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Water in society: An interdisciplinary course to support undergraduate students' water literacy

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- Fostering water literacy in both science majors and nonmajors
- Helping 2-year college students improve microscopy skills
- Incorporating current scientific advances into a biology course

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Water in Society: An Interdisciplinary Course to Support Undergraduate Students’ Water Literacy

By Cory T. Forbes, Nicholas Brozović, Trenton E. Franz, Diane E. Lally, and Destini N. Petitt

The most challenging global problems of our age involve coupled human–environmental systems within the Food–Energy–Water Nexus. The undergraduate students currently in our classrooms will be tomorrow’s global citizens, each of whom must be prepared to understand and reason about these challenges and ultimately make decisions about them in a variety of contexts. Postsecondary institutions, then, must afford students multidisciplinary, STEM-based experiences that help them develop this knowledge and skillset. In light of this need, we developed and taught an introductory undergraduate course—Water in Society—grounded in contemporary, real-world, “socio-hydrological” issues. The course, designed to serve the needs of both STEM majors and nonmajors, was designed and offered by an interdisciplinary team of hydrology, economics, and science education faculty. Key course themes include engagement with authentic data, scientific models and modeling, multimodal forms of scientific communication, and research-based best practices for effective STEM instruction. Here, we describe the first iteration of the course, including elements of the class that exemplify these primary course themes and pedagogical reflection on instructional experiences and student feedback.

Societies today face an array of global challenges, such as population growth, food production, natural resource use, and environmental degradation. A crucial element shared by each of these challenges is water. As recognized by the National Science Foundation (NSF Advisory Committee for Environmental Research and Education, 2005), “All human and natural systems are influenced by the distribution, abundance, quality, and accessibility of water” (p. 6). In turn, humans are increasingly viewed as a core component of hydrologic systems. These “socio-hydrological” systems are central to the global Food–Energy–Water (FEW) Nexus (Food and Agriculture Organization of the United Nations, 2014), in which water is fundamentally intertwined with production and consumption of both food and energy. However, as King, O’Donnell, and Caylor (2012) noted, “the truth of the matter is that we *do not know* how to resolve the greatest hydrological challenges in the world . . . to simultaneously ensure hydrological, economic, social and environmental sustainability” (p. 4030). The challenges facing humanity, including educational endeavors to prepare individuals to confront these challenges, are very real.

Postsecondary education must play a central role in addressing this need. Recognition of this has led to increasing emphasis on systemic postsecondary STEM (science, technology, engineering, and mathematics) education reform (National Research Council [NRC], 2012), including efforts to foster water literacy in both science majors (Wagener et al., 2012) and nonmajors (Amador & Miles, 2016; Halvorson & Wescoat, 2002; Sabel, Vo, Alred, Dauer, & Forbes, 2017). However, research has shown that water literacy in the United States remains underdeveloped. For example, despite an emphasis on water in discipline-specific science education standards (Earth Science Literacy Initiative, 2010; NGSS Lead States, 2013), research has illustrated gaps in students’ knowledge of core hydrologic concepts across the K–16 continuum, including at the elementary, middle, secondary, and undergraduate levels (e.g., Forbes, Zangori, & Schwarz, 2015; Cardak, 2009; Gunckel, Covitt, Salinas, & Anderson, 2012; Halvorson & Wescoat, 2002). These misconceptions carry forward into adulthood. In a 2005 survey of U.S. adults (American Museum of Natural History, 2005), researchers found that <10% of respondents could estimate the percentage of drinkable water on Earth, <25% could identify groundwater as part of the water cycle, and <33% could accurately identify agriculture as the dominant source of water use worldwide. These statistics suggest a fundamental disconnect between the U.S. population and socio-hydrological systems of which they are a part.

As colleagues from interdisciplinary contexts (hydrology, economics, and science education), we are each involved in supporting water education efforts across formal, informal, and nonformal settings. The new 100-level, interdisciplinary undergraduate course described here—Water in Society—provided an opportunity to collaborate in finding innovative ways to support a diverse array of undergraduate students to both develop knowledge of hydrologic concepts and learn to apply those to real-world, socio-hydrological problems. The experience of developing and offering the course for the first time has been rich with opportunities for self-reflection and professional development, both as a team and within the bounds of our unique disciplinary identities. Here, we share core elements of our course, as well as observations and "lessons learned" from its first iteration, in hopes of contributing to ongoing discussions about interdisciplinary approaches to undergraduate STEM education, particularly as focused on present and future water-related challenges that will continue to fundamentally shape our world. This article lays the foundation for future dissemination of results from discipline-based education research and course evaluation.

Setting the context

The current environment and priorities of the University of Nebraska–Lincoln (UNL) have afforded an innovative environment in which a course like this could come to fruition. UNL has a long history of global leadership in water resources research and is home to a globally recognized Water for Food Global Institute. More recently, UNL has made a commitment to the far-reaching Science Literacy Initiative, including the establishment of an interdisciplinary undergraduate FEW-Nexus minor available to students from across the university. Additional administrative support for team-based approaches to teaching and research (including discipline-based education research) and the underlying Land Grant mission have helped create a synergistic environment for innovative, multidisciplinary water education efforts. Financial support from the National Science Foundation and the Water for Food Institute ensured appropriate personnel—three faculty members and two graduate teaching assistants (authors)—were able to contribute as members of the instructional team.

First offered in spring 2017, this 3-credit-hour course served 44 students. One of the goals of this course was to attract both STEM majors and nonmajors. Students who enrolled represented majors such as journalism, history, agribusiness, prehealth, and fisheries and wildlife biology. They were evenly distributed by gender and academic standing. Adding to the diversity of this group were Chinese and Rwandan study-abroad students. This unique combination of students afforded a valuable and unique context for innovative, interdisciplinary science teaching and learning.

Course design

With this target population in mind, we articulated overarching course goals that aligned with undergraduate general education requirements focused on both (a) science concepts and (b) civic engagement. The two performance-based student outcomes were to:

1. Explain fundamental hydrologic concepts and use this knowledge to engage in scientific practices, including posing and answering scientific questions, exploring hydrologic phenomena, analyzing and making inferences from data, and determining validity of conclusions.
2. Engage effectively in principled analysis of and reasoning about socio-hydrologic systems, including their scientific, ethical, social, economic, cultural, and civic dimensions, to make informed decisions about water resource use in [state] and around the world.

Given these outcomes, we were next faced with the challenge of designing course experiences that would (a) afford students iterative opportunities to engage in these practices with increasing sophistication during the semester and (b) enable effective assessment of students' learning. To aid in this process, we identified a set of key instructional design principles or heuristics that drove our efforts to design and teach the course, each of which is described in more detail in the sections that follow.

Effective STEM teaching and learning

Effective teaching in STEM content areas has evolved from traditional perspectives on teaching and learning that prioritize one-directional information transmission through instructor-led lectures and "canned" activities with stringent, predetermined outcomes. Instead, contemporary perspectives emphasize active learning, a process in which instructors and students coparticipate in higher order thinking and cocreate knowledge and meaning (Handelsman et al., 2004). Active learning involves an array of alternative classroom structures, including small- and large-group discussions, problem solving, practicing, questioning, and feedback, through which students, create, analyze, and evaluate evidence and knowledge claims for natural phenomena (Bonwell & Eison, 1991). Indeed, active learning is so critical to students that use of reform-based pedagogy can increase student test scores by half of a standard deviation, whereas lecture alone increases the odds of failure for a student (Freeman et al., 2014). This compelling evidence underlies current emphases on use of active learning strategies and principles of effective STEM instruction in undergraduate STEM courses.

These ideas had a systemic influence on the course, one in which we have sought to use active learning in many ways. The course is structured to include two whole-group class meetings and one smaller discussion group meeting each week. In whole-group class meetings, we use a learning assistant model to support student interaction and provide instructional support during whole-class meetings. Class meetings involve an array of learning structures, including large-group discussions, small-group discussions, group writing prompts, and sharing ideas and questions from small-group to large-group settings. In particular, we sought to foreground scientific communication as a core active learning strategy to support students' critical thinking and reasoning about course concepts. Over the course of the semester, students worked collaboratively to produce infographics conveying complex but critical information about real-world socio-hydrological challenges. Infographics are potentially powerful ways to highlight core information selected to cater to specific audiences. Their infographics were framed by questions (e.g., What will happen to ecosystem services with global climate change? How will water availability change in the next 50 years?). Discussion, discourse, and collaboration around these infographics helped frame much of the active learning strategies used as part of the course as students worked together to build new knowledge about a topic, solve problems with their new information, and create an infographic. As a culmination of this project, students had the opportunity to present their infographics to scientists, policy makers, and educators as part of a session at a global conference late in the semester.

Multidisciplinary through real-world cases

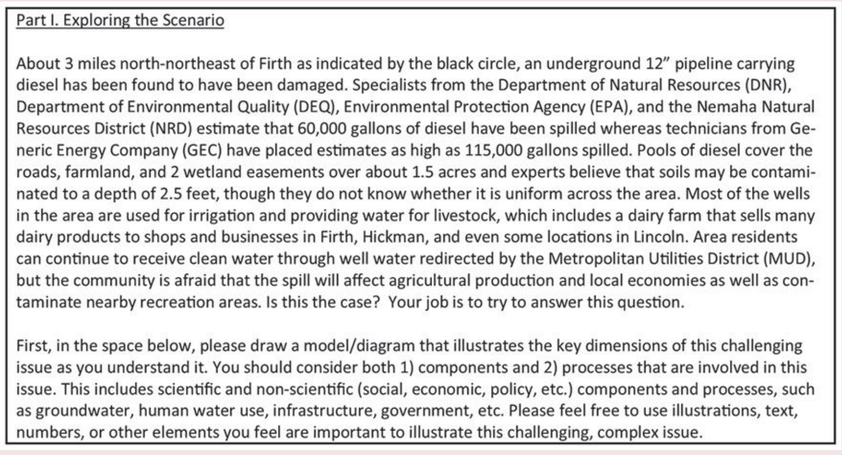
In the sciences, it is common to foreground isolated natural systems as units of study. Increasingly, however, there is recognition of the role of humans in these systems and, in many cases, their reconceptualization as coupled human–environmental systems. The specific relationship between humans and water illustrates this point. As Vogel and colleagues (2015) noted, "Human impacts on the terrestrial hydrosphere are now so widespread that it is difficult to find a watershed or aquifer that does not reflect interaction among human and natural hydrologic processes." As such, humans are inseparable from natural water systems, "co-evolving" (Liu, Tian, Hu, & Sivapalan, 2014) as coupled systems and bringing about socio-hydrology as a new science of people and water (Sivapalan, Savenije, & Blöschl, 2012).

We believed that capturing this unique, transdisciplinary "lens" for the course was critical. Rather than treat the two course outcomes as parallel entities, we sought to integrate them in meaningful ways through purposefully designed learning experiences for students that reflected this socio-hydrological perspective. Our primary approach to accomplishing this through curriculum and instruction was to build core-learning experiences around real-world water-related challenges and scaffold students' engagement with both natural and human dimensions of those issues. Students worked in teams over the course of the semester to engage with a specific, contemporary socio-hydrological issue. These topics were question driven, framing them as real-world water-related challenges in need of resolution. Throughout the semester, we also used smaller scale, fictional scenarios related to contemporary water issues to afford students repeated opportunities to identify and account for both human and natural components of unique socio-hydrologic systems grounded in challenging problems. For example, Figure 1 shows a scenario provided to students as part of a course assignment.

After being presented with this

FIGURE 1

Scenario prompt about a groundwater-focused socio-hydrologic issue.



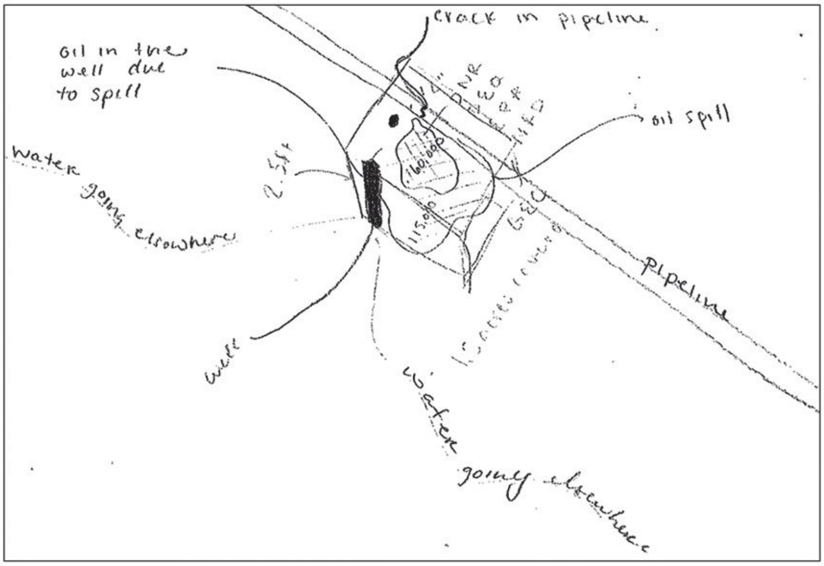
Part I. Exploring the Scenario

About 3 miles north-northeast of Firth as indicated by the black circle, an underground 12" pipeline carrying diesel has been found to have been damaged. Specialists from the Department of Natural Resources (DNR), Department of Environmental Quality (DEQ), Environmental Protection Agency (EPA), and the Nemaha Natural Resources District (NRD) estimate that 60,000 gallons of diesel have been spilled whereas technicians from Generic Energy Company (GEC) have placed estimates as high as 115,000 gallons spilled. Pools of diesel cover the roads, farmland, and 2 wetland easements over about 1.5 acres and experts believe that soils may be contaminated to a depth of 2.5 feet, though they do not know whether it is uniform across the area. Most of the wells in the area are used for irrigation and providing water for livestock, which includes a dairy farm that sells many dairy products to shops and businesses in Firth, Hickman, and even some locations in Lincoln. Area residents can continue to receive clean water through well water redirected by the Metropolitan Utilities District (MUD), but the community is afraid that the spill will affect agricultural production and local economies as well as contaminate nearby recreation areas. Is this the case? Your job is to try to answer this question.

First, in the space below, please draw a model/diagram that illustrates the key dimensions of this challenging issue as you understand it. You should consider both 1) components and 2) processes that are involved in this issue. This includes scientific and non-scientific (social, economic, policy, etc.) components and processes, such as groundwater, human water use, infrastructure, government, etc. Please feel free to use illustrations, text, numbers, or other elements you feel are important to illustrate this challenging, complex issue.

FIGURE 2

Sample student model of socio-hydrologic scenario.



fictional scenario, students' first task was to map the socio-hydrologic system in question, identifying important components and processes involved in this particular issue. As shown in the sample student diagram in Figure 2, some of these included natural processes and systems, such as the local geology, gradient, and properties of substrate to calculate saturated hydraulic conductivity (K), porosity, and Darcy's Law.

Others included human dimensions of the issue, including stakeholder entities, their priorities and interrelations, and pathways through which they interacted with other stakeholders and/or natural water systems. Through iterative opportunities such as this, students were able to learn to use "systems thinking" to map the complexities of multiple socio-hydrologic systems of varying scale, complexity, and unique foci.

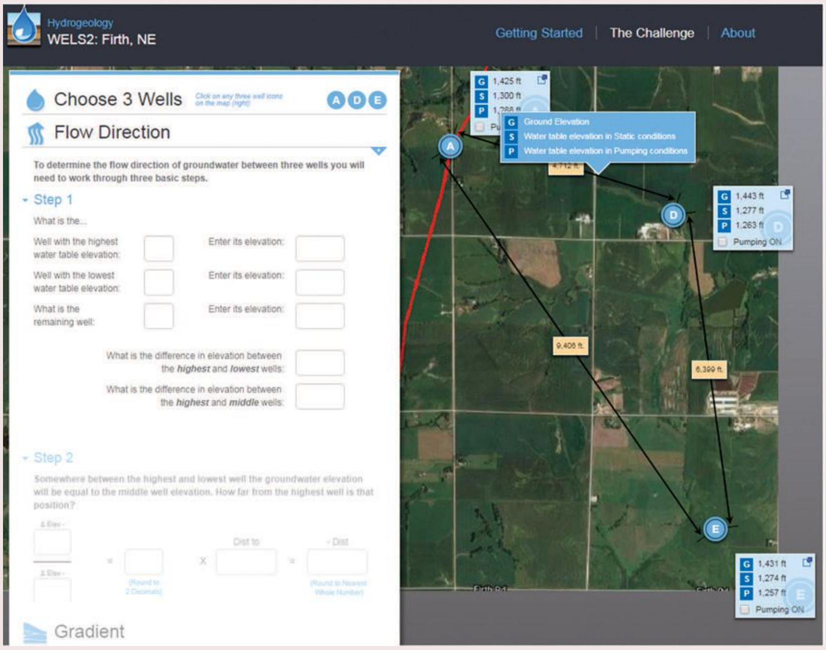
Use of models to engage with primary data

Hydrologists use models extensively to make sense of complex, large-scale water systems and make recommendations to policy makers and managers. To afford students opportunities to engage with water systems, it is important that they also have access to the tools that enable scientists to study water systems. As such, a critical component of the course involved affording students experiences with various computer-based models and simulations that enable scientific investigation of water-related phenomena while still being appropriate for students at the 100 (introductory) level. A focus on scientific models and modeling has been increasingly advocated for in science education across the K–16 continuum (Forbes et al., 2015; Schwarz et al., 2009; NGSS Lead States, 2013). Actively engaging students with models can help them build a strong understanding of scientific knowledge, which in turn may provide them with the ability to reason more scientifically. In particular, these models involved authentic data collected by university researchers and state agencies.

Here, we highlight two computer-based models students used to complete assignments in the course: the Hydrogeology Challenge (HC) and the Water Balance Model (WBM). The HC (Figure 3) is a learning tool designed by a partnering nonprofit

FIGURE 3

Screenshot of the Hydrogeology Challenge interface.



To determine the flow direction of groundwater between three wells you will need to work through three basic steps.

Step 1

What is the...

Well with the highest water table elevation: ☐ Enter its elevation: ☐

Well with the lowest water table elevation: ☐ Enter its elevation: ☐

What is the remaining well: ☐ Enter its elevation: ☐

What is the difference in elevation between the *highest* and *lowest* wells: ☐

What is the difference in elevation between the *highest* and *middle* wells: ☐

Step 2

Somewhere between the highest and lowest well the groundwater elevation will be equal to the middle well elevation. How far from the highest well is that position?

Δ Elev ☐ / Δ Elev ☐ = ☐ (Round to 2 Decimals) × Dist to ☐ = Dist ☐ (Round to Nearest Whole Number)

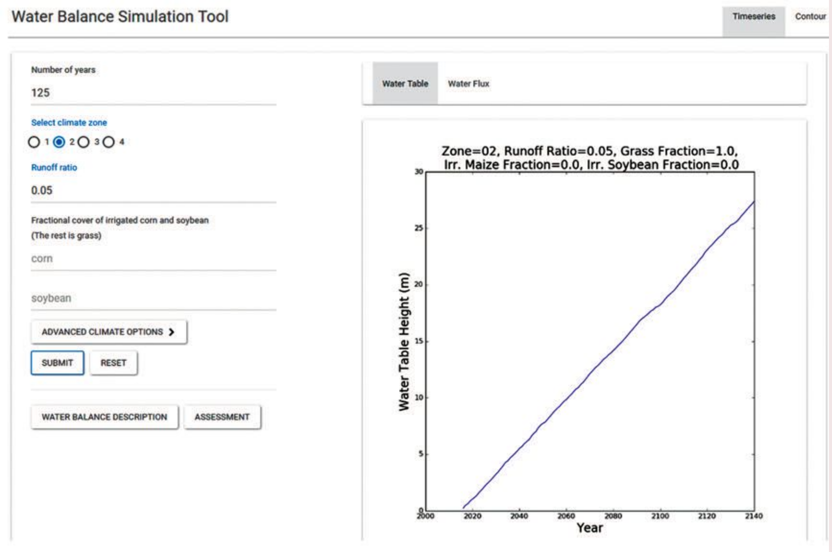
G Ground Elevation
S Water table elevation in Static conditions
P Water table elevation in Pumping conditions

Well	G	S	P
A	1,425 ft	1,300 ft	1,288 ft
D	1,443 ft	1,277 ft	1,263 ft
E	1,431 ft	1,274 ft	1,257 ft

☐ Pumping ON

FIGURE 4

Screenshot of the Water Balance Model interface.



Water Balance Simulation Tool

Number of years: 125

Select climate zone: ○ 1 ● 2 ○ 3 ○ 4

Runoff ratio: 0.05

Fractional cover of irrigated corn and soybean (The rest is grass)

corn

soybean

agency to introduce students to basic groundwater modeling and the various concepts involved in groundwater flow, groundwater velocity, and contaminant transport. The WBM (Figure 4), developed for this course by the instructional team led by Dr. Franz, was designed to increase student understanding of the diverse factors that affect the water balance within a large-scale system.

Both models were designed for the intended audience and are easy to navigate with numerous user-friendly features. These two models were used in two different, but similarly structured, multiweek assignments in which students used the models to make predictions about specific socio-hydrological scenarios (such as the one presented in the previous section). The objective of these experiences was to help students experience how models can be used scientifically to provide empirically based insights into complex water-related phenomena. In both, students were first introduced to the models and practiced using them in groups to complete highly scaffolded and walk-through-together scenarios. Students received feedback from the instructors and were able to check their thinking both with their peers and internally through embedded prompts in both models. Using this approach, we wanted to ensure that no student felt overwhelmed by the many features of the models. Students also engaged in whole-class discussions about the inherent features, affordances, and limitations of the models themselves, which helped them consider epistemic dimensions of their model-based investigations. Finally, students were asked to use the models to engage with an open-ended scenario and document their model-based reasoning throughout the process.

Outcomes, reflections, and lessons learned

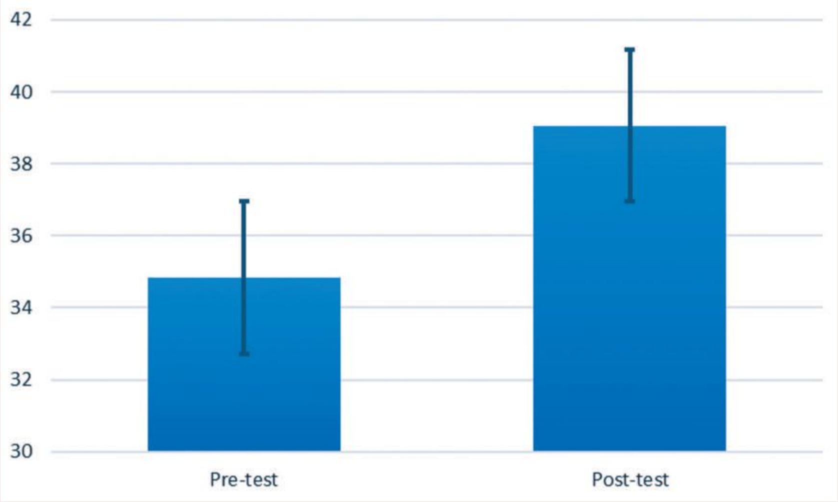
The opportunity to offer this course for the first time has yielded many helpful insights into this interdisciplinary, team-based approach to supporting students' learning about socio-hydrological systems. First, innovative instruction and active learning are crucial to a course that foregrounds reasoning about complex, large-scale socio-hydrologic challenges and teamwork. We integrated these elements into the course in its first iteration, and students reported positive feedback about opportunities for whole- and small-group questioning, problem solving, and discussion. Scores on a pre- and postcourse assessment of students' knowledge of core water-related concepts (Figure 5) provide evidence of student learning in the course, $t(45) = 8.64$, $p < .001$, $d = 2.0$.

However, we strongly believe further efforts in this domain would enhance students' experiences even more. In particular, a flipped-style classroom would prioritize collaboration, interaction, and collective reasoning around focal socio-hydrologic issues. Taking this approach to course structure would maximize time in class meetings for the instructional team to directly support student learning about socio-hydrological systems through more structured discussions and group activities, as well as both whole-group and individualized scaffolding targeted to concepts and tasks in which students may require additional support. Meanwhile, students would be held responsible for completing outside coursework in preparation for in-class meetings.

Second, there are many benefits to computer-based modeling of water systems, including enhancing conceptualization (Singha & Loheide, 2011). Students found the course modeling tasks to be highly engaging due, in large part, to their relevance and applicability to real-world challenges. There was consistency in students' performance between the modeling assignments (no statistically significant difference was observed between the two), and they were strongly correlated, $r(44) = .54$, $p < .001$. However, we observed that they need more help with learning to use these models and learning to in-

FIGURE 5

Scores from pre- and postcourse assessment of students' knowledge of water concepts.



terpret results. For example, students most commonly did not understand the importance of contour lines nor how to interpret them in various graphic forms. They also struggled with terms such as *inflation and deflation factors* and *potential evapotranspiration*, which were critical to being able to explain model results. In future iterations of this course, we intend to provide more direct support for and scaffolding of modeling skills to attain the desired level of modelling competency, including multiple practice models, practice partner-problem solving using the computer-based models, and spend more focused attention on the purposes, benefits, and drawbacks of using models to answer questions.

Third, the first iteration of the course served a diverse array of students from both STEM and non-STEM backgrounds. The unique perspectives brought by these students was an affordance of the course, and both students and instructors benefitted from these perspectives. However, we observed differences in how these students approached course experiences. For example, STEM majors were more comfortable with the computer-based models despite never having previously used the two course-specific programs. This begs the question—how do we best meet the needs of students from diverse academic backgrounds while increasing the interest for all students? What types of supports will benefit a diverse population of undergraduate students? There is a fundamental tension underlying any interdisciplinary course intended to serve the broadest population of students. We intend to address this by purposefully grouping students to enhance interaction with students from different backgrounds and the expertise each brings to collaborative, small-group work, as well as to include better communication with students about the course meta-structure. This includes informing students of the expectations for course participation and the emphasis on thinking through issues using science, not just science content. We believe these modifications to the course will help each student connect to the course and maximize the benefits of engaging with others.

Fourth, each of us benefitted a great deal from the opportunity to collaborate as part of an instructional team to develop and teach the course for the first time. Each faculty member and graduate student brought respective expertise to bear on the course that was reflected in learning experiences for students. However, as a team, we continue to explore optimal approaches to true interdisciplinarity in the context of the course. Although socio-hydrologic issues are inherently so, the ways in which we design course experiences can too easily and often unnoticeably shift toward a particular disciplinary perspective. This may be to the detriment of the primary objective of the course—helping students understand humans as a core component of global water systems. We continue to explore models and strategies for maximizing interdisciplinarity, both the human and natural dimensions of socio-hydrologic systems, in ways that fully leverage the expertise of the instructional team. ■

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