Investigating Water Pathways in Schoolyards

Based on a learning progression of student understandings, this hands-on activity provides high school students with a locally-relevant way to learn about the water cycle

Photographs: Andrew Warnock

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ON AN OVERCAST DAY, hundreds of students make their way up the winding driveway of Baltimore City High School. As the students climb the old stone steps and enter the building, large rain drops begin to fall from the sky, splashing onto the manicured lawn, asphalt sidewalks and gently sloping roof of the school building. Puddles form on the playing fields and parking lots and gutters fill with rainwater runoff. Inside the school building, toilets flush, sinks run and store bought water coolers provide students and staff with drinking water throughout the day. On the top floor of the building, one environmental science teacher is using this rainy day as an opportunity to engage her students in a new kind of investigation: tracing water pathways in the schoolyard. Her students pull on their rain coats, grab their notebooks and school maps and head outside into the rain. For the next five days, these students are engaged in a new curriculum unit developed to enhance student learning of water cycle concepts: The School Water Pathways Activity.

Most textbooks depict the water cycle as a simple diagram consisting of clouds, mountains, streams and the ocean. These depictions rarely reflect the landscapes in which the vast majority of students live. This textbook image of the water cycle can lead students to believe that the pathways through the water cycle are simple, linear, and disconnected from their built community. In reality, however, water pathways are complex, nonlinear, and heavily influenced by human action. The goal for the Pathways Activity is to help students learn to trace water along multiple pathways and to consider the local factors which influence the volume of water that flows along any particular pathway.

The Pathways Activity is a weeklong inquiry-based lesson organized using the 5E educational model[1], and framed to *engage* students in answering two guiding questions: how much water falls on our schoolyard during a year, and where does that water go? Five hands-on *explorations* provide students first hand experiences with water cycle pathways and processes. Embedded in the explorations are tools for assessing student understanding of key big ideas. Students use a flow chart to *explain* how much water and where that water moves throughout their schoolyard based on the results of the explorations. Students then use the flow chart to *elaborate* on a variety of scenarios impacting water movement in their schoolyard. Finally, a summative *evaluation* is completed by students to assess knowledge gained through the activities.

Learning Progressions

The Pathways Activity is based on a learning progression of student understanding about water in environmental systems[2].

A learning progression is a research-based framework that describes how student thinking about a topic changes over time. Learning progressions are the foundation for the organization of the recommendations in the *Framework for K-12 Science Education*[3] and the forthcoming *Next Generation Science Standards*. Research on student understanding of water has shown that when first reasoning about where water goes, young students view water in isolated locations unconnected to water in other places. They are aware of only the immediate world around them, often focusing on the role of water in satisfying the needs of people (level 1). As students gain more experiences with the world, they begin to recognize that water moves from one location to another (level 2). These students often attribute the movement of water to actors or agents that do things to water, such as clouds sucking up water. In school, students usually learn the school science stories about how water moves in a cycle. They are able to name processes that move water and identify water in hidden locations, such as groundwater, or in invisible states, such as water vapor (level 3). Ultimately, we want our students to use model-based reasoning about water in complex systems and apply scientific principles to reasoning about how water moves through these systems. Students should be able to trace water along multiple pathways and at multiple scales (level 4).

Research shows that most middle and high school students are between level 2 and level 3 understanding[4]. The Pathways Activity is designed to support students in moving towards developing level 4 reasoning. To accomplish this goal, teachers can make use of eight Learning Progression-Based Teaching Practices (LPTPs; see Table 1). These teaching practices emphasize the importance of attending to learning goals, matching instruction to students' learning needs, and engaging students in place-based, inquiry experiences.

Learning Progression-Based Teaching Practices (LPTPs)

Table 1

LPTP #	LPTP Title	Practice
LPTP #1	Focus on big ideas	Identify and focus instruction on important big ideas in the field of study.
LPTP #2	Plan based on learning progressions	Plan instruction based on anticipated level of student understanding of the topic at hand.
LPTP #3	Use formative assessments	Develop and use formative assessments to guide selection of instructional strategies and sequences.
LPTP #4	Respond to student thinking	Support student learning through careful a) attention and b) response to student thinking during classroom discourse and in comments on student work.
LPTP #5	Engage students in inquiry	Engage students in guided or open inquiry with authentic events and experiences.
LPTP #6	Support student scientific explanations	Support students in developing explanations of environmental processes.
LPTP #7	Link to real world problems and local contexts	Link environmental science to real problems in the local context, anchoring students' learning in their culture and place.
LPTP #8	Engage in citizenship practices	Encourage students to engage in and reflect on science-based citizenship practices – using science skills and understandings to investigate, evaluate, and critique arguments, and to use science in everyday decision-making.

LPTP #1 encourages focus on important big ideas in the field of study. Throughout the Pathways Activity, targeted understandings for each exploration point to the big ideas we want students to understand about water pathways and processes.

Learning progression-based teaching practices also emphasize aligning instruction to students' level of understanding on the learning progression (LPTP #2). Students reasoning at a lower level in the learning progression may need additional learning experiences addressing foundational concepts while students at a higher level in the learning progression may be ready to expand upon their thinking towards more model-based reasoning. Formative assessment probes are associated with four of the five explorations and are designed to aid teachers in assessing their students' levels of understanding during various points in the lesson (LPTP #3). Teacher materials associated with each probe provide descriptions of common conceptions of student reasoning for the assessed concept at each level of the learning progression. Materials also include suggestions for improving student understanding of the concept for students reasoning at different levels. Formative assessments should be given to students in advance of each exploration to allow time for the teacher to tailor lessons based on the instructional needs of her students (LPTP #4).

Building a model-based understanding of water moving through systems requires understanding of the drivers that move water and factors that constrain water movement along potential pathways. Using the schoolyard as the study area, the, Pathways Activity supports teachers in engaging students in inquiry-based investigations of water in both natural and human-built landscapes (LPTP#5). The explorations emphasize developing explanations of water cycle processes and pathways (LPTP #6). Additionally, the schoolyard context supports teachers in involving students addressing water issues specific to their local watershed (LPTP #7). The end result of these activities includes encouraging each student to use science in every day decision making including investigating, evaluating, and critiquing popular arguments about water use and land management pressures on supplies of clean water (LPTP #8).

Engage

Students are initially assessed by drawing their own depiction of the water cycle. Teachers can identify informal conceptions or missing ideas about the water cycle from their students' drawings and use that knowledge to build a level-appropriate course of action for the rest of the activities. For instance, do students include humans or human influenced systems in their drawings? Is groundwater identified in student drawings and if so, how is groundwater linked to the rest of the water cycle? Teachers engage students in the activities by initiating a class discussion about where water falling on the schoolyard will go (i.e. guiding questions #2 above). A PowerPoint presentation introduces students to the guiding questions, key vocabulary terms and an aerial image of the schoolyard. Students use the aerial image of their schoolyard to make predictions about water pathways and the amount of water following each pathway during a given precipitation event.

Explore

To answer the first guiding question — How much water falls on our schoolyard during a year? — students use the annual precipitation for their town and the area of the school grounds to determine the volume of annual water input. Investigating the second guiding question regarding where the water goes, is much more complicated and is broken down into five separate explorations. These explorations provide students with first hand experiences of water cycle phenomena and supports them in developing model-based explanations about water movement. Each exploration helps students think through the scientific principles that explain water movement along pathways including the forces that move water (e.g., gravity) and, the factors that constrain water movement (e.g., topography).

Exploration 1: Land Cover in the Schoolyard

Targeted Understanding: Gravity and topography drive and constrain surface water pathways.

Precipitation that falls on the school's property has to go somewhere. The type of surface a precipitation falls on influences where a water molecule will go. The molecule could infiltrate, runoff, evaporate, or transpire by plants. Topography and surface type play a large role in constraining surface water flow. Exploration #1 begins with a formative assessment to gauge students' abilities to make inferences about topography from a simple map. Students responding to the assessment at a level 2 may not recognize that depictions of land on a 2D map represent an actual land surface with shape, slope and cover. The subsequent exploration provides students with a first-hand opportunity to connect features on a paper map with associated topographic features in their schoolyard.

To determine where water falling on the schoolyard goes, students need to estimate the proportions of the major types of surfaces in the schoolyard, including vegetation and built environmental features. Students are given a map with outlines of the major surface features of their schoolyard, overlaid on a grid. These maps can be created by importing an aerial image of the schoolyard into PowerPoint. Drawing tools are used to outline the major features of the schoolyard

and then the aerial image is deleted from the PowerPoint slide. A grid can be inserted on top of the remaining schoolyard feature outlines.

Students take their maps outside and work in teams to determine the surface type of each outlined section. This activity works best if students color their map sections according to the surface types identified. To save time, the teacher can divide the schoolyard into sections and have each team investigate only one section of the schoolyard (additional teachers or parent volunteers can help supervise student teams). Teams then combine their maps and create a pie chart showing the proportions of the different surface types in the schoolyard Because surface type has such a large impact on the pathways that water will follow after falling as precipitation, student identification of surface types in the schoolyard provides the foundation for the remaining schoolyard explorations.

Exploration 2: Measuring Runoff Potential in the Schoolyard

Targeted Understanding: Gravity drives surface water downward and topography constrains its direction.

Now that the students have a clear understanding of the different surface types in the schoolyard, they can revisit their maps, observe sloping features and predict runoff potential. This exploration begins with a formative assessment that elicits student ideas about runoff. By understanding how students are thinking about surface water flow, teachers can provide more focused guidance in helping them reason about pathways for runoff on the schoolyard and more broadly, what forces drive surface water flow (i.e., gravity) and what variables constrain surface pathways (e.g., slope, surface permeability).

During this exploration, students perform simple observations in the schoolyard to assess the slope of different surfaces. They use colored pencils to indicate on their maps where water should go based on topography and surface type. Students locate gutter downspouts, stairways, mounds, drain grates, depressions, etc. Students can test their predications by pouring buckets of water on different surfaces. In addition, a simple inclinometer may be used to help students measure the slope of the surfaces in the schoolyard (see photo, left).

By the end of this activity, students should be able to reason about where surface water flows and why, including an understanding that gravity pulls water downhill and that topography and surface type constrain the pathways water takes across a surface.

Exploration 3: Measuring Evaporation in the Schoolyard

Targeted Understanding: Heat energy moves water from a liquid state on the land surface to a gaseous state in the atmosphere.

Some of the water that lands on the schoolyard will evaporate. Understanding the process of evaporation is often a challenge for students reasoning at level 2 because the process itself is invisible. Engaging students in conversations about water evaporation may provide insight into their level of understanding of the process. Do your students understand that water can exist as an invisible gas (note that many students confuse invisible gaseous water vapor with visible forms of liquid water in the atmosphere such as fog, steam and clouds)? Do students understand that heat energy is necessary to convert liquid water into a gaseous state at a molecular scale? The variables that influence rates of evaporation include , relative humidity and wind speed. Students can easily investigate the effects of various abiotic factors on evaporation rates in the schoolyard.

In the investigation, each student team is provided with baking pans to use as evaporation pans. The pans are filled with water to a depth of one inch, covered with window screen material to prevent animals from drinking the water, and placed outside in different locations. Student teams test and compare different locations: shade, full sun, calm wind, and full wind. Students use a ruler to measure the height of the water at the edge of the pan in the same place and at the same time each day. An empty pan should always be placed next to each full pan as a control and to capture any precipitation that may fall during the study period. After several days, each team extrapolates their evaporation rates to estimate how much water evaporates from the schoolyard in one year. A total class average can be calculated and used to discuss seasonal variation in evaporation. By the end of this activity, students should be able to discuss the driving forces (i.e., heat energy) and constraining variables (e.g., relative humidity and wind speed) influencing varying evaporation rates in the schoolyard.

Exploration 4: Measuring Transpiration in the Schoolyard

Targeted Understanding: Water moves from a liquid state in a plant to a gaseous state in the atmosphere.

Plants obtain water through their roots, which extract water from the soil. The water is drawn up the trunk and out through the branches to the leaves. Most of the water is then released back into the air as water vapor in a process called transpiration. Movement of water through a plant is driven by capillary action and partly by differences in pressure resulting from transpiration from stomata. In this exploration, students conduct a transpiration experiment and then estimate how much water transpires from their schoolyard in a year. Through conducting this investigation, students should be able to: 1) explain how water moves through plants, 2) explain how water changes states, and 3) make estimates about the total contribution vegetation in their schoolyard makes to moving water from the land to the atmosphere.

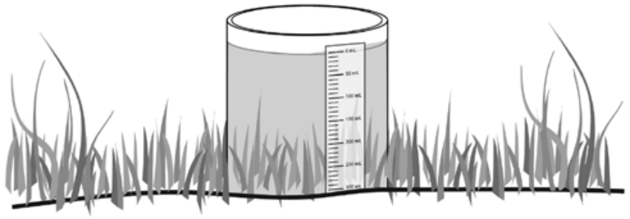
To begin, students take a formative assessment about transpiration. (A level 2 student will realize that plants take up water, but not realize that water leaves plants as water vapor. A level 4 understanding of transpiration should include an understanding of transpiration as a process that moves water from a liquid state in a plant to a gaseous state in the atmosphere.) After this assessment, students go outside and find a suitable tree with reachable limbs. A clear plastic, water tight baggie is placed over a batch of leaves of approximately the same size or as many needles as will fit into the baggie, and use duct tape to create an air tight seal around the branch. The taped part of the bag should be situated higher than the bottom of the bag to prevent leakage. The leaves or needles where the duct tape is placed should be removed to ensure an airtight seal.

Students return to the tree in two or three days and carefully remove the baggie without spilling any water. This can be accomplished by cutting the branch just above the bag seal and bringing the entire setup inside. Using a graduated cylinder, students measure the volume of water collected. The volume of water can then be divided by the number of leaves or needles originally placed in the baggie to calculate the volume of water transpired per leaf or needle. Multiply the volume of water per leaf by the estimated number of leaves or needles on the tree to get a broad estimation of the amount of water the tree transpires over the number of days the baggie was on the tree. Then extrapolate to estimate annual transpiration for that tree. Teams can subsequently compare and discuss the variation observed from different trees and locations; for example, the transpiration of deciduous vs. evergreen trees, north vs. south facing, young vs. old, etc. By the end of this exploration, students should be able to discuss the principles behind transpiration including recognition of water conservation across system boundaries and in and out of hidden and invisible places.

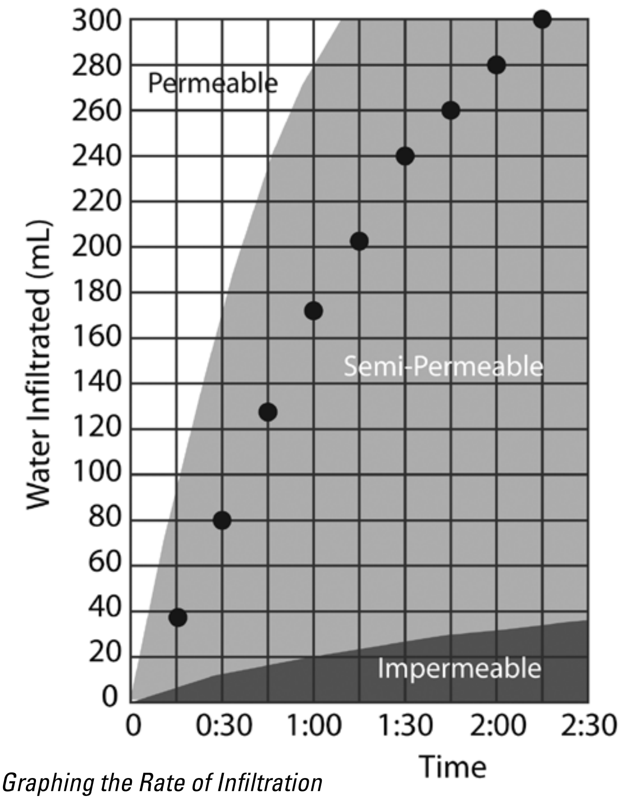
Exploration 5: Measuring Infiltration in the Schoolyard

Targeted Understanding: Gravity and soil structure drive and constrain water movement in the ground.

Different surface materials have different porosities and permeabilities. This activity addresses permeability and



A Simple Homemade Infiltrometer



Graphing the Rate of Infiltration

infiltration rates of different surface materials in the schoolyard (note: this activity will not work if the ground is frozen!).

An infiltration formative assessment is available to gauge student understanding of this process. (Level 2 students may not realize water exists in hidden places such as in pore spaces between soil particles. High-level student responses should include an understanding that infiltration into the ground depends on the porosity and permeability of soils and that gravity pulls water into the soil.) Once underground, water can follow multiple pathways. Most water will flow downwards, however some water near the surface may evaporate into the atmosphere and some water may enter plants.

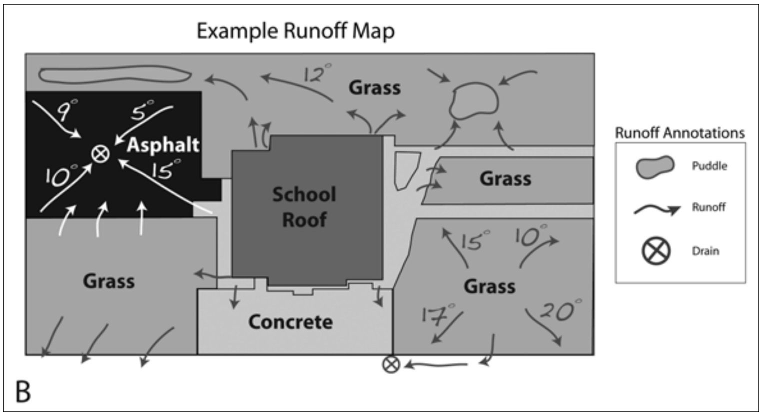
To complete the exploration, students begin by predicting which surfaces will have the fastest rate of infiltration and which surfaces will have the slowest. Simple homemade infiltrometers are used to measure the rate of infiltration for each different surface material (see above). Students press a clear plastic graduated tube into the soil and use a stopwatch to time the rate of infiltration of the water. Modeling clay can be used to make a seal between the tube and solid surfaces such as concrete, asphalt, and roof shingles. Students graph their results and revise their original predictions (see above). This simple tool easily demonstrates the large differences in permeability within the schoolyard and allows students to discover for themselves which surfaces are permeable, semi-permeable, and impermeable.

Explain, Elaborate, Evaluate

When the students complete all five explorations, they will have a map that works as a visual explanation of the water pathways in their schoolyard. Once students understand the individual processes and pathways that influence water movement in their schoolyard, they are well positioned to explain the relative proportions of water traveling through the different pathways. A flow chart is used to help students visualize the relative amounts of water moving through different pathways in the schoolyard. This flow chart helps students calculate the relative volumes of water evaporating, infiltrating, transpiring, and running off given the proportions of different surface types present on their school grounds and allows the students to answer guiding question #2 (where does water go?) with confidence. The proportion values are taken directly from the pie chart students created during exploration #1. The given values in the flow chart are broad estimates of actual rates of evaporation, runoff, infiltration and transpiration determined by consulting water science experts. We expect and encourage students to question these rates and suggest alternative rates based on schoolyard location, design, and local climatic patterns.

Now that students have completed all five explorations and explained water movement in their own schoolyard, they can elaborate by using their flow chart to test scenarios such as evaluating the impact of replacing a lawn with a parking lot or identifying sources of pollution that could contaminate runoff. A final assessment of student knowledge is the redrawing of the water cycle by each student. How do these final drawings compare to initial drawings? Do students include new pathways for water travel? Can they explain the forces that drive water and the factors that constrain flow?

With minimal preparation time, the Pathways Activity allows a teacher the chance to expose their students to a hands-on and locally relevant way of learning about the water cycle. The traditional water cycle model falls short in that it doesn't teach students about the non-linear pathways



water follows, the function of surface type in influencing the pathways that water follows, the rates of water movement along these pathways, and the scale of processes in the water cycle. It also does not address how human alterations of natural surfaces affect water pathways. This activity addresses these shortcomings by exploring individual pathways and processes within the water cycle and calculating real rates of water movement at a small and locally relevant scale.

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The most recent version of the Pathways Activity teaching materials (including all formative assessments, student worksheets and introductory PowerPoint) may be found at: http://edr1.educ.msu.edu/EnvironmentalLit/publicsite/html/water.html

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