Groundwater in Science Education

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Abstract

Although clean, potable groundwater constitutes one of our most valuable resources, few students or science educators hold complete and appropriate understandings regarding the concept. Recent studies that focus on secondary students' and pre-service science teachers' understandings of groundwater found little difference between the groups' conceptualizations of subsurface hydrology. This article discusses possible reasons for the apparent lack of appropriate understanding regarding the complex concept of groundwater. Specifically, we concentrate on the lack of emphasis concerning groundwater content in standards documents, the need for increased attention to students' spatial reasoning abilities, inadequate formal instruction for science teachers concerning groundwater, and difficulty in designing appropriate assessment of groundwater concepts. We conclude by offering suggestions for enhancing the teaching and learning of groundwater.

Groundwater in Science Education

The National Science Education Standards (NSES) include content goals focused on water cycle processes (National Research Council [NRC], 1996). Most science educators agree with the inclusion of such content goals in these standards due to the critical importance of water in our lives. Many may also consider possessing complete and appropriate understandings of water cycles, including groundwater formation and movement, to be a fundamental component of scientific literacy.

The notions of scientific literacy involve in their most basic forms, understandings of scientific concepts and information regarding human health and survival (Rutherford & Ahlgren, 1990). People need water to live and groundwater serves as one of the primary sources of potable water for many Americans (United States Geological Survey [USGS], 1999). For the vast majority of those in the United States, as opposed to many people in developing countries, accessing sources of potable water in order to survive is not a consideration. Instead, economic survival and prosperity is often the focus of many Americans. Groundwater is important in economic contexts because it serves as one of the primary sources of water for agricultural and industrial operations (Hutson, Barber, Kenny, Linsey, Lumia, & Maupin, 2004). Due to groundwater's importance for good health, and perhaps more importantly to many Americans, a good economy, this source of water is sometimes overtly, but often much more subtly, included in American politics. Decisions made regarding who is allowed access to groundwater resources (e.g. industry, agriculture, and/or the public), how those resources are applied (e.g. how much water is pumped out in a given amount of time), and whether priorities are centered on economics or human health (e.g. what all are we willing to allow in our water before we call it too polluted), are all decisions impacted by a voting public. In order for that voting public to be informed concerning groundwater, they should know from where their water comes, how it gets there, how and where it moves, and how it is used. If voters cannot make informed decisions regarding this resource, others will who may be more strongly influenced by factors other than the public's best interest. This need for the ability of our students to intelligently participate in democratic process regarding issues of scientific import is consistent with many depictions of scientific literacy built upon the more basic form mentioned earlier (Rutherford & Ahlgren, 1990).

Despite the importance of hydrology concepts in developing a scientifically literate public, the science education literature contains surprisingly few studies expressly focused on students' conceptions of groundwater in elementary, secondary, or teacher education contexts. Historically, researchers concentrated on broader topics (e.g. water cycle) that gave cursory attention to groundwater concepts or dealt specifically with post-secondary hydrogeology instruction (Bar, 1989; Carlson, 1999; Gates, Langford, Hodgson, and Driscoll, 1996; Luft, Tollefson, and Roehrig, 2001; Mattingly, 1987; McKay and Kammer, 1999; Nicholl and Scott, 2000; Renshaw, Taylor, and Reynolds, 1998; Rich and Onasch, 1997; Rose, 1997). Recent studies that focus on secondary students' and pre-service science teachers' understandings of groundwater found little difference between the two groups' conceptualizations of subsurface hydrology (Beilfuss, Dickerson, Boone, & Libarkin, 2004; Dickerson, 2005; Dickerson, Callahan, Van Sickle, & Hay, in press; Dickerson & Dawkins, 2004; Dickerson & Wiebe, 2003). Although clean, potable groundwater constitutes one of our most valuable resources, few students or science educators hold complete and appropriate understandings regarding the concept and apparently do not learn anything about it after high school. This article discusses possible reasons for the apparent lack of appropriate understanding regarding the complex concept of groundwater, including: (a) lack of emphasis in standards documents (Dickerson & Callahan, in press; Dickerson, ndunda, & Van Sickle, 2005); (b) need for increased attention to students' spatial reasoning abilities (for example: Dickerson & Wiebe, 2003; Dickerson & Callahan, 2004; Piburn, 1980; Piburn, Reynolds, Leedy, McAuliffe, Birk, & Johnson, 2002; Kali & Orion, 1996; Orion, Ben-Chaim, & Kali, 1997; Provo, Lamar, & Newby, 2002); (c) inadequate formal instruction for science teachers concerning groundwater (Beilfuss et al., 2004; Dickerson & Wiebe, 2003); and (d) difficulty in designing appropriate assessments (Dickerson & Dawkins, 2004; Dickerson, ndunda, et al., 2005; Dickerson, Callahan, Van Sickle, et al., in press). In addition to these four major problems associated with groundwater instruction in formal education contexts, I conclude by offering suggestions for improving conceptual understanding among students and teachers.

Problem One: Lack of Emphasis in Standards Documents

The NSES most directly address groundwater in Grades 5 - 8 Earth and Space Science Content Standards in the context of the water cycle

> Water, which covers the majority of the earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the "water cycle". Water evaporates from the earth's surface, rises and cools as it moves to higher elevations, condenses as rain or snow, and falls to the surface where it collects in lakes, oceans, soil, and in rocks underground (NRC, 1996, p.160).

The excerpt above represents the only explicit reference to water existing in rock below the Earth's surface and the term 'groundwater' is never mentioned anywhere in the document. While the NSES mention sub-surface components of the water cycle, as illustrated above, the remainder of the Content Standard clearly focuses on concepts usually associated with surface processes, like evaporation and condensation. Interestingly, the NSES make a point to elaborate on students' naïve understandings of evaporation and condensation and suggest that "extensive observation and instruction" are necessary to "complete an understanding of the water cycle" NRC, p. 159). Evaporation and condensation are arguably two of the most abstract surface-oriented processes associated with the water cycle and as such demand more intensive instruction. The NSES, however, make no similar cautionary statement regarding groundwater and sub-surface processes. The factor that makes the concepts of evaporation and condensation so abstract is very similar to what makes constructing appropriate understandings of any subsurface processes problematic, namely the difficulty in complete and direct observation of the phenomena. Each abstract concept (i.e. evaporation, condensation, and groundwater) contains hidden, directly unobservable components, from water disappearing and reappearing into and from an invisible medium (i.e. air) to water entering the ground and somehow emerging again from various sources and locations. The literature supports the notion that children and adults often possess alternative conceptions and mental models regarding the properties and processes attributed to water by the scientific community (Brody, 1993; Ewing & Mills, 1994; Hatzinikita & Koulaidis, 1997; McElwee, 1991; Pereira & Pestana, 1991; Wampler, 2001). Creating mental pictures of what happens to the water when it cannot be seen becomes necessary in order to construct complete and appropriate understandings of abstract earth science concepts.

Problem Two: Need for Increased Attention to Students' Spatial Reasoning Abilities

Spatial reasoning abilities heavily contribute to the development of mental images of geologic phenomena like groundwater. For example, Piburn, Reynolds, Leedy, McAuliffe, Birk, and Johnson (2002), conducted a study that analyzed the efficacy of the use of a computer-based instructional tool designed to improve college-level students' achievement in a geology course. Results from this study provide strong evidence for the importance of spatial visualization in the development of appropriate mental models. For example, Piburn, et al. (2002) state,

> Even more important is the finding that visualization and prior knowledge have approximately equal predictive power in a regression equation against post-test knowledge scores. This may be the strongest demonstration yet of the potency of spatial ability in facilitating learning, and of the importance of being able to visually transform an image to the nature of that learning process (p. 40-41).

Other researchers have also studied and described the role of visualization in the construction of appropriate conceptual understandings of geologic structures. Kali & Orion (1996) and Kali, Orion, & Mazor, (1997) analyzed spatial visualization from the perspective of visual penetration ability (VPA) or the ability to visualize what exists inside a structure at various depths. Kali et al. (1997) developed computer-based tools to enhance students' VPA through modeling and case study data yielded positive results concerning the effectiveness of the tool. Although the researchers above studied spatial visualization in the context of structural geology, their findings are applicable to hydrology in that the abilities they identified and studied are the same ones necessary to create appropriate mental models of groundwater.

As such, spatial reasoning development should be considered in deciding how and when more abstract geologic concepts like groundwater are taught. The practical implications of such consideration could result in a change in teacher and student roles, as lessons more explicitly address improving students' spatial abilities. Such a move would be consistent with current cognitive theory regarding concrete and formal operations and student maturation with respect to spatial reasoning (Baker and Piburn, 1997; Woolfolk, 1995). Additional consequences occur in how teachers address groundwater concepts for different levels of spatial abilities, involving the progression from concrete forms of instruction (e.g. physical models) to the use of strategies that employ more abstract representations (e.g. sub-surface mapping in three-dimensions). Developing and implementing curriculum and instructional approaches informed by the understanding of students' spatial development assumes that teachers hold appropriate understandings of the content. Findings from recent studies challenge this assumption (Beilfuss et al., 2004; Dickerson & Wiebe, 2003).

Problem 3: Inadequate Formal Instruction for Science Teachers Concerning Groundwater

Meyer (1987) provides us a history of previous works that document the prevalence of naïve conceptions held by the general public regarding groundwater. In contrast to the scientific community's models, which describe most groundwater occurring in very small pore spaces in unconsolidated or lithofied materials, the American public has held primarily to a belief in sub-aerial riverine systems. Meyer (1987) identifies classical literature (e.g. the Rive Styx) and Biblical scripture (e.g. the

Flood and Noah's Arc) as potential sources or reinforcers of alternative groundwater conceptions. Additionally, manuscripts continued to be published in scientific journals (e.g. American Journal of Science) up until the mid-1800's that argued for a sub-aerial riverine model (Emerson, 1821). By the early 1900's, many hydrologists held conceptions of groundwater that were consistent with those currently held by the scientific community today and were even publishing manuscripts regarding the public's misconceptions. For example, Meyer (1987) writes,

> The American hydrologist R.E. Horton published an article in 1915 entitled "Idiosyncrasies of ground water," a survey of prevalent popular misconceptions regarding the subject. Among them he cited the belief in underground watercourses similar to surface ones, coupled with the belief that many wells were "inexhaustible" because they are fed by rapidly flowing "underground rivers" (Horton, 1915) (p. 194).

Interestingly, recent studies aimed at secondary and post-secondary students' conceptions indicate that such notions of groundwater are still common today (Dickerson, Callahan, Van Sickle, et al., in press; Dickerson & Dawkins, 2004).

Among the reasons for the persistence of such alternative conceptions involves the structure and nature of formal education. Historically, earth/environmental science courses were reserved primarily for non-college bound students. As a result, many current teachers did not take an earth/environmental science course in high school. Additionally, most of those teachers received little if any formal instruction with regard to groundwater concepts in their post-secondary education. Such a lack of appropriate understanding in content holds implications for what goes on in the science classroom.

For example, Magnusson, Borko, and Krajcik (1994) examined subject matter knowledge in the context of the pedagogical content knowledge (PCK) (Shulman, 1986; Van Driel, Verloop, & de Vos, 1998) used by experienced teachers to teach students about heat energy and temperature. They found that some teachers' conceptual "frameworks are logically superior frameworks for teaching" and impacted the strategies teachers considered (Magnusson et al., 1994, p. 14). In the case of groundwater, two probable outcomes emerge for science teachers who recognize the incomplete nature of their understandings concerning groundwater. They may choose to either 1) avoid teaching the concept or 2) use instructional strategies that severely reduce student autonomy in order to limit student questions to the realm of the teacher's content understandings (e.g. use textbook-centered strategies).

The complex and abstract qualities of groundwater make the accurate conveyance of related information solely through two-dimensional graphics and language a difficult proposition for teachers. Wampler (1996, 1997, 1998, 1999, 2000) illuminates this difficulty by regularly publishing papers on groundwater misconceptions conveyed through popular science textbooks. Despite textbooks' limitations, however, many content deficient teachers rely heavily on them for illustrations and vocabulary to teach hydrogeology concepts. This probably occurs because the textbooks serve as the most convenient source of information and minimal coverage of the topic is planned. Students, consequently, construct flawed understandings from such two-dimensional and language oriented instruction (Dickerson, ndunda, et al., 2005). In addition, textbooks and isolated laboratory activities generally make use of a single environment that may or may not be consistent with what students experience in their own surroundings. For example, many textbooks and stand-alone laboratories describe aquifers as composed of unconsolidated sediments, causing conflict for students that may live in an area where aquifers consist of fractured granites. Developing appropriate mental models from such contradictory piecemeal information is unlikely for most students, who will instead construct or modify one of innumerable alternative conceptions.

Problem 4: Difficulty in Designing Appropriate Assessments

The identification of alternative groundwater conceptions is problematic because teachers lacking appropriate content understandings are unlikely to identify inappropriate student understandings. Additionally, the problem of naïve student understandings may go unnoticed even if teachers possess appropriate understandings due to common methods used to assess groundwater concepts. For example, common methods of assessing groundwater understanding usually involve using vocabulary that can hide naïve conceptions. Recent studies demonstrate that student use of vernacular language commonly believed to represent naïve groundwater conceptions may not represent inappropriate understandings and conversely the use of the 'right' words (i.e. those used by the scientific community) may not represent appropriate understanding (Dickerson & Dawkins, 2004). Such findings cast doubt on whether the sole use of multiple-choice and short answer items that rely on the students' appropriate use of content-related vocabulary are appropriate means of assessment regarding groundwater. Additional assessment issues include difficulties in assessing a complete and coherent conceptual understanding. Instead, individual groundwater concepts like porosity and permeability are often assessed as definitions and a coherent and integrated understanding is assumed.

Suggestions

Improving groundwater understandings in both children and adults requires that the science education community successfully address the four major problems identified in this article: (a) lack of emphasis in standards documents; (b) need for increased attention to students' spatial reasoning abilities; (c) inadequate formal instruction for science teachers concerning groundwater; and (d) difficulty in designing appropriate assessments. Building awareness within the science education community that current efforts fail in most instances to effectively teach a complete and appropriate water cycle serves as a reasonable starting point for reform. Recent contributions from researchers illuminate this failure as the body of evidence continues to grow in support of the assertion that people do not know much about groundwater (Beilfuss et al., 2004; Dickerson & Callahan, in press). Once the community's awareness increases regarding the current state of hydrologic understanding and subsequently, the urgent need for effective groundwater instruction, the next step involves consideration of these new research-based views in standards documents.

Addressing the Lack of Emphasis in Standards Documents

One reason groundwater remains mysterious is the lack of attention standards documents, the NSES in particular, pay to this fundamental component of the water cycle. Efforts to explicitly include groundwater concepts along with remaining portions of the water cycle already included in standards documents would go a long way in promoting the inclusion of such concepts in classroom instruction. Without their explicit and consistent presence in standards materials, policy makers, administrators, and teachers have little support when attempting to alter groundwater's role as a disposable component of water cycle instruction.

More explicit and increased inclusion of groundwater concepts is also consistent with most standards documents call for depth rather than breadth (American Association for the Advancement of Science [AAAS], 1993; NRC, 1996). The implication is that teachers should teach for complete, coherent conceptual understanding of fewer topics rather than memorization of large numbers of disassociated facts. This, however, serves as a difficult charge for teachers holding incomplete and inappropriate understandings of the concept. Consequently, hydrologic understandings reform involves more than just adding words to standards documents. Changes must also occur in the way we prepare teachers to teach these concepts. More specifically, teachers need greater PCK concerning groundwater concepts.

Development of Pre-Service and In-Service Teacher PCK

One of the defining characteristics of PCK is the ability to effectively and accurately identify and address student naïve conceptions in the most efficient and effective manner possible for a given concept in a particular context (Gess-Newsome & Lederman, 1999). Equipping pre-service teachers with this type of knowledge requires science teacher educators to effectively teach a variety of instructional strategies and assessments as well as explicitly communicate common misconceptions held by students regarding fundamental science concepts in a variety of contexts (e.g. age, cognitive ability, socio-economic status, location, etc). The following considerations serve as platforms from which teacher educators can begin addressing the issues of students' spatial reasoning abilities in hydrology contexts, science teachers' content knowledge regarding groundwater, and the construction and implementation of appropriate assessments of groundwater understandings.

Addressing the Need for Increased Attention to Students' Spatial Reasoning Abilities

Because relatively few researchers conduct studies regarding groundwater teaching and learning, groundwater related best practices in K-12 contexts, for the most part, remain unidentified. However, by drawing upon areas of research including the teaching and learning of groundwater concepts in post-secondary contexts, spatial reasoning, and current best practice strategies used throughout science education, several instructional approaches emerge as potentially promising. They include development of student spatial reasoning abilities, use of three-dimensional instructional materials, implementation of inquiry-based scientific fieldwork, and use of alternative assessments.

Considering the abstract nature of many scientific concepts, like groundwater, the inclusion of instructional strategies designed to develop and build upon students' spatial reasoning abilities becomes an essential component of effective science teaching and learning. Furthermore, the responsibility for developing these spatial abilities exists at every level of formal education. As with all subjects, the teacher primarily responsible for teaching a given concept is only one link in the chain. Without teachers facilitating the construction of cognitive skills necessary to effectively deal with abstract concepts, science teachers in subsequent grade levels are faced with an enormous task of simultaneously assisting students in the development of both the concepts and the skills needed to construct appropriate understanding. This is a particularly troubling proposition in the case of groundwater given that sustained enhancement of spatial reasoning abilities are considered to occur only over extended periods of time, often on the order of years, and only with repeated practice (Piburn et al., 2002). The implication for science teacher educators is that we must equip classroom teachers with the pedagogical skills necessary to enhance K-12 students' spatial abilities. This charge requires the introduction and modeling of instructional strategies focused on spatial reasoning in both pre-service and in-service teacher education programs.

A variety of developmentally appropriate strategies for enhancing spatial reasoning exist for every grade level. The collective focus of these strategies involves moving students from understanding concrete two-dimensional spatial qualities to appropriately and effectively applying abstract three-dimensional information. Baker and Piburn (1997) offer several strategies and tools for enhancing spatial reasoning abilities including: concept mapping, puzzles (e.g. mazes, identical figures, pattern blocks, tangrams, tessellations, etc), teacher and student drawings (e.g. cross sectional images), mapping and orienteering, and constructing physical models. Many of these strategies involve the use of three-dimensional instructional materials (i.e. three-dimensional models) and scientific fieldwork. One rationale for increased inclusion of three-dimensional models and environments is the notion that these instructional tools contain different, and often more complex, types of spatial information. Increased practice with such tools and information is believed to be beneficial in enhancing, at least some types, of student spatial reasoning (e.g. spatial visualization) (Baker et al., 1997).

Three instructional tools and strategies that may facilitate students' abilities to create appropriate mental pictures of groundwater environments include the use of rock specimens, three-dimensional physical models, and fieldwork. For example, the use of core sections or hand specimens of various types of rock, in addition to unconsolidated materials (e.g. sand), provide students an opportunity to experience, through sight and touch, the materials that are potential aquifers or aquitards. Through those experiences, students now have the opportunity to incorporate appropriate visual and haptic (e.g. the density of materials) information into their own mental models. Both the visual and haptic information likely play an important role in the development of appropriate scale applied to mental models. For example, students have described in our classes seeing the pore space in selected limestone cores as opposed to unfractured granite hand specimens, and feel the differences in the density of a high-porosity sandstone and gneiss. These experiences provide information regarding actual scale of pore size through visual and haptic modes.

The arguments for the use of three-dimensional models (e.g. sand in a beaker, Plexiglas flow models, etc) and fieldtrips are similar to those for the use of cores and hand specimens with regard to visual and haptic information in the construction of mental models. They also provide a visual context for connecting many groundwater related concepts and principles obtained from various sources. For example, the application of information regarding aquifer material and pore size is only effective in developing an appropriate mental model if the student holds appropriate understandings of other components of the system including, permeability, vertical scale, groundwater movement related to high and low pressure gradients, well construction, water volumes, residence times, etc.

Addressing Inadequate Formal Instruction for Science Teachers Concerning Groundwater

It is important for teachers to know that groundwater is an integral part of the water cycle. When teachers read science standards regarding the water cycle and begin creating objectives based on those standards, they make decisions about what information they will include in order to appropriately address the standard. By failing to include groundwater in water cycle instruction, they are teaching an incomplete and inappropriate model of the water cycle. Because many students who enter post-secondary institutions do so holding inappropriate understandings of groundwater, their undergraduate coursework may be the last opportunity to let them know that there is more to the water cycle than just what they see on top of the ground. The implication for science teacher educators is the need to develop course options for pre-service teachers that incorporate explicit and effective instruction resulting in complete and appropriate understandings of historically poorly understood science concepts (e.g. groundwater, earth/sun/moon relationships, density, etc). The case of groundwater serves as just one example of the larger dilemma of providing remedial instruction regarding science concepts in already time-strained education courses focused on pedagogical concepts and skills.

Due to the cyclic effect of a lack of formal instruction regarding groundwater concepts, it is reasonable to tentatively conclude that many in-service teachers differ little in the degree of groundwater related PCK they possess. As such, professional development program designers should consider integrating many of the components described above into program opportunities for practicing teachers. Additionally, more earth science opportunities are needed, in particular, programs that focus on complete water cycle processes, explicitly including groundwater.

Addressing the Difficulty in Designing Appropriate Assessments

A move towards improved groundwater instruction by increased attention to and intentional activation of students' spatial abilities through use of three-dimensional models, drawing, inquiry-based scientific fieldwork, etc would be incomplete, however, without use of alternative forms of assessment. For example, a student drawing may be more appropriate than a multiple-choice test item in assessing a student's mental visualization of a scientific concept. Rationales for use of drawings as an assessment tool are similar to those for use of open-ended questioning. For instance, drawing prompts are often easier to develop and usually provide much more information than can typically be obtained from a well-designed multiple-choice item. The drawbacks are also similar to those of open-ended items in terms of the time and reliability issues. Due to the problems associated with assessing conceptual understanding of groundwater, obtaining an accurate depiction of how students conceptualize underground water demands that multiple forms of assessment be used, often in conjunction with one another. If not, inappropriate mental models are too easily hidden through use of appropriate scientific language (Dickerson, Callahan, Van Sickle, et al., in press). For example, a student may use the word 'pore' appropriately in a discussion about groundwater yet believe that those individual pores are kilometers in diameter.

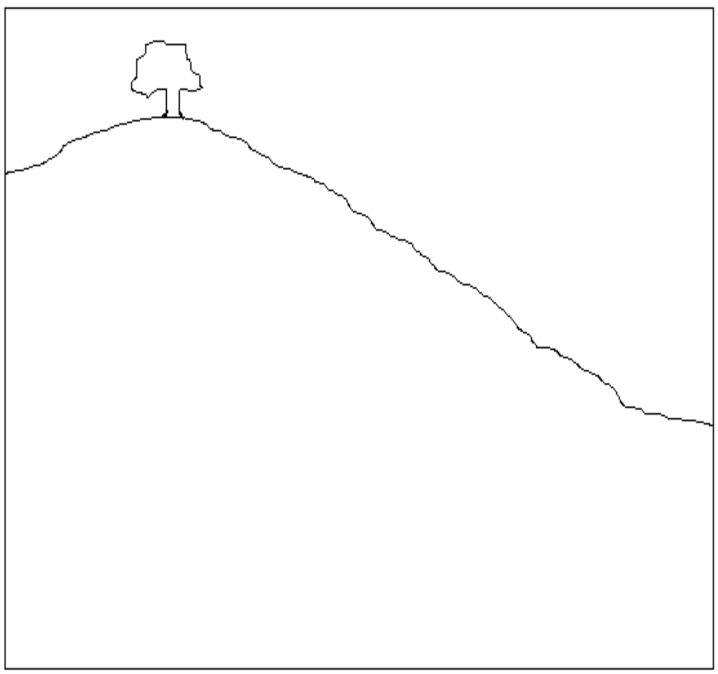
Just as modeling instructional strategies (e.g. learning cycles, scientific fieldwork, etc) in the context of groundwater instruction serves as a means of increasing scientific content knowledge, assessment instruction is equally suitable. For instance, groundwater instruction provides an excellent context in which to assess students' prior knowledge in order to identify naïve conceptions. In addition, students learn about the advantages and disadvantages of, as well as when and how to use, various forms of assessment including multiple-choice items, short answer items, drawings, concept maps, etc. For instance, we model the use of pre-assessment by assessing students' groundwater understandings using various types of multiple-choice items, open-ended questions, and drawing prompts. Students are required to analyze what types of information each item provides and construct an appropriate instructional plan based on the responses. This strategy also teaches students the fundamentals of assessing for conceptual understanding of science concepts. For example, by asking the question in Table 1, the teacher can identify what language the students are using to describe groundwater and consequently what possible alternative conceptions may need to be explicitly addressed. Students learn, however, that the assumption that non-scientific language (e.g. underground stream) represents an inappropriate understanding and that scientific language (e.g. pores) represents an appropriate understanding is fallacy.

Table 1. Multiple-Choice Item Designed to Identify Students' Choices of Descriptors

Multiple-Choice	1. If a person drilled a well to get groundwater, from where could this water come? (choose all that apply) a. river b. sand layer c. underground pool d. water tower e. soil f. spigot or faucet g. solid/fractured rock h. underground stream i. lake j. city water supply

The drawing prompt in Table 2 provides students with an opportunity to express their understandings without using words. While the drawing is not an exact replica of the student's mental model, it does provide spatial information and information regarding the integration of groundwater related concepts often left unexamined by other forms of assessment.

Table 2. Drawing Prompt Used to Assess Spatial Information

Drawing	2. Draw a detailed picture of how groundwater occurs and moves. 

Additionally multiple-choice items, such as the ones in Table 3, provide additional spatial and verbal information that may not be obtained in the other assessments.

Table 3. Multiple-Choice Item Designed to Assess Students' Spatial and Verbal Understandings

<table>
<tr>
<td>Multiple-Choice</td>
<td>
<table>
<tr><td rowspan="5">1. (a) Which structures do you think store most of the groundwater beneath the surface of the Earth in the eastern United States <u>AND</u> (b) what do you think is the size of each individual structure you chose?
Choose all that apply. Be sure to answer Part (a) and (b) of the question.</td><td>O pool/lake</td><td>O microscopic - eraser on a pencil
O basketball/beach ball – car
O house – skyscraper
O other ______________</td></tr>
<tr><td>O stream/river</td><td>O microscopic - eraser on a pencil
O basketball/beach ball – car
O house – skyscraper
O other ______________</td></tr>
<tr><td>O pipe</td><td>O microscopic - eraser on a pencil
O basketball/beach ball – car
O house – skyscraper
O other ______________</td></tr>
<tr><td>O pore/crack</td><td>O microscopic - eraser on a pencil
O basketball/beach ball – car
O house – skyscraper
O other ______________</td></tr>
<tr><td>O other
Please specify:
__________</td><td>O microscopic - eraser on a pencil
O basketball/beach ball – car
O house – skyscraper
O other ______________</td></tr>
<tr><td>3. How deep do you think most human drinking water wells go into the ground in the US?</td><td colspan="2">O 1ft – 10ft O 100ft – 5000ft
O 10000ft – 500000ft O 100000ft – 5000000ft</td></tr>
</table>
</td>
</tr>
</table>

Lastly, the open-ended questions in Table 4 provide students with an opportunity to write about what they know, which can be compared to other data collected by multiple forms of assessment. By examining the congruency between the types of information obtained by each assessment, teachers learn to determine whether students hold appropriate conceptual understandings, and if not, identify the alternative conception(s) at work. The next step is to devise a plan to explicitly address those alternative conceptions, which means employing many of the tools and strategies mentioned in previous sections of this paper.

Table 4. Open-Ended Item Designed to Assess Students' Articulation of Mental Models

Open-Ended	1. Where did your ideas about groundwater come from? 2. Using your picture, describe where the water is underground.

The experience of completing and administering alternative forms of assessment to gather information that would otherwise be unobtainable may increase the probability that pre-service teachers will value and use such assessments in their own classroom. Additionally, effective use of assessment plays a critical role in the ultimate goal of facilitating the construction of groundwater related PCK. By recognizing what assessments are most appropriate for groundwater related conceptual understandings, students will form a foundation of understanding upon which other assessment strategies and content foci can be built.

Research Possibilities

Many lines of inquiry exist for researchers interested in furthering our understandings of teaching and learning groundwater concepts. We need further identification and characterization of conceptions held by children and adults. In particular, populations of immediate concern include K-12 students, K-12 pre-service teachers, and K-12 in-service teachers. We also need much more research in the area of development and implementation of groundwater related instructional strategies, materials, and assessments in K-12 and teacher education contexts. Although we described a number of strategies, materials, and assessment tools, the literature provides very little information on the efficacy of any of these approaches when used to teach groundwater in K-12 and teacher education contexts. Additionally, the science education community currently has little understanding of groundwater related teacher PCK and its impact on enhancing students' scientific literacy.

This issue of examining subject matter knowledge, teacher PCK, teacher practice, students' scientific literacy, and the relationships between all these elements, constitutes a research concern greater than groundwater. Enhancing students' scientific literacy must involve the study of subject matter knowledge of core science concepts (e.g. geologic time, evolution, water cycle, forces and motion, structures of matter, etc) in relation to teaching and learning. This notion that more research is needed regarding subject matter knowledge of specific science concepts was addressed at the ASTE conference in Colorado Springs during the Subject Matter Knowledge Research Matrix session (Gess-Newsome, Simmons, Norman, Abell, Luft, & Jones, 2005). Some of the suggestions offered reiterated Magnusson et al. (1994) who argued that results from such research should be considered in a context of PCK. They further assert that such research is essential to the effective practice of science teacher educators and would "benefit practicing teachers as they strive to become more effective science teachers, and to teacher educators who work with them… planning and implementing instruction at the preservice level" (Magnusson et al., p. 19-20). The goal of enhancing students' scientific literacy by building upon our understandings of teachers' and students' subject matter knowledge of key science concepts should continue, as should the conversation regarding what science concept understandings define literacy.

The avenues available for research in the area of groundwater teaching and learning are innumerable, yet critically important. As potable water issues continue to increase both domestically and globally, the knowledge we develop today will directly impact the quality of decisions made in the future. Providing adequate content instruction for our teachers, equipping them with a cadre of appropriate instructional strategies and alternative assessments, and developing standards and curriculum that couple groundwater instruction with students' cognitive levels in order to maximize the potential for successful learning and teaching is critical. Until such steps are taken, we will continue to see little difference between teacher and student understandings of groundwater.

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