Designing An Interdisciplinary Field And Lab Methods Course In Hydrology To Integrate STEM Into Undergraduate Water Curriculum

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Abstract

An interactive, field-based course on the environmental aspects of natural water was developed as part of undergraduate STEM initiatives at the University of Northern Iowa, USA. The project is funded by the National Science Foundation. The course, titled Field and Laboratory Methods in Hydrology, is focused on two fundamental student skills, such as hydrologic field procedures and analytical methods. For field procedures, an area watershed called Dry Run Creek was delineated as a natural laboratory and integrated into the course curriculum by designing creek-side learning activities. For analytical methods, instrumental setup and analysis for water and soil samples were designed to cover core concepts in hydrology. The primary goal of the course is to portray water's important role in the natural environment. Exercises are written in an interdisciplinary setting making sure that students can identify real-life environmental problems and offer realistic solutions to them. By taking part in this project, students gained new knowledge on stream gauging, groundwater simulations, ion chemistry, GIS applications, bio-pollutants, wastewater treatment, hydrologic systems, and sampling protocol. Students also gained important skills in handling state-of-the-art equipment, including ion chromatograph, spectrophotometer, sediment analyzer, data-logger, and well purging systems. Outcomes assessment indicates that students who took the new course are more efficient in data collection, compilation, and interpretation associated with the availability, movement, and impairment of natural water. They are able to think more critically about the aquatic environment and the interrelationships among its components. Overall, the students view this course as one that has improved their learning in water sciences. Hands-on activities were very useful to critically think about natural processes that impact the water environment. They better understood how field and laboratory research data are used to implement water policies.

Keywords: Field methods; Lab methods; Hydrology; Curriculum development; Watershed

Introduction

Over the last two decades, science, technology, engineering and math (STEM) education has become an important component of undergraduate education across the United States (Talanquer, 2014). The primary reason for success in STEM education is its simplistic approach. STEM activities provide hands-on lessons, making math and science more fun for the students. In many instances, STEM education is designed through discipline-based curriculum where elements like critical thinking skills and improved learning are experimented within a given area of science (Newton et al., 2018). Students find it an efficient way of learning where they are involved in activities that are part of their lives. Also, they find it an active learning environment with reduced anxiety (Cooper et al., 2018).

In this project, a field-based hydrology course dealing with the environmental aspects of natural water was developed as part of the undergraduate STEM initiatives at the University of Northern Iowa (UNI), USA. Designing interdisciplinary hydrology courses at the undergraduate level can be challenging as well as rewarding. The challenges come from the lack of adequate content knowledge of students in hydrologic sciences. Even though some students take one semester of an Earth Science class before entering college, it is almost always true that they do not study the basic principles that define the hydrologic system. Therefore, an introductory college course in hydrology must begin by defining the most fundamental concepts of water paradigm. The course must present the traditional models while teaching the necessary skills and concepts that are needed to understand the changing environment. On the other hand, teaching hydrology can be a useful opportunity to educate students on climate variability and water's important role in making Earth a habitable planet. What creates the opportunity is the students' general interests in water. They find the course topics to be connected to their lives. They frequently hear about negative impacts of human activities on water resources from their parents or teachers during their high school years. Some grow up hearing a lot about the deteriorating conditions of surface water bodies in their own community. Others learn from the news media that industrial activities are largely responsible for degrading water quality. As a result, there is considerable interest among college students to enroll in water related courses. They are not only interested in the science behind the stories, they also want to know more about the increasing value of this important commodity. Ultimately, instructors find it professionally rewarding to teach hydrology where they can bring these students into geosciences.

Hydrology is an interdisciplinary subject area. Encyclopedia Britannica defines hydrology as *"a scientific discipline concerned with the waters of the Earth, including their occurrence, distribution, and circulation via the hydrologic cycle and interactions with living things. It also deals with the chemical and physical properties of water in all its phases"* (The Editors of Encyclopedia Britannica, 2007). The hydrologic cycle operates by moving water through various components of the global systems, namely hydrosphere, lithosphere, atmosphere and biosphere. To gain a complete understanding of the hydrologic environment, hydrologists study the chemical properties, biological interactions, and the physical processes that govern the water cycle. Therefore, as an academic area of study, hydrology overlaps with major scientific disciplines, namely oceanography, limnology, glaciology, meteorology, chemistry, geography, geology and environmental science. All these areas are linked by the basic concept of water cycle. It makes water science an ideal platform for STEM education where interdisciplinary method of instruction is of high value. Water cycle describes the continuous movement of water within the global system by way of evaporation, condensation, precipitation, and runoff. These systems readily respond to changes in natural and human forces such as climate variability, water use and water infrastructure, and land cover change. The above changes subsequently impact socioeconomic, ecological, and climate systems, leading to a coevolution of all components of the broader system (Vogel et al., 2015). Therefore, to allow students the full benefit of a field hydrology course, it must be taught in an interdisciplinary manner. Accordingly, a new course on hydrologic methods has been designed at the University of Northern Iowa to portray the natural connectedness of the global systems by putting water as a common theme. The course includes hands-on activities for undergraduate students dealing with physical, chemical and biological aspects of the hydrologic environment. Although the course is offered from the Department of Earth and Environmental Sciences, a faculty from biology is part of the teaching team. In addition, lab activities in chemistry and geography are routinely incorporated in the course. The host Department itself is a mix of multiple curricular areas and faculty with diverse specialties. In particular, the lecture-based hydrology courses in the Department are traditionally taken by students from multiple disciplinary backgrounds, such as geology, meteorology, environmental science, chemistry, biology, geography, natural resources and engineering. We expect this new hydrology methods course to evolve as a truly interdisciplinary learning platform for our students.

Departmental Structure And Academic Mission

UNI has approximately 11,500 students, including 1600 graduate students. There are over 90 majors distributed among 4 colleges. The College of Humanities, Arts and Sciences (CHAS) is the biggest college with 14 departments and includes the Department of Earth and Environmental Sciences (EES). The Department has undergraduate degrees in Earth Science, B.A. (teaching and non-teaching), Environmental Science, B.A. and Environmental Science, B.S. covering curricular areas of geology, meteorology, hydrology, astronomy, environmental science, and earth science education. The department offers minors in air quality, astronomy, earth science, earth science teaching, environmental science, and geology. Students have numerous opportunities to conduct field investigations as well as laboratory-based research in the department's well-equipped facilities. Currently, the Department has 85 undergraduate majors of which 27 are females and 58 males. The Department also draws close to 300 non-majors to our Introduction to Geology course. Another 500 or so students are annually enrolled in our Elements of Weather and Astronomy classes. Our programs prepare students for careers as environmental scientist, geologist, geoscientist, teacher, hydrologist, geochemist, astronomer, natural history interpreter, and meteorologist. The Department is also involved in the Science Education graduate programs administered within the College.

As a commitment toward strong student teaching and research, the departmental curriculum was expanded in the areas of environmental science and hydrology in recent years. The idea was to provide our students a strong environmental science/hydrology education and an opportunity to continue at the graduate level with a solid background in research. Close to $ 500,000 in external grant money was used to broaden our hydrology program in the last 10 years. The grants include one from the Iowa Carver Charitable Trust to build a state-of-the art hydrology laboratory and another from the NSF to expand the lab facilities and build a real time hydrologic data acquisition and transmission facility on UNI campus.

Course Objectives

The objectives of this project were to develop field activities and associated lab methods and to effectively design a course on hydrological methods at a comprehensive university in the Midwest United States. The new course is focused on two important aspects of experiential learning: field methods and lab analytical skills. For field methods, an area watershed called Dry Run Creek (DRC) was integrated into the course curriculum by designing creek-side learning activities for students. For lab methods, practical experiments and analysis were designed to cover core concepts in hydrology. The course is titled "Field and Laboratory Methods in Hydrology". The class is designed to meet once a week for 4 hours through the semester. Visuals by way of overhead transparencies, PowerPoint slides, and physical models are used to present the basic concepts and discuss their relevance to the natural world we live in. A short version of the course was experimentally offered in 2011. Over the period from 2010 to 2013, an integrated DRC sampling scheme was developed to facilitate data for the planned course. Preliminary data on student interests and ideas were collected through trial runs of activities at different sites within the watershed. Several lab exercises were written for this course to cover watershed characteristics; others were written to portray water's important role in the natural environment. The design of a full blown course was completed in 2013 and was proposed to the university curricular committee for approval as a 3-credit course. The class was subsequently approved and included in the course catalog. The course is intended to become an essential part of department's hydrology curriculum. The project was supported by a successful CCLI (Course, Curriculum and Laboratory Improvement) grant from the National Science Foundation (grant # DUE-0836325).

The long term goal of the project is to make earth and environmental science graduates better prepared for the job market. They are expected to obtain necessary skills in field and lab data collection, compilation, analysis and interpretation associated with the availability and movement of water in the geo-hydrologic systems. In addition, they gain experience in handling state-of-the-art hydrologic equipment, including ion chromatograph, spectrophotometer, sediment analyzer, data-logger, and well purging systems. Although there are two other hydrology courses that are taught in the Department, the idea behind this new course is to involve students in more experiential learning activities. The other courses are lecture-based, covering basic principles and theories of hydrology, but do not allow adequate time for the students to gain field experiences.

Pedagogical Approach

Pollution has always been used as a common theme for environmental education of students (Graney et al., 2008). Frequently, students struggle to holistically conceptualize Earth systems because they do not clearly understand the processes involved. Also, most of them do not know how to develop conceptual models that help solving real life problems (Herbert, 2006). Unfortunately, traditional undergraduate education does not provide enough opportunities for students to conduct environmental field research (Koretsky et al., 2012). In the past 25 years, the number of published studies dealing with students' understanding of environmental processes has grown, but there is still a gap in understanding of core concepts in the field (Sexton, 2012; Englebrecht et al., 2005; Libarkin & Kurdziel 2001; King, 2008; Cheek, 2010). Investigators found that students use their preconceived ideas of the natural world to learn new science topics (Bransford et al., 2000; Scott et al., 2007). Any misconceptions must be corrected before they can move on to the next level in a meaningful way. Sexton (2012) studied students' alternative concepts and said that their life-long understanding of alluvial processes serve as a foundation of their learning of new river concepts. Graney et al. (2008) state that "cross-linking between hydrology, geochemistry, and ecology is essential for the holistic understanding of pollution input, processing, and export at the watershed scale". It allows students to link their activities with field-scale environmental issues.

Positive results from hands-on activities for improved learning of hydrology have been reported from many investigators across the country. Investigators in western Kentucky incorporated a watershed-based field exercise into an introductory hydrogeology course. Students were involved in variety of hands-on activities, including hydraulic head, stream-bed seepage, specific discharge, groundwater flow mapping, and hydraulic gradients. All students who performed these activities said it was worthwhile, and 36 of 40 students said these activities prepared them enough for the take home exam that followed. By comparing results with classes prior to the exercise, the authors reported increased median scores on elements like "gained understanding of concepts and principles", or "helped ability to solve problems" (Fryar et al., 2010). Day-Lewis et al. (2006) reported several pedagogical benefits by establishing an on-campus well field in hydro-geophysics education and undergraduate research. They found that the students prefer working with real field data over data provided in a textbook. In addition, the access to on-campus wells expanded the opportunities for field-based labs in number of other courses, such as geo-physics, hydrogeology, and environmental geology. Effective teaching of hydrologic concepts through hands-on activities has also been reported by Iqbal and Chowdhury (2007). Several on-campus or nearcampus water activities were incorporated in a number of environmental courses simultaneously at the University of Northern Iowa and SUNY, New Paltz. In both projects, authors found that experiential learning opportunities can change previously held misconceptions and thus allow improved learning of hydrology. Noll (2003) discussed the effectiveness of integrating field experiences and hands-on laboratory exercises in a hydrology course. The course is offered in a traditional lecture-laboratory schedule on the fundamental aspects of the hydrologic cycle. Relationships between fluid flow and the physical properties of rocks are emphasized to provide a basis for examination of the management and environmental aspects of groundwater hydrogeology. Results indicate a positive impact on student learning. Overall, students said that they learned more in this type of laboratory setting than in more traditional labs. Lautz et al. (2007) presented results from a dye tracing experiment carried out by undergraduate students as a part of their hydrogeology week at the field camp. In addition to conducting exercises on water table, hydraulic conductivity, and chemical parameters of water, the students were involved in injecting Rhodamine WT dye at the upstream end of a river. Subsequently, they recorded dye concentrations at its downstream end. In this experiment, students used dilution gauging techniques and data acquisition skills. Students gave the dye tracing project the highest rating as a valuable experience. The event was covered by the local media, which gave them the opportunity to interact with the public and see how their work was relevant to the real issues. Trop et al. (2000) discussed development of a hydrology mini-course that integrates field and lab exercises to improve students' understanding of groundwater flow. The course is focused on analysis of a local aquifer that provides drinking water to the university community. The students study the aquifer characteristics and develop a laboratory model for the aquifer. The investigators found that the mini-course was an effective learning mechanism that allowed students to make connections between field observations and target concepts. The majority of the students said that they learned the most from their field experiences and participation in group discussions.

The new course at UNI is designed in a way to provide an opportunity for students to form teams and learn research methods, including hydrologic sampling protocol, chromatographic analysis, and the full sequence of field tests. They learn about water's controlling influence on the Earth's biosphere. With factual knowledge and interactive experiences students learn how to develop hypotheses, interpret data, offer constructive arguments, and make predictions. Above all, it promotes the basic elements of science standards among students, which includes curiosity, observation, data synthesis, reasoning, and objective conclusions (Clough & Clark, 1994). This approach also allows students an opportunity for teamwork, which is a very important component of effective learning. The students discuss hydrological differences among field sites and look for multiple factors that cause them. Site discussions end up with student-student or student-instructor debates and dialogues over probable remedial measures to restore the sites that are considered impaired.

Timeline	Topics/activities
Week 1	Course objectives, lab tours, Surface water/Ground water concepts
Week 2	Gaging of streams for stage, water discharge, and sediment load
Week 3	Groundwater flow simulation, Measurement of Temperature, pH, TDS, Conductivity, Dissolved Oxygen
Week 4	Ionic analysis of water, making standards, instrumental calibration
Week 5	Ion chromatography, spectrometric analysis
Week 6	Application of GIS techniques in hydrology
Week 7	2-hr Field trip: Visit well sites for Ground Water quality assessment
Week 8	4-hr Field trip: *A day in the Watershed*: Dry Run Creek sampling protocol, Water Quality Index (WQI) calculations
Week 9	Midterm Examination
Week 10	Investigations of bio-pollutants in stream water
Week 11	4-hr Field Trip: *A day in the Prairie*: Hydrology of Cedar Hills Sand Prairie and Beaver Valley Wetland, Cedar Falls
Week 12	4-hr Field trip: Visit wastewater treatment plants in Cedar Falls/ Cedar Rapids
Week 13	Group meetings for term project, data compilation and report preparation
Week 14	*No Class (Thanksgiving Break)*
Week 15	Student presentation of term projects (open to public)
Week 16	Finalize project report and submit

Table 1. Tentative course outline

A unique aspect of this project is that the course takes students across multiple hydrologic boundaries, such as uplands, prairies, wetlands, lakes, and river basins, and then show their interrelationships. In the current literature, the investigators primarily focus on the added value of hands-on experiences to learn hydrologic principles. The new course at UNI not only allows experiential learning, it also shows the students how the physical as well as the chemical characteristics behave differently as they go from one hydrologic unit to another. This course serves as a new example also because it has been developed entirely as a semester-long course. In most other cases, the investigators added one or two field modules to their traditional hydrology courses. Others have added two to three weeks of hydrology field activities to an environmental science course. Some experimented with hands-on hydrology as part of their field camp or a short summer course. A full-semester undergraduate course purely on field and lab methods in hydrology is uncommon.

Methods

Design of the course

Based on the results obtained from two experimental offerings of the course, the following outline was developed for the full course first offered during the fall of 2016 (Table 1).

Course Title: Field and Laboratory Methods in Hydrology

Course number: EARTHSCI 3360/5360 (undergraduate/graduate; 3 credit hours)

Class meeting times: 9:00 – 11:50 a.m., Thursday, plus 1 hour arranged

Catalog description: Methods of data collection, laboratory procedures and error analysis associated with water in the geo-hydrologic systems. Develop skills in using hydrologic equipment, including ion chromatograph, spectrophotometers, water monitoring sondes, and well purging systems. Field trips; Discussion/lab, 4 periods. Prerequisite(s): junior standing. (Odd Falls)

Field resources

The DRC watershed serves as the outdoor teaching resource for the new course (Fig. 1). This is a suburban watershed, which is largely within or in close proximity to the University of Northern Iowa campus in Cedar Falls, Iowa. The total stream length in the DRC watershed is just

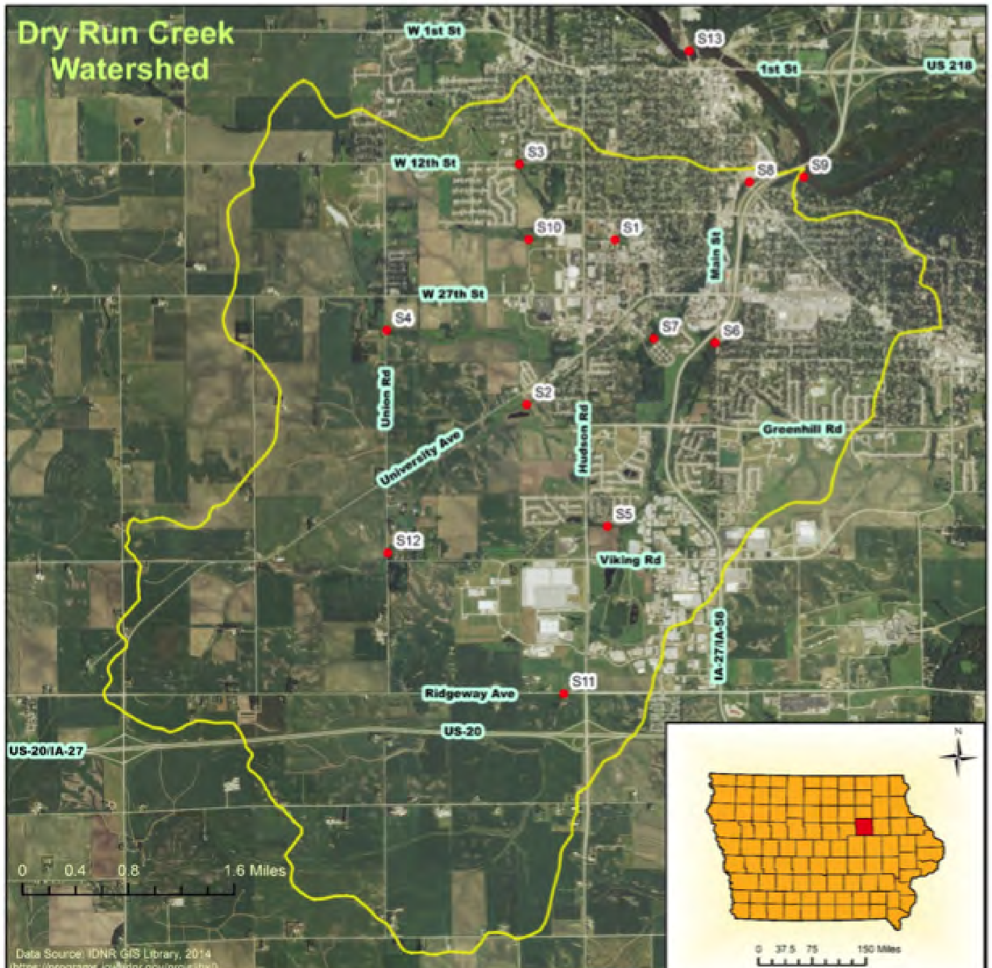

Fig. 1. Locations of the 11 sampling sites. [Sites 9 and 13 are outside the project area]

Fig 2. On campus hydrology instructional site with real time data acquisition and transmission equipment.

over 50 miles. The main channel is 22 miles long, has a sinuosity of 1.34 and a slope of 10.2 feet per mile. The DRC basin has a stream density of 1.26 mi/sq mi and an average basin slope of 0.3 percent (Palmer and Buyck 2011). DRC drains 24 square miles area before it enters into the Cedar River, which is a prominent river system in northeast Iowa. Students learn water and sediment sampling protocols at multiple sites within the experimental watershed and use those samples to learn lab procedures to analyze water and sediment. Over the summer months from 2013-2016, fifteen (15) DRC sites were visited and sampled to assess their accessibility, collect baseline chemical data, and determine travel times from one site to another. Temporal and spatial data on water quality were used to develop thought-provoking exercises. Laboratory experiments were carried out to write student activities involving flow simulation, ion chromatography, spectrophotometric analysis, and filtration procedure. Preparation of stock solutions and calibration curves were incorporated into the learning activities. Also, facilities like municipal water works and city water treatment plants were visited to write field trip activities for students.

An on-campus experimental site (site # 7) was upgraded with real-time data acquisition and transmission system to provide experiential learning and training opportunities for students enrolled in this course (Fig. 2). The site has 2 metal cased deep wells (70 ft and 90 ft deep) and 8 shallow PVC wells. The deep wells tap into the carbonate bedrock and the shallow wells are installed at different depths (12 to 20 ft) within the alluvial deposits above the pre-Illinoian till. The large pieces of equipment used in this site include the following: 1) Reel E-Z Portable Well Purging Pump System, 2) YSI 6600 V2 extended deployment probe to measure water quality parameters such as pH, TDS, Conductivity, DO, Temperature, Turbidity, and Chlorophyll, 3) OTT RLS Radar to measure water level fluctuations in the creek; 4) Hydrolab MS5 Mini-Sonde to continuously measure pH, TDS, Conductivity, DO, Temperature, Turbidity, and water depth in the deep groundwater wells, and 5) DL 3000 Data logger to receive data from the above sensors in real time and upload them to a remote website for public viewing.

The site was further prepared to have on-site teaching facilities. Bleachers were installed to accommodate a class size of 25 students. Recently, a 12 ft x 20 ft temporary shed has been installed at the site to store equipment as well as hold small-group sessions on chemical measurements. In addition, a whole set of field instruments such as soil moisture probes, flow meters, groundwater level indicators, and suction lysimeters were added to make this site an effective outdoor resource to conduct water-related projects.

Student learning outcomes and assessment

Table 2 shows the goals of the course, what the students are expected to learn from the course, the gen-

	Goals of the course	Student learning outcomes	Teaching approach	Assessment methods
1	Understand and apply basic hydrologic concepts	Understand movement, quality and distribution of water; understand interactions of hydrosphere, lithosphere, atmosphere and biosphere through the hydrologic cycle	Define hydrologic systems through lectures; use flow chart to show the system dynamics and component interactions	Test questions, weekly report, Students' evaluation of course
2	Identify environmental problems	Learn how to compile data to derive environmental scenarios, identify pollution hotspots and develop independent, new ways of thinking	Use case studies in lectures, visit contaminated sites, encourage visual observation to correct misconceptions	Test questions, Term paper, oral presentation, students' evaluation of course, group discussions
3	Experiential learning	Learn how to use field and lab equipment to gather hydrologic data, and gain problem solving skills	Arrange field works to involve them in hands-on activities; present models of problem solving procedures	Test questions, hands-on assignment, instructor's observation, students' evaluation of course, group discussions
4	Develop multiple skills	Learn efficient use of instruments, machine calibration, understand analytical error margins and technical interpretations	Arrange extended lab sessions on running hydrologic equipment, assign short analytical projects	Lab examination, lab report, instructor's observation

Table 2. Student learning outcomes and assessment design

eral teaching approaches, and the general procedures for learning assessment.

Goals of the course

The new course has four primary areas of learning as follows:

(1) Understand and apply basic hydrologic concepts

This focus area encompasses the content knowledge of how the hydrologic system works as our lives are impacted by different components of this system. Students come to classes with their preconceptions. If the new experiences don't fit their original concept, the instructor must reconsider what had been assumed and try to rebuild their internal structures (Texley & Wild, 1997). Some students expressed their misconceptions in this class that groundwater movement requires large openings in the subsurface or wide fractures in the rock. Another goal of the course is to show clear evidence that human activities are responsible for contaminating water resources. General topics include stream gauging, groundwater flow simulations, major ion chemistry, application of GIS, biopollutants and wastewater treatment, variable hydrologic systems, and standard sampling protocol.

For in-class assignments, the students are given written exercises on Darcy flow concepts. They are asked to calculate stream discharge, measure porosity/permeability, estimate available volume of groundwater, and describe contaminant transport scenarios. They construct flow nets and then answer questions on water quality issues. The students learn several concepts through these activities, such as groundwater is contained in pore spaces and fractures, aquifers are recharged by precipitation, human activities can contaminate groundwater, and wells can serve as point sources of pollution, etc. The lecture portion includes a 15 minute student-led discussion to wrap up the topic.

(2) Identification of environmental problems

Pollution of surface water in northeast Iowa is a matter of great local, regional and national concern. Nutrients in agricultural runoff from the state of Iowa result in adverse environmental consequences as far away as the Gulf of Mexico. In particular, phosphorus and nitrogen transported from agricultural lands enhance phytoplankton growth, leading to eutrophication of stream water. In addition, they contribute to the formation of a hypoxia zone commonly referred to as the "dead zone" in the Gulf of Mexico. Phosphorus and nitrate have severely damaged some of the lake ecosystems in Iowa by over-producing biomass in the water (Iqbal et al. 2006). In recent years, the problem of flooding has become an issue of high priority at the state and federal levels. The record setting floods of 1993, 1998, and 2008 have left Iowa citizens in crisis of land management, health issues, and property damage. The level of local interest makes this the best time to educate our students in water quality issues so they can contribute to solving these problems. Dry Run Creek in Cedar Falls is already showing deterioration of water quality in some parts of the watershed and the state DNR has put several segments of the watershed on the impairment list. Primary stressors have been identified as the high levels of bedded sediments, decline in macro and micro habitat availability, and high volume of storm water inputs (Palmer and Buyck 2011). All these factors cause serious hydrological alterations in the creek. Given the relatively narrow width of the creek, sudden increase in flow rates can cause channel and floodplain modifications. Given the natural alterations, the DRC watershed can be used as an effective teaching model in our water curriculum. The students can gain better insights into local hydrology and see how the impacted areas are connected to larger source components. In addition, they can study movement of agriculture-based nutrients across landforms as well as major vegetation boundaries.

(3) Experiential learning activities and resources

The primary goal of this component is to provide experiential learning through field projects. Eleven (11) experiential learning sites along the DRC watershed have been selected to develop activity based curriculum in hydrology (Fig. 1). These sites are either within walking distance or a short trip away from Latham Hall where the Department of Earth & Environmental Sciences is housed. Land use in the Dry Run Creek watershed can be broadly classified into agricultural, residential and commercial/industrial. Agricultural land makes up the largest part of the watershed. More than 50% of the land is characterized by row crops (corn and soybean). Residential and commercial/industrial areas comprise about 15% of the watershed. The rest of the land use are 4% forest, 10% ungrazed grassland and 4% for grazing livestock (IDNR 2002). Agricultural areas cover the upstream parts of the watershed. A gradual increase in urban to suburban areas can be observed further downstream. The small size of the stream makes it highly sensitive to episodic storm events. Apart from the avenues of surface runoff, a large number of subsurface drainage tiles generate high volume of storm water in the creek. The rural part of the watershed receives a considerable amount of fertilizers and pesticides during the farming season. The university has recently built a constructed wetland system for educational purposes, which is a part of the project. The DRC field sites are made available to the students to study variable hydrologic characteristics, including surface runoff, stream discharge, nutrient flux (phosphorus and nitrogen), sediment loss, and response to flood events.

As routine activities, the students in this course collect stream water and sediments at the 11 designated sites. The students visit these sites 2 to 3 times a week. They use field meters and test strips to analyze part of the water samples at the site. They bring the rest of the samples back to the laboratory for further chemical analysis by using ion chromatography and spectrometry. Once the analysis is complete, they use the data to conduct water quality index (WQI) calculations defined by the National Sanitation Foundation. The NSF-WQI assessment includes nine parameters tested for surface water, such as temperature change (from approximately one mile upgradient), dissolved oxygen (% saturation), *Escherichia coli* (colonies/100mL), pH, biochemical oxygen demand (BOD, mg/L), phosphate (mg/L), nitrates (mg/L), turbidity (NTU), and total dissolved solids (TDS, mg/L). In addition to these nine parameters, they test the water for total suspended sediments (TSS, mg/L), conductivity (µS/cm), chloride (mg/L), and sulfate (mg/L). Based on the WQI numbers, the students classify stream water as poor (0-25), fair (25-50), medium (50-70), good (70-90), or excellent (90-100). After finishing field work and sample analysis they compile the data to understand many factors that cause temporal and spatial variations in the area's water quality.

Fig 3. Students learning instrument calibration, sediment filtration, flow simulation, chemical analysis and stream cross section procedures.

Data collected through trial runs over several years have been used to design the new course. Nine 3-hour long lab/field activities and numerous short exercises were written to make sure the students have adequate experiential learning through the course (Fig. 3). The course includes two biology sessions to educate students on biological pollution that make adverse impacts on the quality of aquatic environment. Inclusion of life science content into physical science curriculum is a popular national trend. It allows curriculum developers to test the effectiveness of teaching materials for interdisciplinary courses.

(4) Skills development

The course was developed with 4 specific goals of skill development, namely instrumental operation, team-working, problem-solving and technical interpretation of data.

It is particularly important that students learn efficient use of instruments and machine calibration. Most of the sessions were designed in a way to engage students in handling field and lab equipment. To obtain new data, the students calibrated their instruments and ran machines according to given procedures. They also experimented with multiple calibration standards to fully understand analytical error margins. In recent years, the departmental hydrology lab has been equipped with state-of-the-art instruments to facilitate hydrology teaching and research opportunities to UNI students. The lab is capable of supporting analytical needs of geology, earth science, biology and environmental science students in areas of water quality. Current instruments include a DX-120 Ion Chromatography System with AS40 Auto-sampler and a workstation equipped with Chromatography Management System (CMS) software called Chromeleon. The lab also has a Shimadzu RF-5301PC Fluorescence Spectrometer for dye tracing of groundwater movement and an Armfield S11 groundwater flow simulation system. Besides, the lab has a set of supporting instruments such as spectrophotometer, bench top centrifuge, bench top ion sensor probe, stream surface velocity radar, incubator, filtration manifolds, computers, and pH/TDS/DO meters for student and faculty research. The lab was heavily used during the experimental offering of the new course, which proved highly beneficial to students. In the lab, ionic analysis of water, preparation of stock solution and chemical standards, machine calibration, and spectrometric analysis are integral parts of the course. Lab exercises include solution preparation with variable molar concentrations in water and their successive dilutions. The students are required to repeat sample analysis to gain accuracy and measurement skills. They perform biochemical oxygen demand (BOD) and *E. coli* analysis to understand microbial sensitivity. In addition, they use the lab filtration manifold to determine total suspended sediments in stream water samples.

For bio-pollutant indicators, one important aspect is primary production, which involves the depth of light penetration (using secchi disk), measurement of chlorophyll a (extracted from filtered samples), and determination of biomass (calculated from chlorophyll a or determined by ash-free dry weight). Future exercises include composition of phytoplankton (using microscope or flow cytometer), which is useful for determining relative abundance of cyanobacteria. In addition, they will conduct toxicity tests on stream water (by using Daphnia or brine shrimp). While developing lab and field exercises, efforts were coordinated with faculty in Biology Department to incorporate these activities and estimate the lab and field resources needed for the course. The above activities are expected to improve students' understanding of hydrologic sciences from a combined physical science and life science perspective. The approach gives them an opportunity to study the complex dynamics of natural environments in an interdisciplinary setting.

The above activities are mostly done through teamwork. First of all, the class is divided into permanent teams consisting of 2 to 3 students, which creates a collaborative learning environment. It gives each team member a sense of not being alone in their weekly activities. It raises their confidence as they ask one another questions and articulate their ideas. In addition, there are several sessions where each team interacts with other teams on the day's activities. As an example, on the day of stream cross sections, each team first gets into the channel and measure cross sectional areas of flow and velocity to calculate discharge (Fig. 3). Once the teams are done with their discharge calculations, they engage in discussions by comparing their data. The discussion is led by the instructor where students brainstorm ideas on the multiple hydrological factors that result in the stream discharge to be spatially variable. This practice promotes effective communications on the technical aspect of hydrologic science. Once the students grasp enough knowledge to scientifically explain the process they have just observed, their skills for problem solving and data interpretations drastically improve. In the laboratory, the students are routinely engaged in solving problems based on hypothetical watershed scenarios. These problems include hydrological mapping, common equations and fundamental arithmetic.

The students find the above skills of high value as they move on to the job market. Most hydrology related jobs at the city and state levels in the Midwest require watershed assessment skills. Many of our graduates who are currently working in the discipline found these skills to their advantage and suggested that we expand in these areas. In recent years, our hydrology students took positions as water quality analyst, watershed coordinator, environmental scientist, environmental lab technician, park ranger, natural resources manager, groundwater specialist, well operator, nutrient management specialist, regulatory hydrologist, water resources hydrologist, hydrology research scientist, restoration ecologist etc.

Results and Discussion

Assessment of learning

Student learning in this course was assessed in multiple ways. An indirect assessment of student learning was provided by student responses to a standardized survey

Not at all (%)	A little (%)	Moderately (%)	A lot (%)	Exceptionally (%)	NA (%)
Question 1. The course improved my ability to think independently					
0.0	0.0	18.18	36.36	36.36	9.09
Question 2. The course improved my problem-solving abilities					
9.09	0.0	18.18	27.27	45.45	--
Question 3. The course improved my understanding of concepts and principles in the topic area					
0.0	0.0	0.0	27.27	72.73	--
Question 4. The way the instructor organized the course helped my learning					
0.0	0.0	9.09	45.45	45.45	--
Question 5. Course work (e.g., assignments, presentations, projects, papers) contributed to the learning process in this class					
0.0	0.0	9.09	27.27	63.64	0.0
Question 6. Supplementary materials (other than the textbook) contributed to my understanding of the content of the course					
0.0	0.0	36.36	27.27	27.27	9.09
Question 7. The lecture information contributed to my learning					
0.0	0.0	0.0	45.45	45.45	9.09
Not at all (%)	**Rarely (%)**	**Sometimes (%)**	**Often (%)**	**Consistently (%)**	
Question 8. The course provided new ways to think about the issues dealt with in this course					
0.0	0.0	9.09	27.27	63.64	
Question 9. The course enabled me to apply the information/skills I learned					
0.0	0.0	9.09	18.18	72.73	
Far too little (%)	**Too little (%)**	**About right (%)**	**Too much (%)**	**Far too much (%)**	**NA (%)**
Question 10. The amount of work required for the credit earned was:					
0.0	0.0	100.0	0.0	0.0	0.0

Table 3. The course assessment in fall 2016. The assessment was administered in the Department by using the instrument developed by the university curriculum committee.

containing both Likert scaled and open ended questions during the last third of the semester. The survey was designed and administered by the university, and covered various aspects of teaching and learning. Eleven of the 12 students enrolled in the course (92%) completed the survey. For purposes of this project, we examined student responses to questions in five specific areas based on the course goals and objectives: understanding concepts, new ways of thinking, ability to think independently, improved problem solving ability, and course organization (Table 3).

Overall, all (11) of the students who completed the assessment instrument said that the course improved their understanding of concepts in the discipline (Table 3). This is likely due, at least in part, to the experiential learning style of the course as there were only short introductory lectures on the hydrologic concepts and principles relevant to the week's topic areas. An overall intent of the course was to encourage students to re-think the intrinsic value of water in the context of global environmental change. For example, as part of the class activities, students measured stream discharge at urban and rural sites and observed that the volume of overland flow was much higher at urban sites, and concluded that this was due to the presence of large areas of paved surfaces in the urban environment. Discussions followed on ways to minimize loss of rainwater by overland flow and to improve infiltration and capture systems. Overall, we wanted students to understand how rainwater as a commodity changed from a nuisance to a necessity based on their own observations and analysis.

All 11 students also agreed that the course improved their ability to think independently (Table 3). Each week, students submitted independent reports, which included data analysis, observation and interpretation. For example, one week was devoted to a comparison of water quality analyses among prairies, wetlands and streams. As part of their reports, students were prompted to answer the following question: *What have you learned through today's activities? Critically think about today's activities and explain how these activities helped you to understand the logical steps going from field research to implementation of state water policies.* Their reports, and survey responses, clearly indicate that the course had a positive impact on students' ability to think for themselves.

Ten of the eleven students (91%) agreed that the course improved their problem-solving abilities (Table 3). The course directly involved students in solving problems daily in the lab, such as calculating molar concentrations, preparing calibration standards, and calculating water quality indices. Based on field sampling and *in situ* analyses, students were also involved in higher order problem solving, such as predicting spatial and temporal variations in hydrologic characteristics within the watershed.

Another aspect of the assessment was course organization. Most students responded that the current organization of the course helped their learning. The students also responded very positively on course assignments, projects, and papers. The percent distribution of responses are provided in Table 3.

Students were also able to provide open ended feedback as part of the survey. These comments were quite positive, as indicated in this example: *"I enjoyed the trips out to the field. It really got everyone to engage and help understand a bigger picture when it comes to water quality. I hope this class continues to be offered. It truly gave me ideas for potential research projects and all work after school."* Comments such as this are especially encouraging and useful to the instructors because they indicate that the course activities are translating into bigger picture ideas, and that the course is triggering project ideas for students to pursue beyond their undergraduate degree. In addition, students offered some valuable suggestions for improving their learning in the course. One suggested that instructors should consider rotating members among multiple groups instead of having fixed groups throughout the semester so that they could learn something from other students in the course. Additionally, the students suggested that the 4-hr field trips should be converted to day-long trips, potentially on Saturdays, to expand on the concept of spatial variations. The instructors are considering adopting these ideas in the future.

Direct assessment of student learning focused on course-embedded work such as weekly assignments, field discussions, tests and term projects. The specific areas of focus in the assessment process were students' conceptual knowledge, problem solving skills, and data synthesis. The development of conceptual knowledge throughout the course was assessed by using the weekly assignments as artifacts. After each week's activities, the students were required to submit independent reports. Students' knowledge was rated weekly in one of three categories: exceeding expectations, meeting expectations, or not meeting expectations. During the course of the semester, most students showed significant improvements in their conceptual knowledge. By the end of the semester, most students were able to present their models by way of schematic diagrams or concept drawings.

Students' proficiency in problem solving skills was assessed by using practice problems and test questions as artifacts. Questions included measurement of water quality indicators, preparation of calibration standards from stock solutions, making molar solutions from given salts, dilution of stock solutions, plotting data on trilinear and shape diagrams, and measurement of discharge in a groundwater flow simulation tank. Over 80% of students either met or exceeded expectations on these questions. During class, individual students were also asked to describe how they had solved practice problems, sometimes coming up to the board and solving the problems in front of the class. From the instructors' standpoint, this was a very useful technique as it allowed us to assess the students' confidence as they critically analyzed problems and offered some reasonable solutions. It sometimes also triggered discussion and debates in the classroom involving students who approached the problem differently or came to a different result, ending with a solution that was acceptable and understandable to all.

Students' ability to synthesize data was assessed by field discussions, involving student-student and student-instructor dialogues and debates. As students engaged in hands-on activities, they were prompted to consider the purpose of the activities and what conclusions could be drawn from the data they generated. Over the course of the semester, students' responses to these prompts improved considerably, and included reflections on their knowledge of hydrologic systems from the readings and lecture material. As they understood the system better, they were able to define their conceptual models more accurately. These are clear indications that the new course considerably improved students' learning in hydrology.

A long-term goal of the project is to track these students after graduation and further assess their successes as they obtain employment. For future growth, it would be beneficial to the hydrology program to record how the current course added value to their critical thinking skills and professional success.

Limitations of assessment

One of the important aspects of teaching and learning in a higher education institution curriculum is evaluation of student learning. Careful evaluations of content and methods by both students and instructors can help the institution improve learning outcomes. Although the methods of evaluation used in this study are long established, they are not without limitations. Some of the limitations in evaluating this course are discussed below.

1. Assessment questions were not specifically written for this course, instead UNI's standard instrument was used. Consequently, some important data may have been missed. The instructors, however, strongly believe that using university's standard instrument helped in avoiding evaluation bias. The major areas of evaluation for the course were already included in the UNI's standard questionnaire.

2. Average student responses were used to assess success of the course. Individual perception data could not be collected due to student confidentiality issues. However, instructors' personal observations were useful in avoiding probable bias in this regard.

3. The evaluation reflects student performance and not necessarily how well the class is taught. This will remain as an issue until the class is taught several times. Additional years of data will allow instructors to design the course with teaching methods that are most effective.

4. Evaluations are done at the end of the semester. There is no opportunity to modify the curriculum and experiment with the same group of students. The next class population is different.

5. Individual students come with their own preconceptions, knowledge and skills. It is the same class, but their learning starts at different levels. Course evaluations are impacted by these differences in preparation, ability and learning style. Therefore, in certain situations, an overall improvement in learning could be associated with lower average numbers in student assessments.

Some of the above limitations were largely overcome by combining direct and indirect assessment.

Conclusion

The new course is now included in the University of Northern Iowa's academic catalog with the title of Field and Laboratory Methods in Hydrology. This is a required course for those who pursue the hydrology track under the Environmental Science, B.A. major. This is also a suitable elective course for all other students majoring in this or other departments in the sciences. Because the course requires lab seating arrangements and adequate supply of field and lab equipment, the enrollment is capped at 12. During the fall 2016 offering, the class filled very quickly with 10 earth/environmental science and 2 biology majors. The enrolled students were 5 seniors, 5 juniors, and 2 sophomores. Although this is an upper division course, the sophomores were allowed by instructor's consent after determining that they were adequately prepared to take the class and were close to being classified as juniors. All students except the sophomores were within 3 semesters of their graduation. They were mostly done with their liberal arts core requirements including math and physical sciences. The primary goal of this course is to provide hands-on skills to those students who had completed their content courses for the basic sciences. Accordingly, the 2016 student mix was very much in line with target audience. The class consisted of 8 male and 4 female students. The goal for the upcoming years is to expand the lab resources to accommodate about 18 students. Many students in this class also take the other two water-related courses currently offered in the Department, namely *Hydrogeology* and *Environmental Hydrology.*

The new course is designed in line with the university's STEM learning initiatives. The hands-on activities are expected to integrate STEM into Department's water science curriculum. It will allow students to gain important analytical skills through their access to modern laboratory and field equipment. Because the new course is focused on methods and analytical skills, students completing the course will be in a much competitive position as they get into the job market or graduate schools. In addition, the course will help to setup the right mindset for undergraduate students to more fully understand emerging water quality issues. Through their projects in particular, they will critically think about natural processes that impact our water environment. They will better understand how field and laboratory research data are used to implement water policies. Based on assessments, the students view this new course as one that has improved their learning in water sciences. Also, it has considerably expanded the existing hydrology curriculum at UNI.

Suggested ideas for other investigators

Developing the course was a useful learning experience for the instructors. Some of our methods proved quite beneficial whereas in others we missed an opportunity. We hereby present some ideas for interested instructors at other institutions:

(1) Watershed approach: Identify a single watershed and design activities to understand the interrelationships among its components. We have had much success by taking this approach rather than simply arranging isolated field activities.

(2) Student teams: Rotate students among different teams instead of fixed groups through the semester. This suggestion came from the students whereas we took the fixed group approach. We now believe that group discussions and debates would have been much more enlightening if the students were rotating among groups.

(3) Outdoor resource: Develop an outdoor instructional site for the course. Students frequently have difficulty connecting between their classroom learning and the real world, which is a core theme of STEM education. Our on-

campus field hydrology site was very effectively used to make that connection.

(4) Course evaluations: Conduct a mid-semester evaluation of the course and modify activities where appropriate. We assessed the course at the end of the semester only. A mid-semester evaluation can help identify the types of activities or examples that would be most effective in teaching the student population enrolled in a given year.

(5) Weekly reports: Ask students to submit a full report for the week including a conceptual model of what is learned that week. We have had much success with this measure. Follow-up discussions on these models made the course even more interactive. The students showed better understanding of the hydrologic environment in general.

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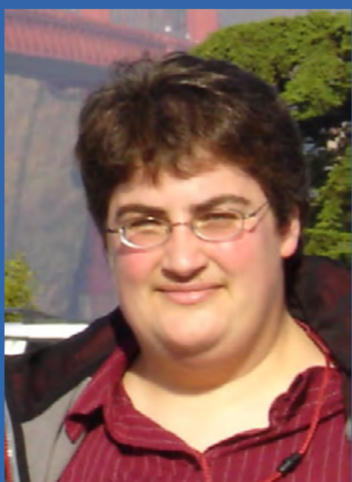

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