1 to 8.0 for the post-survey. For both the pre- and post-surveys, the top three positive scoring statements are, “I like science” (means: pre = 7.9, post = 8.0), The things I can learn are important to my tribe” (means: pre = 7.1, post = 6.8), and “I could be a scientist and live my cultural way of life” (means: pre = 6.7, post = 6.6). The 2022 cohort had generally more positive results than 2023 with means higher by up to 3.6 points for most statements, except for two statements where the 2023 cohort was the same or more positive --the “Western Science and Native American Views” Venn diagrams and “It would be easy for me to be a scientist”.

The statement with the largest standard deviation in scoring (the greatest variability in student opinions) for the combined 2022 and 2023 data is, “I could be a scientist and live my cultural way of life”, with a standard deviation of 3.0 for the combined 2022 and 2023 pre- and post- survey data. “I like science,” had the smallest standard deviation (greatest consensus). Yet, these two statements both ranked in the top three most positive responses, illustrating that there is not a pattern in consensus in responses and whether responses are positive or more negative.

Table 3.2 provides each participant’s change in response pre- and post-assessment for each survey statement listed in the columns. The statement columns are ordered from left to right based on what had the most positive change for rankings. This is calculated from the sum of changed rankings, combining 2022 and 2023. Green-shaded cells signify a more positive agreement with the statement in the post- survey, red-shaded signify a negative shift in agreement with the statement, while no color signifies no change. The rankings. Blacked-out boxes are for students who identified as non-Native and who were more saturated the color, the more change there was between pre- and post- statement not required to answer the associated statements.

TABLE 3.2. PARTICIPANT CHANGES TO RANKINGS BETWEEN PRE- AND POST- SURVEY

Participant ID*	It would be easy for me to be a scientist	It's a strong possibility that I will be a scientist	My tribe has been doing science for a long time	Scientists and people in my tribe think about nature the same way	I like science	Western Science and Native American views overlap (1-4)	I could be a scientist and live my cultural way of life	The things I can learn in school are important to my tribe	Science is something we only learn in a classroom
2022-001	1	-1	1	0	0	0	-1	2	-3
2022-002	0	0	2	0	1	0	0	0	2
2022-003	0	2	0	0	0	0	0	-2	1
2022-004	0	1	0	-2	0	-1	0	0	-1
2022-005	2	2			0	0			0
2022-006	0	0	0	0	1	0	-1	0	-4
2022-007	2	1	1	1	1	0	1	0	0
2022-008	0	-3	-2	0	0	0	0	0	2
2022-009	4	2	2	0	1	0	2	1	0
2022-010	2	1	2	5	1	0	1	0	-2
2022-011	2	2	-1	1	1	1	1	0	0
2023-001	-1	-1	-1	0	-1	0	-2	0	-4
2023-002	-1	-1	0	-2	0	0	0	0	-1
2023-003	0	-1	-1	0	0	0	0	-2	-2
2023-004	-1	0	-1	0	-2	1	0	0	-1
2023-005	0	-2	2	2	0	0	0	-2	2
2023-006	1	-1	0	-2	0	0	-3	-3	0
2023-007	1	1	1	1	0	0	0	0	-1
2023-008	0	0	0	0	-2	0	0	0	0
2023-009	-2	0	-3	0	0	0	0	-2	2
2023-010	3	0	1	-1	0	-1	0	1	-1
2023-011	2	1			1	1			3
Magnitude of change	25	23	21	17	12	5	12	15	32
2022 Sum	13	7	5	5	6	0	3	1	-5
2023 Sum	2	-4	-2	-2	-4	1	-5	-8	-3
2022 & 2023 Sum	15	3	3	3	2	1	-2	-7	-8

*N = 22 participants

Similar to the pattern mentioned above, when comparing the 2022 and 2023 cohort results with respect to negative and positive changes between pre- and post-surveys, the 2022 cohort not only had more positive responses in general, but they also had more positive change from pre- to post-survey, while the 2023 cohort illustrates more negative changes (Table 3.1B, Table 3.2). When averaging the sums of each year, 2022 had an average of 3.9, while 2023 had an average of -2.8. The statement with the greatest absolute value of change (positive and/or negative) is, "Science is something we only learn in the classroom", with a summed magnitude of 32 points change. The statement with the lowest absolute value of change is the "Western science and Native American views overlap" Venn diagrams, with a summed magnitude of 5 points change.

Most important for results and discussion is that the statement with by far the most positive change is, "It would be easy for me to be a scientist", with an increase of 15 points for the combined 2022 and 2023 data. No other statement had a positive change over 3. This suggests that, after this exercise, students could better visualize themselves as scientists. Conversely, the statement with the most negative change is, "Science is something we only learn in the classroom." Students who agreed with the statement was seen as positive, while those who disagreed was seen as negative; so the rankings were inversed. This statement's sum is -8 points. This suggests that students might believe they learn from lecture, rather than a hands-on activity. This sum is weighted by three students, where two answered a negative change of 4 points, and one at 3 points.

A similar magnitude of negative change occurred with the statement, "The things I can learn in school are important to my tribe", with a decrease of 7. In this case, the negative change was entirely from the 2023 cohort, not the 2022 students. This implies that students in the 2023 cohort believed the rainfall-simulator exercise was not important to their tribe. On the other hand, this may be due to different contexts of instruction in 2022 versus 2023, such as the timing of the exercise within the overall Intro Geology course, or different attitudes of the cohorts from their geology class experience or their lives. This is expanded upon in the discussion section.

3.4.2 Qualitative Analysis

The qualitative coding of group interview data and subsequent memoing resulted in the identification of three primary themes: 1) interview participants liked that the activity was hands-on and easy to visualize, 2) the activity enhanced their understanding of geoscience and were able to make connections to their lives, 3) and they showed an interest in geoscience.

When directly asked about what they liked about the activity, a student said, “I could like see it in like my vision, you know, like not vision, but more of like, it's right there, you know?” Another student mentioned, “What I liked about the rain simulator is that it was very hands-on, and it wasn't, you know, you weren’t behind a screen, you were actually up there in person and you were actually doing something.” In both responses, students emphasized the tangible nature of the rainfall simulator activity as compared to a virtual experience, such as watching a video of someone conducting an experiment. Hands-on learning can also be an outlet for sense-making (Furtak and Penuel, 2018), which drives learning and communicating knowledge in IKS (Barnhardt & Kawagley, 2005), so it is important that the students emphasized liking the hands-on portion of the activity. While IKS are often implicit (Barnhardt & Kawagley, 2005), it is possible that the hands-on nature of the simulation activity made sense to the students culturally, in ways that many other school-based activities do not. In contrast to the hands-on, in-person rainfall simulator activity, many programs at USU Blanding involve videoconferencing into classrooms taught at the main Logan Campus. For example, while geology is offered as a degree available at USU Blanding, the classes are held via broadcast for students there. As a result, students don’t have as many in-person interactions, especially hands-on lab and field experiences

In contrast, one student mentioned not understanding the analysis portion of the rainfall simulator activity, a portion of the exercise that wasn’t as hands on. When the students were asked about what they didn’t like about the activity, this student mentioned, “[The analysis] wasn't explained well. It was more someone had to do it for us. I mean, I understand the reasoning behind it, but it would've been kind of more useful if the equations were explained and you know, what the variables mean in terms of geology, 'cause some terms aren't universal.” The same student also mentioned, “[the analysis] seemed like it just kind of flew by, but other than that it was good.” For the analysis portion, data were graphed in Excel, where students could see the data input. The analysis was rushed due to time limitations. As the student said, it was not explained well, and the students didn’t have sufficient time to go through the related equations in depth. Overall, this portion was delivered in a traditional lecture style. Although only one student mentioned finding the analysis portion of the activity difficult to follow, this provides further support for the addition of hands-on activities and thorough explanations about the reasoning behind the analysis conducted.

Interview results also suggest that students enhanced their understanding about geoscience. Students went from knowing a more basic background in geoscience to a more sophisticated understanding, specifically about infiltration, a main concept explored in the exercise. When students were asked what they knew about the geology before doing the experiment, they mentioned knowing geoscience as rocks and minerals. One student reported, “Rocks. That's rocks and minerals.” This student followed up with, “I know like formations, different formations were caused from like water. But I didn't think it would like directly involve, you know, water.” Another student also mentioned geology as being as, “like the earth, rocks…” However, the students’ understanding of geology did become more sophisticated, evidenced by one student reiterating what we did. They said, “…We tried to see how much the ground would try to absorb water, like the soil part of it. And we put stuff on top that would like disperse water into the ground and we would measure how long it would take for it to be completely gone…”. Another mentioned, “…I did have an understanding that the ground can absorb things, but I just didn't really know how fast.” Students were able to explain the activity and used vocabulary from the experience, specifically infiltration. In the students’ explanations, mentioning seeing how the ground absorbs water points to their understanding of infiltration.

One student was able to apply the concept of infiltration outside of the classroom and make connections to previous experiences. They discussed watering plants with their grandma who’d say to water plants slowly, to allow water time to infiltrate into the soil. “Doing the infiltrometer thing, like I guess my Grandma does like this, a similar thing when she waters her plants in like a flower pot, she says you're going to have to wait a bit, when you put in a little bit 'cause it's going to absorb really quick, and then it'll come back out. So, you're going to have to wait a while and then it'll start absorbing it slower and little did I know, you know, I made that connection to the lab we did today". This student went beyond what was learned in the activity and was able to connect the concept of infiltration to something their grandma did to make sure her plants were adequately watered. Students connecting STEM to their daily lives makes STEM more relevant (Moll et al. 1992). In summary, engagement in the hands-on rainfall simulator activity enhanced students understanding of infiltration specifically, and geoscience more broadly, with one student connecting these concepts to her daily life.

The last themed identified from the analysis is that students showed interest in geology more broadly. At the end of the interview, when given the option to ask questions, the students asked what it's like to take geology, how would double-majoring in geology work, and how hard the classes I took were. For example, a student who was studying early childhood education asked about the geology program, so while they weren't necessarily going to switch to geology, they were still curious about the field. Students also asked about additional topics in geology, such as erosion and how it works. Another student brought up a relating geoscience topic important in the Four Corners region. They asked, "I was just wondering how is it that geoscience can help contain the, I don't know, like harmful materials that have been laid out? Kinda like the uranium mines?" While I had brought up uranium mines earlier in the conversation, the student followed up with additional statements. Because abandoned uranium mines have significantly impacted the water quality and safety (often making it unsafe to drink and use for agriculture) and the health of Indigenous peoples in the Four Corners area, it seems likely that the student was making important connections between geoscience and the health of their community. This is another example showing how place-based learning can be useful because it can relate to relevant issues Native people experience. As student questions illustrated, increased interest in geoscience can be expressed by applicating relevant issues, like uranium mining waste in the Four Corners region.

3.5 DISCUSSION

One of the major patterns in this study's results is that the 2022 survey responses are systematically more positive in survey statement rankings and in changes between pre- and post-surveys. 2023 results have lower average rankings and increased negative change between pre- and post-surveys. Here, I discuss three possible reasons for this. First, the timing of the exercise during the student's introductory geology course was different. In 2022, the exercise was conducted toward the end of the 4-week geology class, on the second to last day of instruction. In 2023, the exercise was held at the start of the second week of class. Students in the 2022 cohort had been taught all concepts taught in the course, while in the 2023 cohort, they'd only learned about plate tectonics, minerals, and volcanism, which are not related to hillslope hydrology. When students have been learning for four weeks, their conceptions about geoscience have most likely enhanced by the time the rainfall simulator instruction began. The amount of time in the classroom might also play into class dynamics, the second possible reason for differences between the two cohorts. The 2023 cohort of students was observed to be noticeably shyer on average than the 2022 cohort. This was noted by the instructor of the course, and it was seen in class observations during the exercise instruction with the students primarily keeping to themselves, rather than chatting with their peers. Finally, different classroom instruction may be another reason. 2022 had five instructors assisting the exercise, while 2023 had three instructors. Instruction in 2022 was led by an experienced lecturer, while 2023 was not. 2023 instruction also ran out of time, with a half hour less in exercise instruction, cutting out time from data analysis and interpretations, when students can connect the rainfall-simulator activity and its broader importance. This was expressed in the group interview, when a student explained that they had to be given the analysis rather than walking through the data and understanding it themselves.

Although responses in 2023 were less positive than in 2022, a major result is that the overall responses were generally positive, given that the lowest survey scores are, in fact, neutral values of ~4 to 6 on a scale of 1 to 10. Thus, what stands out are the statements that produced a strongly positive response from students (as listed in previous section). Statements free of a student's self-concept and esteem about science garnered a generally positive result. This includes, "I like science", and, "Things I can learn are important to my tribe." The students generally agreed that science is likable, and what they can learn in science can hold importance. In contrast, the lowest, actually neutral, statements in Table 3.1B relate to a person's self-concept related to science. Overall, most self-concept and tribal identity statements received generally neutral responses. This lack of positivity might be explained by students not having past experiences where they can imagine themselves as scientists, and the societal dichotomy between Indigenous Knowledge and Western Science.

Considering the high standard deviation, students attitudes varied the most about, "I could be a scientist and live my cultural way of life." There was also less consensus among participants for. "The things I can learn are important to my tribe," "My tribe has been doing science for a long time," and "Science is something we only learn in the classroom." These three statements relate to a student's concept about their tribal identity and science. These might garner a greater range in attitude depending on how they're taught science growing up within their tribe, or how they view the relationship between Indigenous Knowledge and Western Science.

When it comes to the greatest change in attitude over the course of the exercise (Table 3.2), "It would be easy for me to be a scientist", has more positive shift than other statements. A main goal of the rainfall simulator exercise is for students to visualize themselves as scientists. This clear, positive change in response suggests this goal was met, and they felt confident enough to agree with the statement.

The first primary finding is that responses to the survey statements about science and its connections to the students and their cultures were neutral and positive, rather than outright negative. There isn't a statement that started out with a low score, which is numerically advantageous considering some statements had negative changes between the pre- and post- surveys. This is reassuring, in that students are coming in with predisposed notions that they could be scientists one day. Secondly, although there is concern about whether students think they can only learn science in the classroom, interview data suggests students like learning when it's more interactive and hands-on. For more enriching, likable learning experiences, it would be ideal for classrooms to incorporate more hands-on experiences.

Additional takeaways from qualitative analysis shows that hands-on experiences are more likeable, and to make the analysis portion more interactive like the simulator portion of the activity. Going forward, to improve this or implement similar exercises with Native students, it is essential to smooth out issues in the analysis, interpretation, and discussion portion of the exercise. Better explaining concepts can impact how a student feels about learning. Making the analysis more interactive, where originally planned the students would plot the graph together on the board, and walking through each individual step through the analysis, could better teach the concepts. Thinking of ways to make the analysis of data as interactive as the simulator portion of the activity is an important consideration for future iterations of the activity and might be informed by Indigenous research methodologies. This involves ensuring plenty of time for this portion. In the interpretation and discussion, explicit connections between the activity and place-based implications are necessary to get across how hillslope hydrology applies to Native students' livelihoods and cultures.

Making direct connections about STEM to their daily lives makes meaningful takeaways. I think this can be easiest achieved by tying in place-based learning and connecting teaching to daily-life activities. When teaching is designed for a region, it can create meaningful experiences that might motivate a student to learn more about geoscience or related fields.

From this study's findings, it would be best to conduct the rainfall-simulator exercise toward the end of the introductory course once students have already learned about geoscience more broadly and landscape processes, so they can see how they can apply their learned concepts about hillslope hydrology to a hands-on experiment. Also, ensuring plenty of time for analysis is vital. As for conducting the survey, it's recommended to give the pre-survey at the beginning of the course, and the post-survey at the end of the course after the exercise activity. The survey statements can be changed to specifically relate to geoscience. There can also be post-survey statements or questions specifically relating to the rainfall-simulator activity. Continuing to tie in student interviews with the survey can provide more qualitative insight on the rainfall-simulator activity.

Finally, for the future, a simpler version of this exercise might be more effective in engaging Native students in geoscience. The rainfall-simulation exercise we developed is better suited for upper-division learning of hillslope hydrology and infiltration-excess overland flow. Freshmen and sophomores are dealing with a more basic understanding of concepts. A hands-on exercise that can communicate the same takeaways and tie in place-based learning without the potential of error associated with the current rainfall simulator might involve using a stream table. The intent of our exercise includes making connections between flooding and erosion. A stream table can better show how erosion works, and the students can try to recreate their homelands on the stream table. If instructors can still tie in place-based connections, this alternative activity would be a feasible hands-on activity.

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APPENDICES

APPENDIX A: STUDENT SURVEY INSTRUMENTS

Practice Questions:

Many questions below involve circling responses to indicate how much you agree with certain statements. Here are 2 practice questions so you know what to expect:

Please circle the number that reflects how much you agree with the following statements (with 1 being "strongly disagree" and 10 being "strongly agree"):

I enjoy eating ice-cream.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									***Strongly Agree***

I like stubbing my toe.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									***Strongly Agree***

There will be many other types of questions as well.

You can now turn the page and answer the next set of questions.

Survey Questions:

Please circle the number that reflects how much you agree with the following statement (with 1 being "strongly disagree" and 10 being "strongly agree"):

1. I like science.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

2. Science is something we only learn in a classroom.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

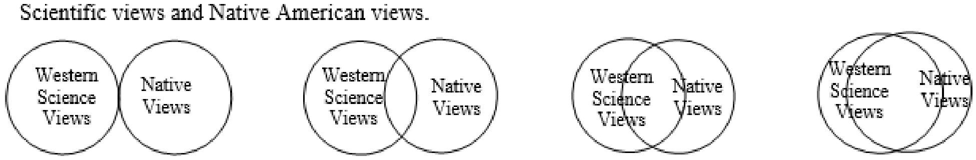
3. It would be easy for me to be a scientist.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

4. It's a strong possibility that I will be a scientist.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

5. Please circle the picture below that best describes the way you see the relationship between Western Scientific views and Native American views.



You can now turn the page and answer the next set of questions.

If you circled 'Yes' to the question asking if you are Native American, please complete the following questions.

Please circle the number that reflects how much you agree with the following statements (with 1 being "strongly disagree" and 10 being "strongly agree"):

6. My tribe has been doing science for a long time.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

7. Scientists and people in my tribe think about nature in the same way.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

8. I could be a scientist and live my cultural way of life at the same time.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

9. The things I can learn in school are important to my tribe.

1	2	3	4	5	6	7	8	9	10
Strongly Disagree									*Strongly Agree*

APPENDIX B: GROUP INTERVIEW PROTOCOL

Group Interview Protocol

Disclaimer: Further follow-up questions may be asked. In turn, such follow-up questions may not be asked, depending on whether the participant already answered them when asked the general question.

Script: The following questions will relate to your overall experiences in Upward Bound and the rainfall simulator activity you participated in yesterday. I am interested in knowing more about your experiences with the activity so that I can improve it for future students.

Warm-up Questions:

1. Introductions: What are your names, what year are you in school, and what major are you? If you haven't yet declared a major, what are some things you are thinking about?
2. Tell me about your experience with the Upward Bound Program so far?
    a. What are some things you especially like about it?
    b. What are some things that have been challenging about it?
    c. Do you have a favorite class? Why is it your favorite?
    d. Do you have a least favorite class? Why is it your least favorite?

Main Questions:

3. Tell me about your experience with the rainfall simulator activity?
    a. What did you particularly like about the activity?
    b. What did you dislike about the activity?
4. If you were going to tell someone in your family about geoscience and the rainfall simulator activity, what would you tell them?
5. What did you know about geoscience before we did the rainfall simulator activity?
6. Was there something about participating in the rainfall simulator activity that changed how you were thinking about geoscience?
7. Did any of you feel like you changed your responses between the pre- and post-survey?
    a. Can you tell me why you changed your mind?

Wind-down Questions:

1. Is there anything else I should know about your experience with this activity?
2. Have you had other experiences with geoscience? Can you tell me about them?
3. After participating in the activity yesterday, is there anything else you want to know from me about what geoscientists do or what it's like to major in geoscience?