Groundwater

Issue Paper/

From the Mental to the Conceptual Model: The Challenge of Teaching Hydrogeology in the Field

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Abstract

Field-based learning in hydrogeology enables students to develop their understanding and application of practical methodologies, and to enhance many of the generic skills (e.g., teamwork, problem-solving). However, teaching and learning hydrogeology in general, and especially in the field, presents cognitive difficulties, such as the diversity in student education and experience, the hidden nature of water movement and transport of chemicals, and the preexisting students' mental models of the subsurface, in particular. At any given experimental or teaching site there is only one reality for which lecturers can have an approximate conceptual model, including aquifer(s) geometry and functioning (e.g., flow direction). However, students' preconceptions (i.e., mental model), in some cases misconceptions, influence not only their outcome from the learning strategy designed, but also the conceptual model expression (i.e., flow chart, block diagram, or similar) for the study area or site. In practice, two general "teaching challenges" are identified to enable students' transition from the mental to the conceptual model: (1) identify and dispel any prior misconceptions and (2) show how to go from the partial information to the integration of new information for the development of the conceptual model. The inclusion of specific prior-to-field lessons in the classroom is recommended and in general, done. However, introducing a prior-to-field survey to learn about students' backgrounds, and methodologies for the development and expression of hydrogeological conceptual models and for testing multiple plausible conceptual models will help students transition from the mental to the conceptual model.

Challenges of Teaching Hydrogeology in the Field

Groundwater hydrology, or hydrogeology, is an applied science driven by the current anthropogenically induced environmental challenges with a markedly interdisciplinary nature at the interface between geology, hydrology, hydraulics, soil science, physics and chemistry, and more recently biology (Hakoun et al. 2013; Lyon et al. 2013). In addition to the fact that subsurface processes are abstract phenomena that are neither visible nor can they be directly experienced (Unterbruner et al. 2016), training future hydrogeologists in the field presents two general "teaching challenges": (1) the students that take part in a field course have diverse course backgrounds and preconceptions, in some cases misconceptions, and (2) the use of teaching strategies targeted to a diverse student audience that accommodate new concepts while still highlighting basic concepts to contributing to the development and expression of the conceptual model for the studied area or site (Lyon et al. 2013).

Students come to the field with preconceived concepts, for example, disconnection between surface waters (rivers) and groundwater, and models, that is, mental models, which can deviate in form from the conceptual models (Vosniadou 2013). Lecturers often assume that

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Received January 2023, accepted September 2023.

doi: 10.1111/gwat.13355

these mental models will evolve into accurate or more plausible conceptual models (Norman 1983; Duit and Glynn 1996). While a conceptual model is an external and simplified representation based on scientific knowledge of a system and/or its functioning (Norman 1983), for example, a diagram explaining the water cycle, a mental model is an internal, personal, idiosyncratic, and commonly incomplete representation of a system and/or its functioning (Horton 1915; Greca and Moreira 2000). An important characteristic of mental models is their recursiveness character, that is, a mental model is a dynamic representation never complete. Students with preconceptions can be resistant to a conceptual change, impeding the development of further or more accurate knowledge (Unterbruner et al. 2016). When approached with a conceptual model, students may instead extract only those elements they consider relevant (e.g., organization of aquifer layers but ignoring the artesian character of one of the layers) and incorporate them into their mental model, resulting in a mental model that might differ from a reasonable or plausible conceptual model for the studied area or site (Greca and Moreira 2000).

Field hydrogeology lecturers, who often are scientists and engineers, implicitly assume they understand the functioning of a system if they have a conceptual and/or computer model that explains or even predicts the observations for the studied area or site, the so-called scientific model (Vicsek 2002; Bredehoeft 2005). Although at any given studied area or site there is only one physical system, the "art" of hydrogeology is making the right simplifications to be able to represent the system—more specifically to represent the processes of interest—without making too many or incorrect simplifications. This requires thoughtful teaching approaches that recognize the processes of simplification and of learning, that is, implement pedagogical improvements (Sell et al. 2006; Gleeson et al. 2012). However, all teaching approaches present inherent difficulties. For example, some studies have highlighted how active learning or learning-by-doing strategies can risk the perpetuation of inaccurate preestablished concepts (Fuller et al. 2000). Teaching strategies often ignore the effects of the diversity in the prior knowledge of the enrolled students (Bransford et al. 1999), at both undergraduate and graduate levels, and therefore on the development of conceptual models and their expression.

Advances in Teaching Hydrogeology in the Field

While classroom lectures are typically lecturer-centered (students are more passive), field courses invite active-learning methods (Hakoun et al. 2013; Lyon et al. 2013; Van Loon 2019). Active-learning courses are student-centered as the instructor acts as a "facilitator" as the students "learn by doing" (Pathirana et al. 2012), that is, students collect, analyze, and interpret data. This gives them ownership of their learning and is, therefore, excellent vocational training (Gleeson et al. 2012). Teaching through a learning-by-doing strategy has been demonstrated to increase student learning in hydrology and other applied sciences (Gates et al. 1996; Lee 1998; Noll 2003; Cutrim et al. 2006; Prince and Felder 2006; Thompson et al. 2012) and as well as student satisfaction (Laird et al. 2008). A characteristic practice in science (She 2004), inquiry-based learning (a form of active learning that starts by posing questions, problems, or scenarios; Rowell and Ebbers 2004) has also been proposed by instructors to enhance student understanding and development of their cognitive skills (Prince and Felder 2006; Sell et al. 2006; Hakoun et al. 2013). Studies have demonstrated the advantages of inquiry-based learning (Pawson and Teather 2002; Sell et al. 2006; Coe and Smyth 2010), with a large part of the success relying on the active engagement of each student (Prince and Felder 2006). The learning-by-doing strategy in the field can also include collaborative learning, in which a group works toward a common goal of transferring knowledge and skills among its members (Millis and Cottell Jr. 1997; Allen et al. 2001).

The teaching of hydrogeology in the last years presents a clear shift toward the incorporation of field and laboratory techniques in teaching strategies (Blöschl et al. 2012; Gleeson et al. 2012). When teaching hydrogeology in the field, lecturers often show block diagrams or sketches representing a conceptual model for a hydrogeological system, but how these conceptual models have been elaborated is often not described in detail. To overcome this issue, the development of students' spatial reasoning skills, for example, through two-dimensional (2D) or three-dimensional (3D) digital and numerical models (Greca and Moreira 2000; Bredehoeft 2005) or with the inclusion of physical models for classroom (prior-to-field) teaching—"making the invisible visible"—(Rodhe 2012; Cardiff and Heinle 2019; Shanafield et al. 2019; Mohammadi et al. 2021), have been considered (Gleeson and Paszkowski 2014). Spatial, that is, spatial visualization skills, and temporal, that is, knowledge of the characteristic times of processes, reasoning abilities contribute substantially to the development of plausible conceptual models of systems and processes such as those found in groundwater (Dickerson et al. 2007). For example, visual penetration ability, that is, the ability to visualize what exists inside a structure, is a key skill aiding the appropriate conceptual understanding of geologic structures (Kali and Orion 1996; Kali et al. 1997). Numerical and physical models help develop spatial and, in some cases, temporal reasoning abilities, that is, help the conceptual model expression (i.e., flow chart, block diagram, or similar).

Conceptual models' uncertainty is one of the major sources of uncertainty in groundwater hydrology (Rojas et al. 2008). Hypothesis testing is essential to increase system understanding by analyzing and refuting alternative conceptual models. Therefore, a pedagogical alternative in field courses is testing either individually or in groups competing alternative hypotheses, that is, competing conceptual models for the study area or site (Chamberlin 1890; Ferre 2017). This starts to be a common practice for exploratory analysis in hydrogeology research (e.g., Dwivedi et al. 2019; Enemark et al. 2020). While this approach requires a thought adaptation for teaching purposes (i.e., how to confront groups of students and hypotheses without disregarding any of the options), it promotes not only the integration of the partial information for the conceptual model development, but also the reuse of the data collected by the students in the field to support accepting or rejecting the hypotheses.

Recommendations for Transitioning from the Mental to the Conceptual Model

Subsurface hydrology is growing more interdisciplinary and complex (Wood and Wood 2014), making the shift to a more integrated pedagogy (combining classroom, lab, and field lessons), a critical next step in the training of our next generation of hydrogeologists (Gleeson et al. 2012). In the following, recommendations to address the two identified "teaching challenges" and to help students transition from the mental to the conceptual model are provided.

Although there may be a number of other variables that may affect student learning, for example, students' attitude and motivation or lecturer knowledge, student prior knowledge is a very important variable controlling the success in the development of a plausible conceptual model for the study area or site in a hydrogeology field course. Therefore, getting information on the students' background through a prior-to-field survey can be very valuable (e.g., Sell et al. 2006). The survey can consist of asking about prior attendance to courses including, but not limited to: geology, sedimentology and stratigraphy, geomorphology, geochemistry, geotechnical engineering, geophysics, hydrology, hydrogeology, soil and vadose zone, water resources management, hydraulics, geographical information systems, cartography, and forestry and landscape ecology. Further, after a brief introduction to the study area or site, the students can be asked to elaborate a drawing (either 2D or 3D) of their preestablished model, that is, mental model. These two prior steps before initiating the active-learning part of the field course would help to address the first "teaching challenge"—identify and dispel any prior misconceptions—defining teaching strategies, such as recalling basic concepts when and if needed.

To address the second "teaching challenge"—how to go from the partial information to the integration of new information for the development of the conceptual model—lesson plans need to teach conceptual model development and expression prior-to-field (e.g., Lee 1993). For this purpose, the lecturer can start by explaining the concept of a conceptual model. Second, emphasize that a conceptual model is an abstract representation of a hydrogeological system. Then, provide examples of conceptual models from several study areas or sites. Finally, discussing the importance of conceptual models in helping us understand complex systems and in building numerical models, and communicate ideas effectively as well. The steps in the conceptual model development include: (1) the identification of entities (elements within the system, e.g., aquifer layers, rivers); (2) defining the attributes (characteristics or properties of the entities, e.g., thickness, hydraulic conductivity); (3) determine the relationships, that is, connections between entities, for example, arrows indicating sense and magnitude of flows. The integration of this partial information through block diagrams or sketches will allow the creation of a coherent representation of the system or processes, that is, arrangement in space of the entities and relationships in a logical and meaningful way, making revisions and adjustments as new information is collected. Some of these steps can be obviated based on the level and needs of the students.

To conclude, and in general, lecturers should be aware that learning cannot be understood as the replacement of an incorrect concept by a correct one (Vosniadou 2007), or as the replication of their thinking by the students. Instead, in field courses that invite active learning, lecturers should encourage the students to think for themselves, while continuously seeking to establish links between the field content and the theoretical concepts, that is, to establish the bounds in the process of simplification or abstraction (Sanders 1998).

Acknowledgments

The author thanks Pia Scherrer and Philip Barth (Department of Educational Development and Technology, ETH Zurich) for the enriching discussions. The author declares that any opinion, finding, and conclusion expressed in this document are those of the author and do not reflect the view of his affiliations or institutions. Open access funding provided by Eidgenossische Technische Hochschule Zurich.

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