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Grounding Water: Building Conceptual Understanding through Multimodal Assessment

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ABSTRACT

The world's population is growing by about 80 million people a year, implying an estimated increased freshwater demand of about 64 billion cubic meters annually (World Water Assessment Programme, 2009, Water in a Changing World: United Nations World Water Development Report 3, Chap. 1, p. 3–21). Groundwater depletion, which reduces the amount of valuable water available for drinking and food production, has become a global crisis. Decision-makers at all levels desperately need to understand the unseen system beneath their feet and its connection to the earth's hydrologic cycle. Yet teaching groundwater concepts is extremely challenging; foundational misconceptions about groundwater's location, movement, and connection to the hydrologic cycle are common. Quality, multimodal instruction, and assessment of groundwater topics will help to clarify elementary students' misconceptions and assist them in constructing accurate mental models of the groundwater system. This study examines student responses to different forms of assessment, including drawing prompts, to determine the best way to ascertain what students really know about the groundwater system, a key component of the larger water cycle system. The assessment tools included dichotomous, multiple-choice, and drawing questions used to elucidate students' conceptualization and understanding of the groundwater system. Assessment results show that students who are able to answer objective questions about groundwater are not necessarily able to demonstrate their knowledge; calling into question their conceptual understanding of the system. © 2011 *National Association of Geoscience Teachers*. [DOI: 10.5408/1.3604827]

INTRODUCTION

An understanding of the hydrologic cycle is not just about defining evaporation, condensation, and precipitation, but also about articulating how water changes states and moves from one part of the system to another. Water is undeniably fundamental for survival and as most of the world's populations are increasingly reliant on indefinite water supplies, an understanding of the groundwater system within the hydrologic cycle is essential for wise water use and good water stewardship worldwide. This research examines conceptions and misconceptions about groundwater held by elementary school students in the arid Southwestern United States, in an effort to identify the best way to assess conceptual knowledge of the groundwater system and its relationship to the hydrologic cycle.

To ascertain students' understanding of the groundwater system, researchers elected to evaluate the extent to which fourth graders retained the overall "big picture" concepts of the location, use, storage, and movement of groundwater. In accord with the 4th grade earth science learning benchmarks (Arizona Department of Education, 2005), the Arizona Water Festival (AWF) learning experience focused on students at this grade level. Students living in the arid Southwestern United States are reminded daily of the lack of visible water in their environment, begging the question: "Where does the water they use come from?" While student comprehension of the entire cycle deserves further analysis, this study focused on the complex and unseen groundwater system due to the disquieting lack of understanding of it as an essential part of the hydrologic cycle.

CONTEXT

The Importance of Grounding Water

The world's population is growing by about 80 million people annually, implying an annual estimated increased freshwater demand of about 64 billion cubic meters (World Water Assessment Programme, 2009). Over the past century, groundwater withdrawal has grown to exceed natural renewable groundwater storage (or safe yield) in many areas of the globe (Narasimhan, 2010). Groundwater withdrawn for agricultural use in Bangladesh, China, India, Iran, Pakistan, and the United States accounts for well over 80% of global groundwater use (Shah *et al.*, 2007). The deep-well turbine pump, first deployed for agriculture in California in 1907, made it possible to lift large quantities of water from depths of tens of meters in wells, limited only by the availability of adequate energy (Freeman, 1968).

According to the U.S. Geological Survey, a century-long observational record of groundwater depletion exists for the United States major aquifer systems (McGuire *et al.*, 2003; Narasimhan, 2009). In two unconfined systems, one of which includes the aquifer system in the study region, withdrawals have been accompanied by tens of meters of permanent water decline with no prospects of recovery in the foreseeable future (Narasimhan, 2009). Three confined aquifer systems—the Dakota, Atlantic Coastal Plains, and California's San Joaquin Valley aquifers—have experienced 80% nonrecoverable compaction due to groundwater withdrawals (Narasimhan, 2009). Groundwater development in India presents another example of overdraft. The introduction of turbine pumps during the 1960s to enhance agricultural production was successful in meeting its goals, but also led to severe declines in water levels

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and alarming depletion of groundwater storage over many parts of India (Narasimhan, 2006).

Groundwater depletion has become a global crisis. In many regions where population is rapidly growing, immediate action must be taken and policy makers will be expected to make educated decisions on the inter-related topics of water supply, water quality, and water policy. Along the same lines, students who are just beginning to form their conceptions and understandings of the natural world may be the most important stakeholders as they are the future educators, voters, leaders, policy makers, financiers, consumers, and water users.

Of great concern is that groundwater is not regularly covered in school curricula, in spite of the fact that 78% of community water systems in the United States have groundwater as their primary source (U.S. Environmental Protection Agency, 2010). Researchers, who have only recently begun to take notice of how students are taught and learn about groundwater, note that teachers themselves are often ill-prepared to teach the topic (Dickerson and Callahan, 2006) and that the term groundwater never appears in the National Science Education Standards (Dickerson *et al.*, 2007). In the state of Arizona, where this study took place, the term groundwater is listed as one of four examples provided in a performance objective that states: *Identify the sources of water within an environment* (Arizona Department of Education, 2005). Although groundwater is only briefly mentioned in the science standards, understanding groundwater as an integral part of the hydrologic cycle is important, especially in arid states like Arizona, where groundwater is 44% of the water supply (Arizona Department of Water Resources, 2006).

Groundwater, water beneath the earths' surface which saturates the pores and fractures of sand, gravel, and rock formations (U. S. Geological Survey, 2009), is unseen, and therefore difficult to visualize or articulate. Deeply held, naive conceptions based on what can be seen at the land surface interfere with groundwater instruction. Such conceptions develop from formal instruction and emerge from errors or misleading representations in texts, lectures, and inappropriate or misapplied practical experiences throughout the student's history (Dickerson and Dawkins, 2004). Instructional tools that use concrete representations of concepts as abstract as groundwater must remain as complete and accurate as possible in order to serve a useful purpose (see Fig. 1).

Oversimplified or carelessly prepared models or graphics may prompt students to develop disconnected, isolated notions of groundwater concepts that yield an incomplete and inaccurate mental image (Dickerson and Dawkins, 2004).

Building a Foundation for Conceptual Knowledge Acquisition

The Arizona Water Festival program aims to provide children with "basic water literacy," introducing fourth grade students to the topics of watersheds, groundwater, the water cycle, and water conservation through standards-based, hands-on activities both in the classroom and at the Water Festival itself—a two-hour field experience. Through formative evaluation of the Arizona Water Festival program over the last decade, coordinators have improved both the instructional method incorporating

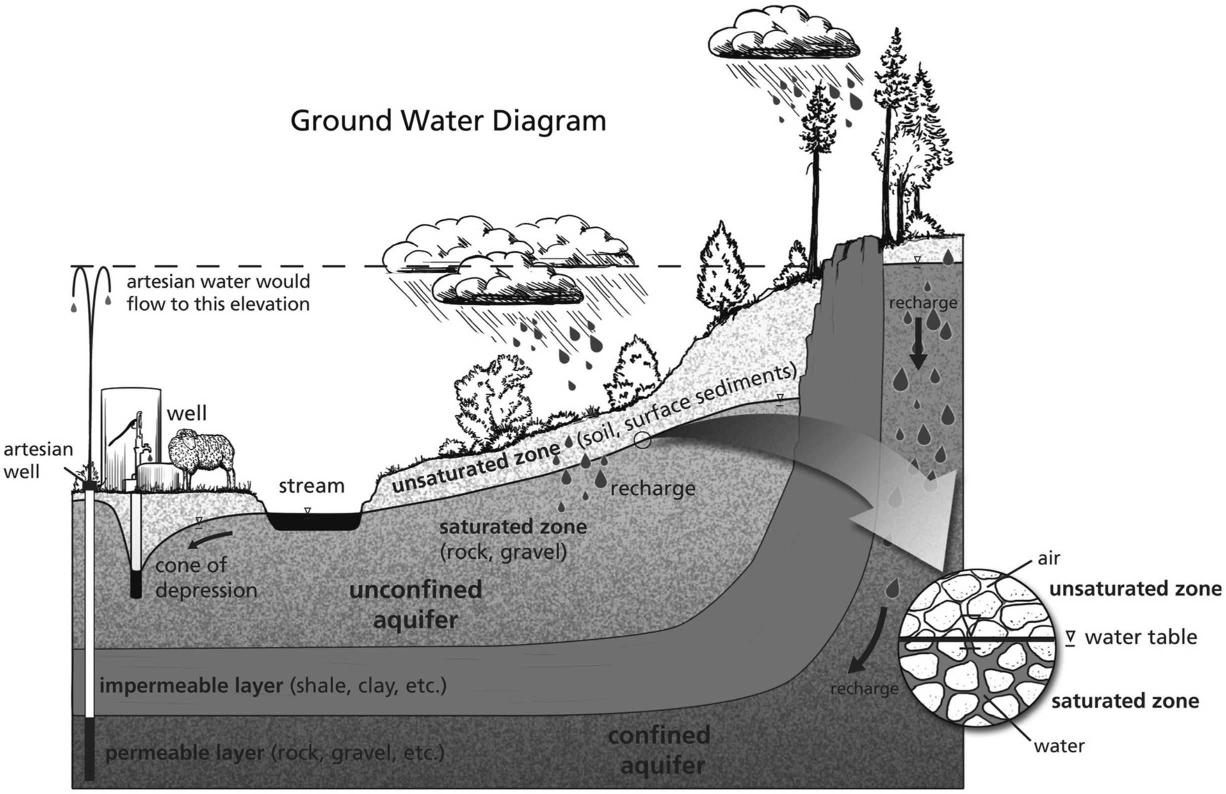


FIGURE 1: A diagram of the groundwater system shows groundwater between the grains of sand and gravel under the ground, connected to surface water, and connected to the human system through pumping (Howe and Schwartz, 2007).

varied learning styles and assessment tool. Neuro-cognition research supports the need for multimodal methodologies in education. "Intermodal redundancy theory" states that learning is facilitated when information about the exact same subject is presented via two or more modalities (Bahrick and Lickliter, 2000). The "modality effect" (Penney, 1989) suggests that the processing mechanisms are specific to either the auditory or the visual stream, and each stream has different properties and capabilities, resulting in different ways of representing information.

Dickerson *et al.*, (2007) suggested that a students' understanding of groundwater can be improved by the use of hands-on learning materials that enhance a students' understanding of groundwater by expanding their spatial reasoning about the topic. Similarly, Hobson *et al.* (2010) found that using models and representations helped children to understand spatial concepts, such as placement, which they may otherwise have found difficult to conceive or illustrate. Reinfried (2006) also discovered that college students who were instructed using mental model-building methods, including hands-on models, were more likely to improve their understanding of groundwater systems than students who learned about groundwater through lectures and curricula that excluded mental model-building. The need to identify students' preconceptions about groundwater is critical to providing effective instruction.

Teaching in a multimodal fashion augments learning potential but necessitates multimodal evaluation to accurately measure student learning. Multimodal assessment is a credible and widely accepted method for gauging learning and aptitude (Prain and Waldrip, 2006). The benefits of using a multimodal evaluation are that knowledge and understanding can be assessed through multiple routes (O'Bryne, 2009). Waldrip *et al.* (2006, p. 87) defined "multimodal" as "the linked use in science discourse of different modes to represent scientific reasoning and findings." Multimodal assessments enable students to display their knowledge and understanding through forms of assessment that highlight their strengths and provide a robust review of a learner's comprehension.

By allowing students to interact with groundwater models during lessons, educators facilitate students' "mental model" building. In their work on conceptual learning, Magnusson *et al.* (1997) suggested that learners typically grasp knowledge in terms of concepts, emphasizing the need for conceptual science teaching. During the assessment process, rather than focusing on a rote answer, students are then able to convey areas where understanding is lacking while simultaneously referring to and sharing their own mental images of concepts learned. This knowledge, stored in the learners' individual mental models, may not be captured in a standard assessment instrument.

Considerable research has been done on open and closed, oral and written questions, yet drawings are often overlooked or underutilized as a tool in assessment even though they serve as an alternative form of articulation (Dove, 2006). In this study, responses to drawing prompts are used as a means of determining what students truly know about the groundwater system. Anning (1997) maintains that drawing can be a means to clarify thinking and effectively represent ideas to others. Similarly, in their study of mental model building Glenberg and Langston (1992) proposed that pictures assist in the construction of mental models and parlay into working memory. They support relationships that are implicit and assist learners in articulating more complexity.

METHODS

Using results from the Arizona Water Festival intervention, the objective of this research was to determine the best way to assess what 4th grade students understand about the groundwater system. The overall water education experience was delivered in multiple modes on the day of the event and bolstered by similarly multimodal pre- and post-festival lessons taught in the classroom. Our assumption was that the use of multimodal teaching methods, like those used in the intervention, provides the best instructional practice for teaching about the groundwater system.

Setting and Intervention

The Arizona Water Festival program in 2009 trained 622 volunteers to deliver engaging water education to 6924 fourth graders and their 313 teachers. An AWF held outdoors at a community park is a highly structured and organized event in which as many as 500 students rotate through four learning activities in the morning and another 500 rotate in the afternoon. Students move through four stations with their whole class, ranging from 15–35 students, where 2–4 trained volunteer instructors facilitate activities. Learning activities are 30 min in duration and address four topics: groundwater, watersheds, water cycle, and water conservation. In the AWF setting, students are fully engaged in learning because they are in a new setting, learning from new instructors, and exposed to interactive demonstrations and models that they would not likely be exposed to in the classroom. Before and after the AWF, teachers conduct pre- and post-festival lessons covering the same four topics in the classroom. The AWF water education program has reached 33,337 students in 20 Arizona communities, using multimodal instruction over a decade.

The 2009 AWF Summative Evaluation, using pre- and post-student questionnaires, demonstrated statistically significant results for student gains in overall water content knowledge. Student knowledge about water increased pre- to post-water festival and their enthusiasm for water conservation and learning about water increased (Thomas-Hilburn and Schwartz, 2009). Furthermore, students in the classes of teachers who participated in the professional development workshop showed greater gains than those who did not. According to post-festival survey results, 100% of participating teachers agreed that water festivals teach water concepts more effectively than the teachers could accomplish in their classrooms and 98% agreed that their students were more likely to conserve water after festival attendance. Teachers also rated their students' reaction to the festival as "excellent" and felt that the water festival should be repeated in their community. Thus the AWF program is an effective instructional model as evaluated through formative and summative assessment.

The use of trained volunteer presenters who are not classroom teachers creates a situation in which presenters can be specifically trained in teaching techniques appropriate for that lesson. In a 2 hour training session, volunteers are trained to facilitate the lesson by first observing master facilitators model the lesson as they would with 4th grade students and then presenting the lesson back to the master facilitators. As facilitators of learning, the volunteers use kinesthetic, visual, and inquiry methods to assist students in developing conceptual understanding. The facilitators ask questions that lead students to discover the main points of the lesson.

Though the AWF intervention covers the topics of watersheds, groundwater, the water cycle, and water conservation, the focus of this study is on a students' understanding of the groundwater system and the water cycle as it relates to groundwater. The groundwater lesson has three inquiry-based sections using three different models to cover five main points:

- Groundwater is located underground between the grains of sand and gravel.
- Groundwater moves underground.
- Groundwater is connected to surface water.
- Groundwater is a part of the water cycle.
- Groundwater is an important source of water for human use.

During the 30 min lesson on the groundwater system, the facilitator questions the students directly on what they observe—a process designed to build strong foundational knowledge. Lessons incorporate checks for understanding at multiple points that enable the instructor to dispel common misconceptions students hold about groundwater.

In section one, students pour water through open-ended tubes that contain different earth materials and observe the effects of grain size on the rate at which water flows through each material. In section two, they interact with a cross-sectional flowing model that enables them to see water flowing laterally, due to the effects of gravity through the same materials they experimented with in section one. In section three, students use small groundwater basins complete with simulated lakes to experiment with the connection between groundwater and surface water, and further explore how water fills the pore space between particles underground. In both sections two and three, students observe groundwater's connection to the larger water cycle. Finally, students pump water up to the surface from wells with a hand pump, observing the effects on the groundwater system and establishing the connection to the human water supply.

In addition to the core groundwater lesson, the water cycle lesson includes groundwater as one of nine storage places where water can go in the earths system. Other places include oceans, rivers, lakes, soil, glaciers, plants, animals, and clouds. Each storage place is represented by a different colored bead and a unique cube that students roll to determine their next destination. Students "become" water molecules moving through the water cycle and record their unique journey with different color beads. By examining each student's color-coded bead bracelet, representing their unique water cycle journey, students see that water entered and left the groundwater system, thus establishing groundwater's connection to the larger hydrologic cycle.

The prefestival groundwater lesson, using physical and whole-body techniques, also has students experimenting with the movement of water through different earth materials due to gravity. Students design experiments to learn how water moves through different earth materials (sand, gravel, and clay-rich soil), and then use their bodies as water molecules and earth materials to model that movement again. Greene's "spacing-effect in memory" stipulates that retention of items to be memorized is improved by repetition not grasped en mass at one moment (Greene 1989).

The prefestival water cycle lesson has students building a water cycle in a jar and observing conditions over time, thus reinforcing the understanding of processes by which water changes form and moves through the water cycle. The post-festival lesson for both topics re-establishes groundwater as a source of the human water supply, connecting the natural water cycle to the human water cycle. Delivering multimodal content over a 2 week period ensures that content is reiterated in an effort to cement the subject matter and make the overall groundwater knowledge salient.

The Research

The groundwater system remains an unobservable mystery to most, and many individuals do not consider it as part of the hydrologic cycle; yet arguably, groundwater is one of the most important parts of the cycle in the Southwest. With an overall intent to truly ensure that students are building conceptual knowledge toward understanding the groundwater system, researchers decided to take a deeper look at the student assessments on the subject that include multiple choice and dichotomous questions, and drawings. Through multimodal assessment, researchers hoped to better understand the students concepts of the groundwater system. This research will shed light on the best way to gauge a students understanding of the groundwater system and its relationship to the hydrologic cycle. Table I outlines the study.

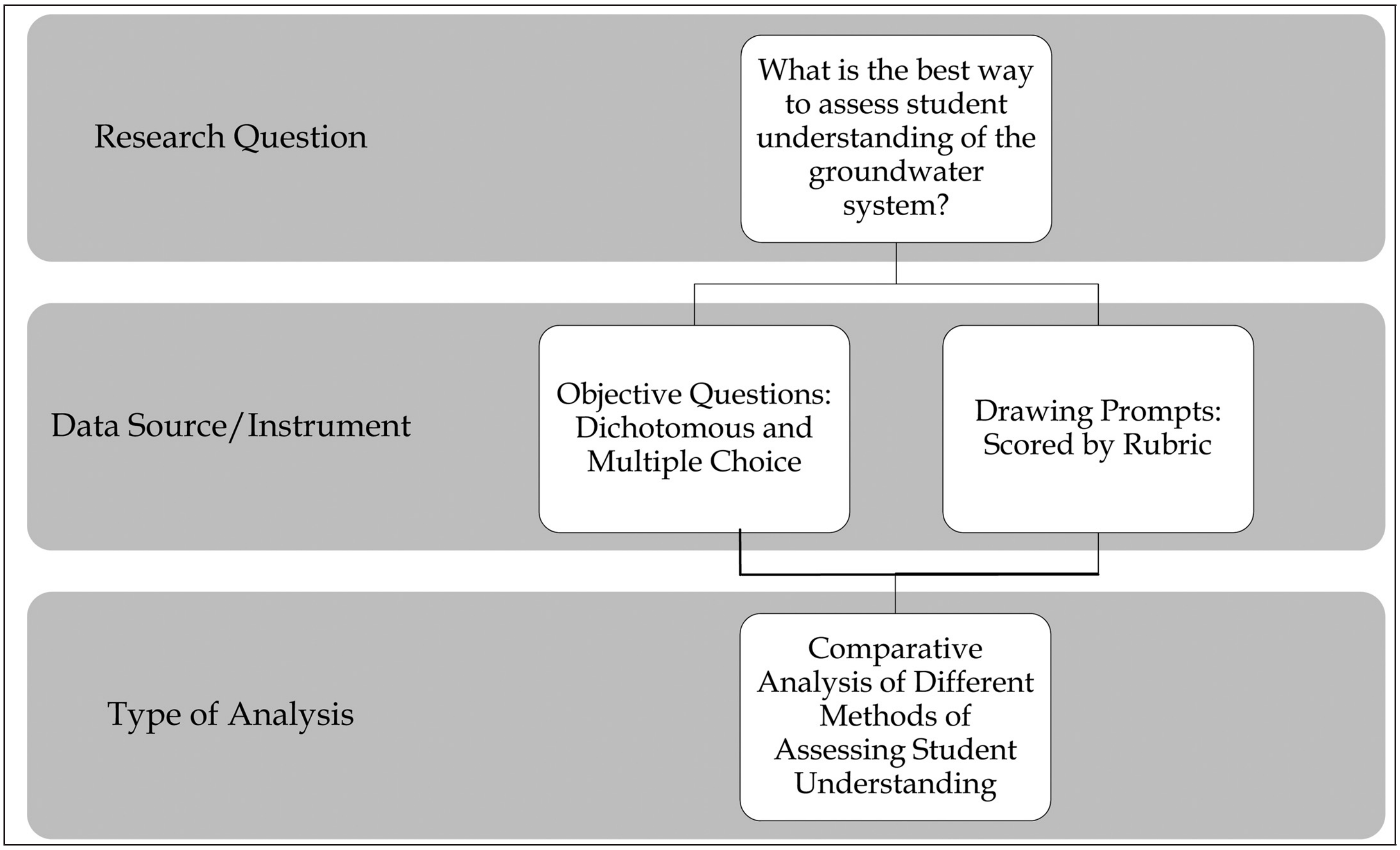
Assessment Instrument

The pre- and post-assessments for the AWF were designed to include a variety of question types, and to assess a student's knowledge of all four topical areas covered at the water festival. *Excellence in Environmental Education: Guidelines for Learning (PreK–12)* (North American Association for Environmental Education, 2004) was used to ascertain the level of skill and knowledge appropriate for 4th grade. Because the students taking the test were diverse in their reading, writing and language abilities, the nonwritten drawing portion of the test was of particular importance to enable students to demonstrate their knowledge, regardless of language capabilities (Medina-Jerez *et al.*, 2007; Rice *et al.*, 2004).

As part of an overall evaluation of the AWF program, the student assessment was given in the classroom by regular classroom teachers who had the option of attending a professional development workshop to learn how to teach these lessons. Of the students in the sample, 43% (n=71) were instructed by teachers who attended the workshop.

As the assessment instrument was intended primarily for use in program evaluation, the emphasis in design was on usability for teachers and students as a learning tool rather than on psychometric properties (which were not all together ignored). The assessment tool was crafted based on the lessons' key ideas in each of four topics: groundwater, the water cycle, water conservation, and watersheds. Initially, questions were developed to test each of

TABLE I: Grounding water: Building a conceptual understanding through multimodal assessment.



the several learning objectives, and then given to students as open-ended sentence stems for completion. The open-ended responses from 120 students were compiled for each question and then grouped into categories expressing the same idea. Some questions were omitted because student responses indicated that the question was not testing the intended learning objective. Responses for the final multiple choice questions were created using actual student language and ideas, with some editing for clarity. The intent was to generate answers that reflected genuine common student misunderstandings. For the drawing prompts, variations in wording were tested on a sample consisting of several classes (120 students total) to find the wording that generated the best student drawings without prompting students to answer in a particular way, or "giving away" the answer.

This study focused only on those responses to items related to groundwater. The set of groundwater items consisted of one multiple choice question and two dichotomous questions in the objective portion of the assessment. Responses to two drawing prompts focused on the groundwater system and its' connection to the hydrologic cycle were also utilized. Assessment items included:

1. *Most groundwater is found in:*
    - a. *a huge lake under the ground.*
    - b. *a river far below the soil we walk on.*
    - c. *between particles of sand or gravel.*
    - d. *solid bedrock underground.*
2. *Groundwater moves underground. True False*
3. *Surface water is not connected to groundwater. True False*
4. *Draw your idea of what groundwater looks like in the space below. Think about where groundwater is found, how it gets there, and what happens to it over time. Draw as many things as you can think of that relate to groundwater and label your drawing.*
5. *Draw a picture of the water cycle in the space below. Include and identify all the places that water can go in the natural earth system. Include all processes that drive the water cycle. Use arrows to show the movement of water from one place to another. Label the ways the water changes form when it moves from one place to another (for example, condensation, freezing)*

It was important that the assessment be relatively simple to administer and score, as the scale of the program did not allow for large amounts of time to be given to the assessment of individual students (e.g., interviewing and drawing discussion). Participants were given a pretest by their teachers before they started the water festival unit. Following the pretest, students participated in the prefestival lessons, the Water Festival itself, and finally the post-festival in-classroom lessons. Post-tests were given to each participant by their teacher upon completion of the water science unit. The pre- and post-tests were identical, yet the multiple weeks between the two minimized the test, retest effects. Upon completion, post-tests were deidentified. The objective sections were entered into a database and linked to the drawings which were scanned and loaded into Atlas.ti, a qualitative analysis software for analysis and scoring.

TABLE II: Groundwater drawing rubric.

5	Drawing correctly displays groundwater between grains of sand and gravel (or mixed with dirt soil), and shows movement of groundwater from one place to another, percolation, and well pumping.
4	Drawing shows a less complete understanding of groundwater, displaying groundwater in the correct location, but static, or inaccurate depiction of movement. Is correctly located under the ground or between grains of sand, but not related to any other water features or systems.
3	Groundwater movement is shown in some capacity, whether via pumping, percolation, or flow from one place to another, but groundwater appears as a large lake under the ground.
2	Groundwater is correctly located underground, but appears as a large lake or river under the ground. Groundwater is not shown to be a part of a system.
1	Shows some understanding of the location or movement of groundwater, but is not clear in their presentation of the location and movement as it relates to the rest of the system.
0	Does not answer or the answer shows no understanding of where groundwater might be found.

Study Population

Nearly 7000 4th grade students (ages 9–10) participated in the water festival in 2009, the year of this study, from the cities of Payson, Cottonwood, Yuma, Sierra Vista, Tucson, and Fountain Hills. All teachers whose classes participated in a festival were invited to submit their students' pre- and post-tests for use in the study. Ultimately, 1474 complete student records (records with both a pre- and post-test) were submitted. To account for variability in classroom setting and educator styles, three students from each classroom that submitted tests for the study were randomly selected to be included in the sample for drawing scoring and analysis. In a few cases, selected records (n=5) appeared to be incomplete, and these were later eliminated. This resulted in a sub-sample of 163 students, creating a manageable number of drawings for scoring purposes.

The average ethnic breakdown across the six school districts that these students came from was 54% Caucasian, 25% Hispanic, 4% African American, 2% Asian, 2% American Indian, and 13% designated as other (National Relocation for People on the Move, 2011). Across the six communities represented, the average number of students on free or reduced lunch was 55%. However, the districts represented in the sample were diverse, with the percentage of students on free or reduced lunch ranging from 15%–93% (National Alliance for Public Charter Schools, 2011). The percentages of English language learners were also wide-ranging, from less than 1%–41%.

RESULTS AND ANALYSIS

Researchers used assessment data collected from a successful instructional model to understand the best way to assess student understanding of the groundwater system and its relationship to the water cycle. The four criteria for 4th grade conceptual understanding of the groundwater system include the following:
Students will:

- Recognize that groundwater is located underground between the grains of sand and gravel.
- Explain groundwater's movement underground.
- Demonstrate groundwater's connection to surface water.
- Illustrate groundwater as part of the water cycle.

Student assessment data for this research included groundwater questions and groundwater and water cycle drawing scores. The groundwater question scores account for the students' ability to answer three objective questions about groundwater correctly. Groundwater drawing scores reflect the students' ability to draw an accurate depiction of the groundwater system based on the rubric in Table II. Water cycle drawing scores reflect the students' inclusion of the groundwater system as a place where water can go in the water cycle. SPSS and Excel were used to analyze data in each category.

To generate groundwater drawing scores, a drawing rubric was created to facilitate scoring of student drawings and identify common student thinking about groundwater and the water cycle. The rubric was written in a collaborative process between two individuals. The first step identified ambiguous wording in the rubric, which was revised and tested again by two raters who were then able to achieve a high inter-rater reliability (Pearson's r=0.7). Since the raters disagreed on a relatively small number of cases, the reviewers then reviewed these cases together, rescoring after discussion of possible interpretations of erroneous features of the drawing. The groundwater drawing rubric assesses three of the four criteria identified for 4th grade conceptual understanding of the groundwater system, while the water cycle drawing provides insight to the fourth criterion.

ATLAS.TI, a qualitative analysis software tool, was used to maintain researcher notes about interesting drawings and to assign a score to each drawing based on the five-point rubric (0–5), with 0 reflecting low complexity (little or no understanding of groundwater) and 5 reflecting high complexity (high understanding of groundwater). In this case, complexity refers to the student's understanding of the location of groundwater, its connection to a system, and its behavior and function in the system. Drawings were scored by two separate researchers who then reviewed all instances of disagreement to choose the correct score. Drawing scores were then correlated to each student's objective scores. Pre- and post-test scores were recorded in a database in Excel 2007 and SPSSv16 software was used to conduct statistical analysis.

This study did not focus on student growth pre- to post-assessment, as researchers were most interested in determining students' conceptual understanding of the groundwater system. That said, it may be instructive for the reader to know that groundwater drawing scores did significantly increase with the intervention: The mean score increased by 0.396, with a standard deviation of 1.46. The improvement was significant, t (163) = 3.478, p=0.001. Likewise, the groundwater question scores also increased, although the number of questions in the sample (three) made that increase less significant. Additionally, students whose teachers participated in the professional development workshop (n=71, M=2.32, SD=1.43) performed better on the post-test than those whose teachers did not attend the workshop (n=93, M=1.87, SD=1.46). This difference was significant, t (162) = 1.98, p=0.049, though not nearly as significant as the overall difference in pre- and post-test scores for all students.

To evaluate the effectiveness of the various forms of assessment, student groundwater question scores were compared to their groundwater drawing scores. Of students who answered the multiple-choice groundwater system question correctly (reported groundwater as being found underground between particles of sand or gravel) (n=61, or 37%) only 18% (n=11) reflected this in their drawings, while 82% (n=30) did not demonstrate this knowledge in their drawings despite having answered the objective question correctly. Of the students whose drawings correctly illustrated groundwater (n=25) as being located underground between particles of sand and gravel, 44% (n=11) answered correctly when asked where groundwater was found within the multiple choice section by reporting that groundwater was "found between particles of sand or gravel."

Such a large discrepancy between students' answers to the multiple choice question and the ability to appropriately draw groundwater was surprising. Thus, the research team then calculated the difficulty and discrimination index for this question to eliminate the possibility that the question was poorly written or too easy. Using the upper and lower 27% of the sample (Kelley, 1939), both indexes were found to be 0.30, or of moderate discrimination and difficulty. Applying Wiggins and McTighe's validity test, the drawing assessments used in this study have a high degree of validity (Wiggins and McTighe, 2005).

There was a similar inconsistency in the dichotomous questions. One would anticipate that students who answered the dichotomous question, "Groundwater moves under the ground" to be "true" rather than "false," would also draw groundwater moving in some way. However only 34% (n=48) of the 139 students who answered this question correctly also indicated in their drawings that groundwater moves. Of those students who actually drew groundwater movement in their depiction of the groundwater system, 94% (n=48 of 51) correctly answered the dichotomous question. Similarly, it could be expected that if students indicated the statement, "surface water is NOT connected to groundwater" was "false," they would also be able to draw some connection between groundwater and surface water. However, the ratio of incorrect drawings to answers was similar to that of the other questions, with just 39% (n=45) of the 114 students who answered the dichotomous question correctly showing a groundwater-surface water connection in their groundwater drawing. Yet again, the majority of students (82%, n=45) who drew groundwater connected to surface water also answered the dichotomous question correctly. Overall, the dichotomous questions were somewhat less difficult (with difficulty indices of 0.84 and 0.75, respectively), which may be expected because of the nature of true/false questions and student guessing. However, the two questions still had relatively robust discrimination indices. The discrimination index for the question regarding the movement of groundwater is 0.24, and for the question regarding surface and groundwater connection, 0.39.

To further explore the students' understanding of groundwater, specifically its connection to surface water and the water cycle, the researchers returned to students' drawings of the water cycle. The drawing prompt did not specifically ask about groundwater or imply in any way that students should include it. Though the drawings were initially scored with a holistic rubric similar to that of the groundwater prompt (see Table III), the rubric did not specifically require the inclusion of groundwater to obtain a good score (though including groundwater would mean that students would likely score higher on the rubric). However, students could not score less than a 4 if they included groundwater in their drawing. All water cycle drawings with a score of 4 or 5 were re-examined for the inclusion of groundwater. A small but significant number of students (18%, n=23) did include groundwater in their conception of the water cycle without being asked to do so. These students, as we might expect, scored higher on the groundwater drawings as well (M=2.30 as opposed to M=2.03 for those who did not include groundwater in the water cycle drawings.). Seventy-four percent (n=17) of those who included groundwater in the water cycle drawing also correctly identified that groundwater is connected to surface water in the dichotomous question, compared to 69%

TABLE III: Water cycle question rubric.

5	Labels and correctly shows five processes of the water cycle (e.g., evaporation, precipitation, condensation, percolation, transpiration, runoff, freezing) and draws at least five places water can go in the earth system (of the nine: plants, animals, soil, groundwater, ocean, lake, glacier, river, clouds).
4	Correctly shows and identifies 3 processes of the water cycle, and draws at least 3–4 places that water can go in the earth system.
3	Confuses some process names, but the drawing shows a basic understanding of how water moves in the earth system. Shows two or fewer places water can go in the earth system.
2	Confuses how water moves in the earth system, or shows disconnected parts of a cycle.
1	Shows that water moves in the earth system, but no understanding of anything much further than rain falling on the earth.
0	Does not answer or the answer shows no understanding of how water moves in the earth system.

(*n*=97) of those who did not include groundwater in their water cycle drawing. In contrast, only 15% of those students who identified that groundwater and surface water are connected in the dichotomous question also drew groundwater into their drawing of the water cycle. This discrepancy again points to a disconnect between what students appear to know in answering objective questions and what they are able to demonstrate in drawings.

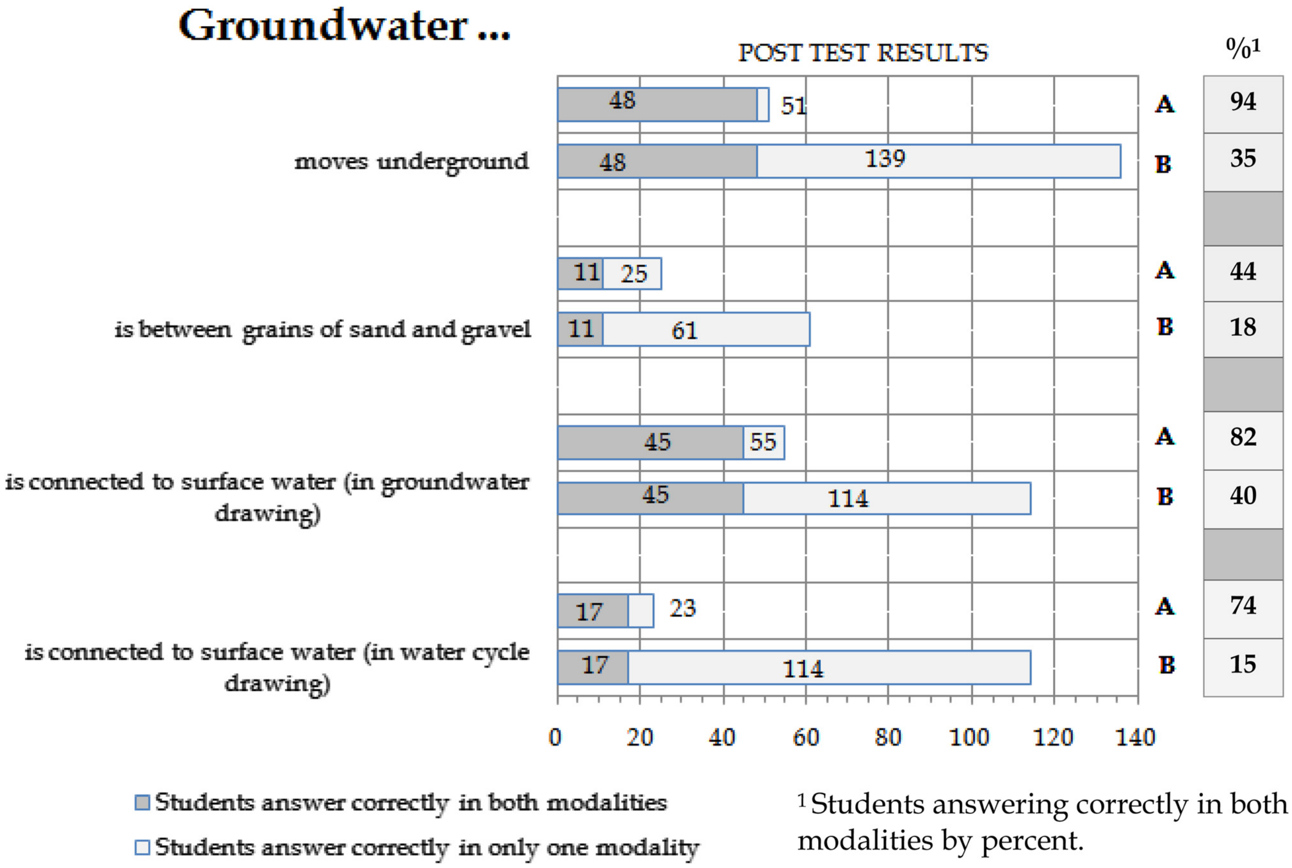
In analyzing what students understand through drawings, researchers found that a comparison of pre- and post-test data is instructive. Many more students were able to express conceptual knowledge through drawing post-intervention. Only 2 students drew groundwater between grains of sand and gravel in the pre-test, while 11 were able to in the post-test. Twenty-six students showed groundwater moving underground in the pre-test, as compared to 48 in the post-test. For groundwater's connection to surface water, 24 and 4 students showed groundwater connected to the surface in their depictions of the groundwater system and water cycle, respectively, as opposed to 45 and 17 students in the post-test. Since it is very difficult to draw something that you do not know about, we can assume that these gains show true gains in conceptual understanding.

The need for robust multimodal assessment that includes drawings to assess true student learning is emphasized in Fig. 2. Paired bars represent multimodal assessment results of a specific criterion. The top, or Bar A, of each pair represents the total number of students who illustrated the listed concept in a drawing, with the darker areas showing those who also answered the related objective question correctly. The lower, or Bar B, represents students who answered the objective question with regard to a particular concept correctly, with the darker area being those students who also reflected that same concept in their drawing.

Overall, students who answer the multiple choice questions correctly are not very likely to reflect that knowledge in a drawing, whereas students who display knowledge in a drawing are relatively more likely to also respond correctly to an objective question testing the same knowledge. In summary, the students that could draw each of the concepts could answer objective questions correctly 44%–94% of the time, while students that could answer each of the objective questions could only draw concepts correctly 15%–44% of the time. This data leads to the conclusion that the incorporation of drawing in assessment is an important discrimination tool in assessing conceptual understanding of the groundwater system.

DISCUSSION

The importance of the groundwater system to humans cannot be overstated, yet groundwater in most earth science instruction is often not included as the essential part of the hydrologic cycle that it truly is. The AWF intervention included a robust approach to groundwater system



[1] Students answering correctly in both modalities by percent.

FIGURE 2: (Color online) Bar A in each pair shows the total number of students who illustrated the listed criteria correctly in a drawing. Bar B of each pair shows the total who correctly answered the related objective question. Of those totals, darkened portions of each bar show the number of students who answered both the objective and drawing questions correctly. The same proportion is shown as a percent to the right of the bar chart.

instruction. This study uses multiple forms of assessment to analyze fourth graders' conceptual understanding of the groundwater system.

To date, there is limited information on how students think about groundwater, and even less information on quality instructional methods that help to correct student misconceptions (Dickerson and Callahan, 2006). Studies that do exist focus on students who are much older than the fourth graders in this study who nonetheless are expected to have a basic understanding of groundwater (e.g., Dickerson *et al*., 2005; Dickerson and Dawkins, 2004; Rienfried, 2006).

Dickerson *et al*. (2007) suggest, among other things, that improving groundwater education will require more attention to students' spatial reasoning techniques and appropriate assessment of student understandings. The use of models as part of the instructional portfolio and drawings as part of the assessment process are essential components of this recipe. In an analogous vein, Anning (1997, p. 219) suggested that "children instinctively use drawing in the same exploratory way that designers use sketching to 'converse with themselves' when generating ideas." McWilliam *et al*. (2008, p. 226) argued that creative capacity building should be repositioned in science, noting that "creativity is not the antithesis of scientific rigor but the core business of scientific thinking" which builds both academic and social capacity. In this study, data collected from the multimodal instruments that include the use of drawing prompts, reflects the Dickerson, Anning, and McWilliam approaches.

The analyses of multiple student drawings allow educators to ascertain even more fully how students think about the groundwater system. Only seven students demonstrated what would be considered a full understanding, by including groundwater in their drawing of the water cycle and connected to the surface in their drawing of groundwater. Figure 3 shows the pair of drawings for one such student. The two drawings together help build a more complete picture of how this student understands groundwater. For instance, the placement of groundwater in the water cycle drawing may have been misinterpreted as a surface feature without the confirmation of groundwater's location in the drawing of the groundwater system. While one could choose to believe that any student who can correctly answer multiple choice questions has learned the content, looking at many forms of evidence of their understanding may reveal larger gaps than previously imagined.

Since drawing prompts have a much higher degree of validity than either type of objective question, it is likely that they represent a more accurate picture of students' understanding of the groundwater system. Also, data show that if students could draw the concept, they were more often than not able to answer the related objective questions correctly, while answering objective questions correctly did not necessarily lead to the ability to draw the concept correctly. This supports the idea that drawing analysis is a valid and useful instrument for assessing student understanding.

Contradictions in Multimodal Assessment Results

Of particular interest are those students whose drawings and answers to the multiple choice question do not express the same conclusion. For example, in this study, 87% of students who were able to either draw or answer a multiple choice question about the location of groundwater were not able to do both. Similarly, while 70% (n=114) of students were able to correctly answer that groundwater is connected to surface water in a dichotomous question, less than half of those (54 students, 47%) were able to draw that connection in *either* the water cycle or the groundwater drawing.

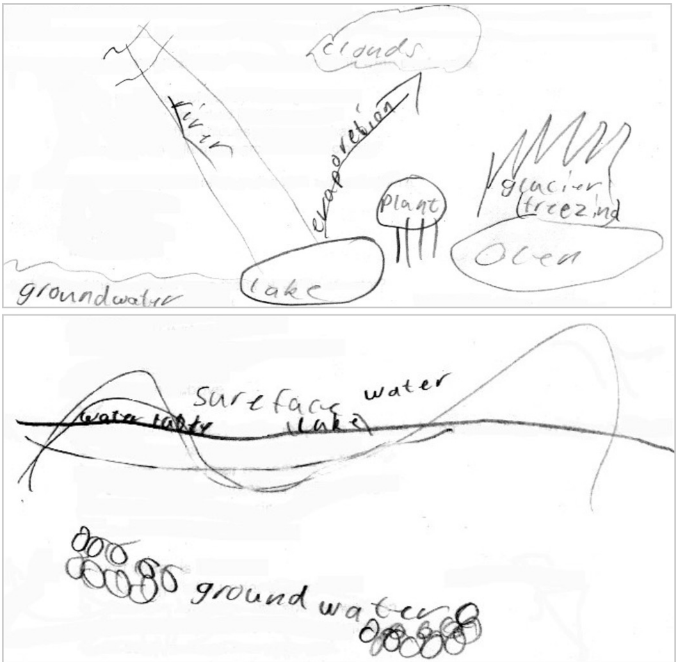


FIGURE 3: A Water cycle drawing (above) and a groundwater drawing (below) from one student provides a more complete picture of the students' understanding of the groundwater system and its relationship to surface water.

One possible reason for incorrect drawings coupled with correct responses to objective questions is that students knew the answer "between the grains of sand or gravel" was correct, but when asked to draw that concept they built upon an erroneous construct for the groundwater system. One common drawing that students created showed a river of water flowing between a layer of sand and a layer of gravel, as in Fig. 4. This does in fact portray groundwater "between the layers of sand and gravel," but not between the grains. In conversations with middle school students, Dickerson and Dawkins (2004) found that students could sometimes state ideas that seemed correct, but with further questioning would reveal that they were using correct terminology to describe incorrect thinking. Thus, some students may be adept at recalling the correct answer through memorization, but may not actually understand the concept.

Another possible reason for incorrect drawings is that it is very difficult to draw the groundwater system. A students' pretest drawings often reflected surface water rather than groundwater, or water that was simply "on the ground." Many professional depictions of groundwater used as visuals for public education show aquifers appearing as blue areas underground. It is artistically difficult to show water between grains of sand and gravel, and, in reality, groundwater is clear and difficult to see in a

FIGURE 4: A students drawing depicting a layer of water between layers of sand and gravel. While this student may correctly identify groundwater as "between the grains of sand and gravel," the drawing reveals an incorrect understanding of the groundwater system.

drawing or model. Students who successfully depicted groundwater as between grains often used labels or inset magnified areas, as in Fig. 5, where they could show what water and sand grains mixed together might look like, much like the professionally produced drawing in Fig. 1. Students who had colored pencils or crayons at their disposal were better able to show where they thought groundwater would be located (all teachers were provided with colored pencils and were asked to allow students to use color, but the vast majority did not).

Similar to the logistical challenge of drawing the groundwater system, it is likewise difficult to design a drawing prompt that will tell students what to draw without actually describing that system. In this study, researchers tested several different prompts before deciding to request that students draw their own idea of what groundwater looks like. The final prompt mentioned several aspects that students should consider, such as where it is located, how it gets there, and what happens to it over time. To avoid giving students the answer, the research team did not explicitly ask them to show the movement or the connections between groundwater and other systems. But it raises the question: *Would students think to depict movement in a static drawing* as is expected in the drawing rubric?

Though rare in the study's findings, some students were indeed able to draw the groundwater system correctly and unable to answer the multiple choice question correctly. These students may have difficulty reading or comprehending multiple choice questions. English language learners, low proficiency readers, and nonlogical learners may be among those who display more success through a visual depiction of their understanding. In Fig. 5, the students drawing reflects prior knowledge about what is underground and indicates an evolving understanding of groundwater, even though this particular students' objective test results did not reflect this knowledge. Research by Xu *et al*. (2009) found that some students may choose to draw a more realistic view of a concept, while others may elect to draw a more abstract view; both views depict the learning experience.

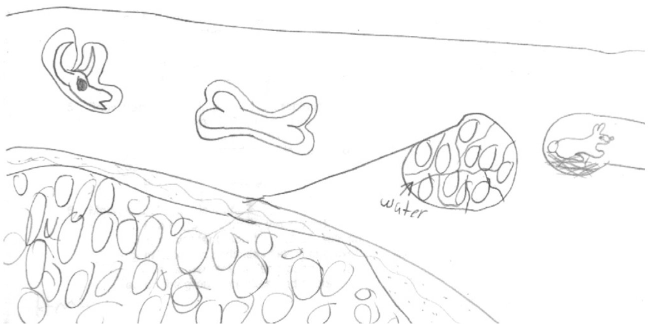


FIGURE 5: Drawing by a student who scored low on the objective portion of the assessment, but depicted groundwater accurately and with creative inclusion of prior knowledge.

CONCLUSION

This research focused on determining what 4th grade students comprehend about the groundwater system and its' relationship to the water cycle. Though instruction that follows best practice is of great importance, this study demonstrates that the ability to interpret student thinking and mental model building is paramount to ensuring the development of a strong foundation on which true understanding of a complex earth system depends. Students' ability to conceptualize the groundwater system as evidenced by drawing seems to be a much stronger predictor of content mastery than the ability to answer objective questions.

Groundwater is the lifeblood of the arid western states, but groundwater alone cannot sustain the metropolises of the Southwest. In the region of this study, the Colorado River supplies water for cities and agriculture in seven U.S. western states and two states in Mexico. Without this water, cities such as Los Angeles, Las Vegas, Denver, Phoenix, Tucson, and Albuquerque will overdraft the aquifers underlying them to dangerous degrees. Yet all predictions point to reduced water flow in the Colorado River system. Woodhouse and Meko (2010) predict that for every 1.8°F (1°C) of warming in the future, the Colorado River flow is projected to decrease between 2% and 8%, according to paleoclimate records over the past two millennia.

In the Southwest, characterized by an arid climate with highly variable precipitation patterns, surface water supplies are diminishing, and groundwater supplies have not recovered from past overdraft. Extended drought and climate change trends may significantly and permanently impact our water supply, and thus our region's ability to sustain the current quality of life and ecosystem health. It is critical that citizens are educated on the subject of our interconnected water resources, especially the unseen and least understood groundwater system, so that they can make wise decisions that will conserve resources to ensure the sustainability and economic vitality of communities in the Southwest.

In teaching and assessing groundwater, students are often tested on whether or not they know the correct words for talking about the system. However, from this study, it is evident that the ability to choose the correct words to describe a system does not necessarily translate to a true understanding of the system. In light of the significance of groundwater as a resource in the arid southwest, and the consequential decisions that will need to be made about groundwater systems in the next generation, educating students to fully understand the system is essential. The use of tools that truly assess conceptual knowledge is critical to obtain a robust understanding of how learners grasp and retain concepts.

Implications

Teachers not only need to include groundwater in their instruction of the water cycle, but also appropriately evaluate conceptual knowledge. The use of drawing to assess age-appropriate conceptual understanding of complex systems like the groundwater system warrants further research. Drawings are underutilized as a tool in assessment even though they serve as an alternative form of articulation (Dove 2006). Drawings combined with student explanations could be a powerful tool to assess conceptual knowledge and identify misconceptions. Too often, quick and easy multiple choice or dichotomous questions are used erroneously to attempt to assess conceptual knowledge.

Of course the time that teachers currently have to gauge student understanding is limited, due to a strong focus nationally on reading, writing, and math skills, as well as the breadth of science content to be covered. The use of drawings requires the development of thoughtful rubrics and time to study what students' truly comprehend about a concept. One possible alternative to the completely student generated drawing is a picture-based multiple choice or short answer question. An example of this appears in Rienfried's 2006 study, in which students are asked to choose one of four block diagrams that best represents their understanding of how groundwater deposits appear underground. This sort of question may provide a middle ground between ease of use and information provided.

A variety of studies (Dickerson *et al*. 2005; Dickerson and Dawkins, 2004) have taken "snapshots" of students learning about groundwater at various age points, both before and after interventions that teach students about groundwater. However, if the aim is to educate the general public to be active, responsible, well-informed citizens able to make good water policy decisions, longitudinal studies of students who have received groundwater education at a variety of age-levels are necessary to avoid the common misconceptions that perpetuate. In other words, studies are needed to determine the point at which learners are able to synthesize their pre-existing knowledge into an accurate overall concept. A further study such as this that includes an opportunity for students to verbally explain their drawings could help build the instructional framework and assessment tools for teaching this complex, though important, subject. The need to clarify student ideas while using hands-on experimental model-building is clear in the Reinfried (2006) study.

Finally, a re-emphasis on drawing in schools may improve students' abilities to express themselves through an art form and assist in assessing conceptual understanding of all content areas. Teachers will need professional development in this form of assessment. Just as artists themselves differ in representations of the same thing, some students may elect to draw a more realistic view, while others may elect to draw a more abstract view, yet both views depict the learning experience (Xu *et al*., 2009). The ability to draw can exhibit spatial intelligence and may provide great insight into conceptual understanding, but usually requires some instruction. The interpretation of student drawings will be enhanced by the inclusion of students' commentary.

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