Students' Conceptions of Scale Regarding Groundwater

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ABSTRACT

We surveyed three groups of students regarding their ideas about the structure, scale, and perceived importance of groundwater. The quantitative methods employed in this study incorporated simple descriptive statistics of the six multiple-choice item responses. The results of this study indicate that many people hold inappropriate conceptions of hydrogeologic principles. They describe groundwater storage using multiple structures other than pores and cracks. Participant responses regarding the size ranges of groundwater storage structures show that students possess a wide range of ideas concerning scale. Many participants selected sizes of the groundwater structures that mirrored the surface analogs, however, some students applied scales on the order of houses and skyscrapers to typical pore and crack structures. The mental models erected according to the frameworks of these alternative scale conceptions are likely to be inappropriate and could detrimentally impact the appropriate mental visualization of other associated groundwater principles. To effectively address students' alternative groundwater conceptions teachers must pay particular attention to issues of scale, as well as the application of those conceptions to individually and socially relevant questions.

INTRODUCTION

The major science frameworks and standards documents (American Association for the Advancement of Science, 1993; National Research Council, 1996) used in the United States explicitly and disproportionately focus on surface oriented hydrologic processes (Dickerson and Callahan, in press; Dickerson et al., in press). These documents do, however, contain a relatively implicit and subtle call for appropriate student understanding of groundwater principles by the repeated and explicit inclusion of the water cycle in content standards across elementary, middle, and high school settings. Consequently, some states' standards documents include hydrogeologic concepts that should result in the inclusion of those concepts in K-12 science instruction. Additionally, hydrogeologic principles are routinely incorporated in post-secondary introductory geology coursework and serve as one of the fundamental components of hydrogeology courses. At every one of these points of instruction throughout a student's formal education, it is the role of the teacher to assist the student in constructing conceptions that are perpetually more consistent with those held by the scientific community.

Altering students' ideas, however, about scientific concepts is complex and based on a wide range of factors. In response, educational researchers have developed generalized models of how this change may occur. Posner, Strike, Hewson, and Gertzog (1982) asserted that for conceptual change to occur, four conditions must be met: 1) students must be dissatisfied with their current idea, 2) the new idea must be understandable, 3) the new idea must be reasonable, and 4) the new idea must be fruitful in new contexts. This basic model is widely accepted in the science education community and many researchers have proposed slight variations (Chiu et al., 2002; Feldman, 2000). Strike and Posner (1992) have emphasized that this model is not intended to be directly applied as a "prescription for instruction" (Akerson and Reinkens, 2002), but rather generalized elements necessary in changing people's conceptions. Science educators have incorporated or identified some or all of these elements in many different constructivist-based instructional strategies including learning cycle approaches (Baker and Piburn, 1997; Llewellyn, 2002).

Usually one of the first steps in conducting a learning cycle involves assessing students' preconceptions (Baker and Piburn, 1997). These ideas are almost always inconsistent with those of the scientific community and are consequently termed alternative conceptions (Harvard-Smithsonian Center for Astrophysics, 2003). Identifying preconceptions and/or alternative conceptions is important in altering students' ideas because it informs the decisions teachers make regarding how they choose to address the elements involved in conceptual change. For example, due to the well-documented tenacity of alternative conceptions (Fisher, 1985; Hewson and Hewson, 1988; Novak, 1988; Özkan et al., 2004; Trundle et al., 2002) and the numerous sources of origin of those conceptions including but not limited to analogy, ontology, instructional materials, and teacher competence (Dickerson et al., 2005; Kikas, 2004), informed educators will appropriately vary the duration of the lesson, instructional tools used, and/or instructional strategies implemented (Tabor, 2003) to effectively teach a given concept.

In the case of groundwater, like many geoscience concepts that are often directly unobservable, teachers will often employ the use of field trips, hands-on experiences, experiments, physical three-dimensional models, mathematical formulas, static two-dimensional images, and animations in addition to text to produce meaningful learning in their classrooms and address students' preconceptions (Dowse, 2000; Hudak, 1998; Kali et al., 1997; Nicholl and Scott, 2000; Trop et al., 2000). These visually-based instructional methods and tools are employed in an effort to assist students in developing an appropriate mental picture of groundwater principles.

Such mental pictures constructed of a variety of conceptions are typically described as mental models (Johnson-Laird, 1983; Libarkin et al., 2003; Vosniadou and Brewer, 1992) as opposed to conceptual models (Nersessian, 1992) that are typically mathematical in nature and are "precise and complete representations that are coherent with scientifically accepted knowledge" (Greca and Moreira, 2000, p5).

For the purposes of this study, we are operating from a generalized definition of mental model, which we consider to be a particular set of relationships between conceptions. To use an analogy, we see the mental model as a house and the individual conceptions as the studs, nails, plywood, shingles, etc. In order for the mental model (house) to be consistent with the scientific model (a house that looks exactly like a real house), the various conceptions (plywood, nails, etc) must also be consistent with those held by the scientific community (building supplies that look exactly like real building supplies). For instance, if a student thinks that all rock is completely solid and there is no such thing as tiny spaces within it (considers plywood made out of light-weight foam), then the mental model constructed of groundwater (house built with light-weight foam plywood) will not be consistent with (look or function like) the model held by the scientific community (house built with wood plywood). Even if the conception is appropriate (plywood is made out of wood), if the scale is inappropriate (the plywood is 1000 meters thick and a kilometer in length), the resulting mental model (house) will also be inappropriate (look unlike a real house). As such, mental models inherently possess an impediment to the progression towards a complete and appropriate scientific model because of the essential inclusion of the absolute and relative scales of the conceptions comprising the model. The effective teaching and learning of scale has historically been considered problematic (Jones et al., 2003), but is extremely important in a variety of geoscience contexts. The spatial relationships between groundwater concepts like porosity, permeability, aquifers, and flow regimes are crucial to the development of appropriate mental models, because inappropriate scale applied to any one of the associated conceptions results in an inappropriate model. As such, we examined how different student populations apply scale to their conceptions of groundwater principles.

METHODS

This paper reports on one aspect of a larger research study conducted to examine understandings of groundwater principles and processes held by children and adults. The study is limited in scope (i.e. small sample sizes from one location) and all assertions are made solely within the context of the sample. The insights gained, however, will aid in developing and refining instruments designed to assess groundwater-related understandings and will serve to inform instructional practice. Larger scale studies are currently in progress to gain a more complete and accurate picture of the teaching and learning of groundwater both in the United States and internationally.

The study population consisted of the purposeful sampling (Gall et al., 1996) of secondary and post-secondary students. Our intent was to select populations with varying levels of interest in and understanding of groundwater. The secondary participants consisted of twenty-nine twelfth-grade Anatomy and Physiology students in a large public high school located in a major coastal city in the southeastern United States. Their teacher indicated that the majority of the students anticipated pursuing post-secondary studies. The students reflected the general school population in all other ways with the exception of gender because twenty-three of the twenty-nine participants were female. Ten of the participants had successfully completed an earth/environmental science course during their secondary school experience and two reported that they had taken a course that focused on groundwater.

The post-secondary participants consisted of two groups of students enrolled in interdisciplinary environmental studies courses at a liberal arts university located in a major coastal city in the southeastern United States. Group 1 consisted of thirty-two students, that included three freshmen, five sophomores, eleven juniors, twelve seniors, and one graduate student all enrolled in one of two elective environmental studies courses that had no geology prerequisites. Sixteen different majors, including 19% of the participants reporting an earth/environmental science related major (n=32), and seven minors, including 50% of the participants reporting an earth/environmental science related minor (n=32), were represented among the students. Two students reported having engaged in scientific research regarding hydrology and two reported that they had taken a course that focuses on hydrology in their post-secondary education.

Group 2 consisted of twelve students, that included two sophomores, four juniors, one senior, and five graduate students all enrolled in one of two introductory hydrogeology courses. The educational backgrounds of the graduate students included holding a B.S. degree in Geology (n = 2), a B.S. in Physics (n = 1), a B.A. in Anthropology (n = 1), and a B.S. in Biology (n = 1). Four of the graduate students reported having participated in hydrogeology research and one reported completing a hydrology course in the past (i.e. Wetland Hydrology).

The teacher from each class administered the instrument to their students during their normal class time. We collected data from the secondary students the last week of classes. The post-secondary students completed the instrument during the first week of the course. All participants completed the instrument entitled Groundwater Survey (available from the authors). The indigenous instrument is composed of a background information section including questions regarding gender, year in school, and prior earth/environmental science and groundwater coursework. The remainder of the instrument is composed of multiple-choice items that deal with issues of structure, scale, and perceived importance of groundwater. In addition to the instrument answer choices on the first and second items, participants had the opportunity to provide an answer of their own using a fill-in-the-blank response option. The development of the first instrument item was informed by earlier studies (e.g. Meyer, 1987) that identified a variety of descriptors used by the general public when discussing groundwater. When we developed the distracters for Item #1, we selected from among these common descriptors (i.e. pools, lakes, rivers, streams, etc) and included the one considered most used by the scientific community (i.e. pores/cracks). In order to collect data regarding how students applied scale to these specific descriptors, we developed Items #2 and #3. Participants had the option of selecting more than one descriptor for Item #1, so we provided scale choices for each of the possible descriptors in Item #2. The development of the options was based on previous scale research that suggests students may use familiar objects when describing the relative scale of natural phenomena (Tretter, 2004) and from data collected during interviews in previous groundwater conceptions studies (Dickerson and Dawkins, 2004). The choices available in Item #3 were constructed to provide researchers with data regarding students' notions of vertical scale. Researchers chose the depth ranges to discriminate between students who held reasonable notions of vertical scale and those who did not. Items #4, #5, and #6 consist of parallel questions designed to illuminate any disparities in perceived importance of groundwater among teachers, voters, and themselves.

Two faculty members from the geology department at a university in the southeastern United States who specialize in hydrogeology completed the Groundwater Survey instrument and provided responses that established face validity (Gall et al., 1996). Researchers also collected data to support the validity of the instrument from the students' perspective. In another phase of this research project, data were collected and triangulated using a variety of methods and instruments that included a modified version of a previously published groundwater conceptions instrument (i.e. a drawing prompt) (Dickerson and Dawkins, 2004), the instrument included in this study, and transcriptions of videotaped think aloud interviews. The think aloud data were considered in this study as a means of instrument validation to ensure that the research team accurately interpreted the words used by the participants. Content validity was established within the context of the participant group as evidenced by interview excerpts explicitly addressing notions of scale (i.e. from the think aloud interviews) and numerical annotations contained in the drawing prompts (i.e. the previously published instrument), all of which were consistent with the participants' responses on the instrument employed in this study. Because all participants were not interviewed, however, due to resource limitations (e.g. time) and due to the small sample size, we make no claims regarding the instrument's validity in other contexts. It should be noted that while this study represents an initial attempt at the development of an instrument designed to assess student understanding of scale in the context of groundwater, additional large-scale studies and instrument refinement are necessary to truly develop a valid and reliable instrument for use with diverse populations. The quantitative methods (Gay and Airasian, 2000; Taylor, 2000) we employed in this study incorporated simple descriptive statistics (i.e. frequency counts and percentages) of item responses.

RESULTS

The results provided an indication of participants' conceptions regarding the storage of groundwater, the scale associated with a given storage feature, vertical scale of wells, and perceived importance of knowing about groundwater. The responses we gathered from the establishment of face validity are considered to be consistent with those held by the scientific community. As such, most groundwater in the eastern part of the United States is considered to be stored beneath the ground in pores and cracks, ranging in size from microscopic to the size of an eraser on a pencil. Additionally, most human drinking-water wells are considered to be shallower than 5,000 feet.

Perceived Importance of Knowing about Groundwater - It was necessary to include the items (i.e. #4, #5, and #6) that addressed the importance of knowing about groundwater because they directly assessed the perceived value of the topic and indirectly assessed participant interest. Both the perceived value of and interest in a topic are influential factors that affect conceptual change, because they directly relate to whether a person considers the concept to be fruitful (Posner et al., 1982). The secondary Anatomy and Physiology participants provided responses that indicate a much lower perceived importance of knowing about groundwater than either of the post-secondary hydrology-oriented participants (Table 1). The post-secondary participant groups' responses (Table 1) were very similar to one another and both groups consistently assigned a high degree of importance to all item groups (i.e. themselves, teachers, and voters). Interestingly, the secondary students ascribed a greater degree of importance of knowing about groundwater to teachers and voters as compared to themselves. We analyzed the secondary participants' responses further because some participants had completed an earth/environmental science course.

Approximately a third of the secondary participants reported that they had taken an earth/environmental science course in their secondary school experience. This subset of the secondary participants provided very similar responses to those who had not taken an earth/environmental science course for Items #1, #2, and #3. The exceptions were the items regarding the participants' perceived importance of knowing about groundwater. In general, participants that completed an earth/environmental science course did assign a greater degree of importance of knowing about groundwater for themselves than did those who had not taken an earth/environmental science course (Table 1). The trend, however, of ascribing a lesser degree of importance for themselves as compared to teachers or voters existed in both subsets of the secondary participants.

Conceptions of Scale - Participants' conceptions of vertical scale were directly assessed through Item #3. The Group 2 participants (100%, n=12) and the majority of the Group 1 participants (88%, n=32) indicated that the depth of most human drinking-water wells in the United States are less than 5,000 feet deep (i.e. the first two distracters in Item #3). In contrast, thirty-four percent of the secondary participants (n=29) thought wells were deeper than 10,000 feet.

In general, participants described the ways that most groundwater is stored underground using a variety of terms (Table 2). These results are consistent with other studies regarding language commonly used to describe groundwater (Dickerson et al., 2004; Meyer, 1987). Furthermore, there is little difference among the percentages of responses selected between participant groups despite the substantial differences in formal geoscience education and levels of interest in and value of groundwater. The largest differences occurred with the terms "pipes" and "pores/cracks". Almost a quarter (23%, n=65 responses) of the responses from the secondary participants were "pipes", as opposed to eight

Parallel question prompts in items #4, #5, and #6	% of responses provided by participants			
	Not at all	A little	More than a little	A lot
Group 1 (n=32)				
For themselves	0	6	25	69
For teachers	0	0	34	66
For voters	0	3	25	72
Group 2 (n=12)				
For themselves	0	8	17	75
For teachers	0	8	0	92
For voters	0	0	17	83
12th graders (n=28)				
For themselves	18	39	32	11
For teachers	11	29	39	21
For voters	18	29	50	3
EE coursework (n=10)				
For themselves	10	40	30	20
For teachers	0	10	50	40
For voters	0	40	50	10
No EE coursework (n=18)				
For themselves	22	39	33	6
For teachers	17	39	33	11
For voters	28	22	50	0

Table 1. Perceived importance of knowing about groundwater (n = the number of responses).

Groundwater storage structures in items #1 and #2	% of responses regarding storage structure		
	12th graders (n=65)	Group 1 (n=84)	Group 2 (n=32)
Underground pools and lakes	23	25	19
Underground streams and rivers	29	29	25
Underground pipes	23	8	16
Underground pores and cracks	20	32	34
Other	5	6	6

Table 2. Participants' ideas about groundwater storage structures and sizes (n = the number of responses).

percent and sixteen percent from Group 1 and Group 2 respectively. Group 2 had the highest percentage of responses (34%, n=32 responses) for "pores/cracks", in contrast to Group 1 (32%, n=84 responses) and the secondary participants (20%, n=65 responses).

Three participants out of seventy-three total, two from Group 2 and one from Group 1, provided responses that matched those deemed consistent with the scientific community. Two of the three participants were graduate students and one was a sophomore. One of the three also reported actively engaging in hydrology research. All the other participants (n=70) provided either, multiple responses, one inappropriate response regarding storage of groundwater, or an inappropriate size range for pores and cracks. As suggested by the number of responses (n) in Table 2, most participants selected multiple responses. Table 3 illustrates participants' ideas regarding size ranges they apply to the structure(s) they believe store(s) groundwater. The variability in size ranges for a particular structure, even within participant group is considerable. For example, most participants who provided a response of "pools/lakes" described them as being "house - skyscraper" large (Table 3). Interestingly however, twenty-eight percent of the responses from 12th graders, forty percent of the responses from Group 1, and thirty-three percent of the responses from Group 2, indicated that "pools/lakes" were "basketball/beach ball - car" size or smaller. The majority of the participants that selected "streams/rivers" as a response again described the structure as "house - skyscraper" large, while thirty-five percent of the responses from 12th graders, forty-eight percent of the responses from Group 1, and twenty-five percent of the responses from Group 2, indicated that "streams/rivers" were "basketball/beach ball - car" size or smaller. The descriptions of size regarding the response "pipes" were more evenly distributed than the descriptions of size of the previous two structures, and included forty-two percent of the responses from Group 1 and forty percent of the responses from Group 2 selecting the size range "microscopic - eraser on a pencil".

Groundwater storage structures in items #1 and #2	% of responses regarding size		
	12th grade	Group 1	Group 2
Underground pools and lakes	n = 18	n = 25	n = 6
Microscopic eraser on a pencil	17	8	0
Basketball/beach ball - car	11	32	33
House - skyscraper	72	60	50
Other	0	0	17
Underground streams and rivers	n = 23	n = 31	n = 8
Microscopic eraser on a pencil	13	3	0
Basketball/beach ball - car	22	46	25
House - skyscraper	61	48	75
Other	4	3	0
Underground pipes	n = 20	n = 12	n = 5
Microscopic eraser on a pencil	10	42	40
Basketball/beach ball - car	60	42	40
House - skyscraper	30	17	0
Other	0	0	20
Underground pores and cracks	n = 15	n = 31	n = 11
Microscopic eraser on a pencil	60	65	64
Basketball/beach ball - car	27	16	0
House - skyscraper	13	16	18
Other	0	3	18

Table 3. Participants' ideas about groundwater storage structures sizes (n = the number of responses).

While most participants who provided a response of "pores/cracks" described them as being the size of "microscopic - eraser on a pencil", forty percent of the responses from the 12th graders, thirty-five percent of the responses from Group 1, and thirty-six percent of the responses from Group 2 provided a description of size that was larger. Some participants also provided responses to the fill-in-the-blank option of "other". Three secondary participants included other structures such as "reservoirs" of every size option available, "wells" the size range of a house to a skyscraper, and "craters" the sizes of microscopic to an eraser on a pencil and the sizes of a house to a skyscraper. Four Group 1 participants included "reservoirs" the size range of a house to a skyscraper and the term "aquifers". The three participants who wrote "aquifer" each described the size differently such that all three size ranges provided on the instrument were used. Two participants from Group 2 also provided "aquifer" as a response. One described an aquifer's size as "other: large/sq miles", while the other participant described the size range as "basketball/beach ball - car".

CONCLUSIONS AND IMPLICATIONS

The results of this study indicate that the participants held inappropriate conceptions of hydrogeologic principles despite groundwater's importance to their health and economic well-being. They describe groundwater storage using multiple structures other than pores and cracks. Although Dickerson and Dawkins (2004) documented that the use of such language (e.g. underground pools and rivers) can represent both appropriate and inappropriate conceptions, the application of scale helps further articulate those conceptions. Participant responses regarding the size ranges of groundwater storage structures show that the participants possess a wide range of ideas concerning scale. Many selected sizes for the groundwater structures they chose that mirrored the surface analogs. For example, participants generally described underground pools and lakes and underground streams and rivers as large features just as they appear on the earth's surface. Likewise, underground pipes were attributed sizes comparable to those of pipes we see in houses and at construction sites. Pores and cracks were also considered small in size by most of the participants that selected that structure. Equally important, however, are the number of participants who chose sizes that deviate from the scale of the surface oriented analog. For example, approximately a third or more of all those that selected underground pools and lakes and underground streams and rivers indicated that those structures were smaller than a car and some even considered them smaller than an eraser on a pencil. Interestingly forty-two percent (n=12) and forty percent (n=5) of the responses regarding underground pipes from Group 1 and Group 2 respectively labeled that structure as small as microscopic and as large as the size of an eraser on a pencil. Lastly, approximately a third of all those who selected pores and cracks chose sizes for that structure larger than a basketball or beach ball. Several students even applied scales on the order of houses and skyscrapers to typical pore and crack structures. It is likely that mental models erected according to such alternative scale conceptions are inappropriate.

Considering these findings it may be more important, in terms of mental model development, for the scale to be consistent with the actual in-situ environment than for the language to be consistent with that of the scientific community. For example, a student's conception of underground pools and lakes that are microscopic to eraser sized may not adversely affect the construction of an appropriate mental model if those terms imply all of the parameters of the term pore space. Conversely, if students use scientifically acceptable language like pore space but think that most groundwater exists in pores that are a half a kilometer in diameter, when they combine that inappropriately scaled conception with their other conceptions of permeability, aquifer, etc, the result is likely to be an inappropriately constructed mental model. In addition, a disconnect may exist between groundwater principles in some of the participants' minds that may adversely affect mental model development. For example, some participants selected the option "pores/cracks", but also described the storage structures of most groundwater in the eastern United States as "aquifers" and "wells" by selecting the distracter of "other" and providing a fill-in-the-blank response in Item #1. This raises the question of whether the students understand the relationship between the two, however further research is necessary to determine if this is the case.

Since students may enter courses holding ideas of groundwater that are inconsistent with those of the scientific community, initial assessment is prudent. Among the more surprising findings in this study is the number of undergraduate and graduate geology majors that enter hydrogeology courses with notions of groundwater storage and scale that dramatically diverge from those held by the scientific community as illustrated above. These findings emphasize the need for early assessment of students' conceptions in order to know where to begin instruction. Assessing students' conceptions and the mental models they construct from them, however, is a difficult task. It is important to begin the development or selection of assessments with the understanding that the development of appropriate mental models involves issues of scale. While vocabulary can be conceptualized a number of ways, sizes based on familiar objects provides insight into how the vocabulary is being used and the appropriateness of the concept. Such assessments are also important in exacting conceptual change and facilitating the development of appropriate mental models of groundwater by making students cognizant of the disparity between their mental models and the scientific community's model. For example, requiring students to articulate their initial mental models in pictures and words provides the instructor with insight into how much or little their students already know while providing a point of comparison regarding the scientific community's model. The role of assessment grows in import based on our results that the resiliency of the participants' alternative conceptions of groundwater scale was strong even after completion of introductory undergraduate geology courses. This is particularly troubling because very few people, including K-12 teachers, pursue advanced coursework in hydrogeology, yet an understanding of potable water (i.e. where it comes from and how we get it) is certainly part of basic scientific literacy, and scientific literacy is something every vote-casting individual should possess.

Instruction should also incorporate a variety of strategies that promote personal relevance construction. Interestingly, a trend emerged among the secondary students in which they ascribed a higher degree of importance of knowing about groundwater to teachers and voters as compared to themselves. These findings possibly indicate that these participants do not view themselves in the roles of either teachers or voters. The results are not completely surprising considering the age of the participants, yet are important to consider when addressing socio-scientific issues in formal education contexts for the purposes of promoting conceptual change. For example, many science teachers use debates and role-playing activities to explore issues of groundwater usage and pollution and to teach groundwater principles. Addressing socio-scientific issues in the classroom may be an effective way to get students engaged, build personal relevance, and facilitate conceptual change, but only if students view the roles as viable. So promoting the use (e.g. voting) of their newly constructed understandings in a personally and socially responsible way is important.

As evidenced by the variety of participant selection of groundwater storage structures and sizes, the use of abstractions (e.g. language) complicates teaching and learning with respect to groundwater. As such, strategies and tools that emphasize visual information and deemphasize vocabulary may be more successful. Examples of such strategies would include common visual experiences such as field trips, teacher use of drawing, use of core samples, manipulation and development of physical and three-dimensional computer models in cooperative learning groups. All of these strategies should also incorporate the use of student assigned descriptors instead of scientific language and explicit instruction regarding scale through direct measurement by students and/or the teacher, visual cues such as labeling, and group discussions and lecture regarding the common visual experiences. After students have begun developing appropriate groundwater conceptions through the use of common visual experiences and explicit instruction regarding scale, scientific labels can then be added.

Further research is needed regarding students' conceptions of groundwater and the ways that they integrate those conceptions to build mental models of subsurface hydrology. Based on the results from this study, which suggests that participants' applications of scale to groundwater concepts were often inappropriate, researchers may consider increased attention to scale components during future conceptions studies. Further refinement of instruments designed to quickly and accurately assess students' notions of scale are also needed.

The teaching of hydrogeology concepts is difficult. Abstraction and perceived irrelevance serve as impediments to conceptual change concerning groundwater. This difficult situation requires that teachers attend to a wide variety of students' conceptions and the relationships between them, paying particular attention to issues of scale. It is also important that teachers provide a context in which the mental models constructed from such conceptions can be applied to individually and socially relevant questions and issues from the students' perspectives. By attending to both scale and relevance in the context of groundwater teaching and learning, we can illuminate the mystery of hydrogeology for all students.

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