Board 99 : Collaboratively Developing an Introductory Infrastructure Systems Curriculum: The One Water Module

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Introduction

The 21st century water challenges posed by decaying infrastructure, climate change, and urbanization cannot be solved by technology and engineering alone. In this context, successful engineering decisions concerning the water infrastructure must be informed by an understanding of environmental, social, and political impacts and constraints. The future environmental engineers tasked with tackling these 21st century challenges are ill-served by a 20th century education that presents technical systems in isolation and does not address the design and operation of infrastructure as a system. Rather, future environmental engineers are better served by an education that emphasizes the important interplay between technical, economic, environmental, political, and social aspects.

Consequently, the objectives of this paper are to:

- Describe the lessons in the One Water module of the Center for Infrastructure Transformation and Education's (CIT-E, pronounced "city") model introductory infrastructure course
- Explain the rationale for developing such a course, and relate it to challenges facing water and urbanization in the 21st century
- Describe the collaborative development process to creating the One Water module
- Inspire readers to access and adopt lessons in the One Water module
- Describe the expected benefits of One Water Module to the environmental engineering curriculum

Background

The Center for Infrastructure Transformation and Education (CIT-E) was formed to address the identified gap in environmental engineering and civil engineering education. CIT-E is a community of practice comprised of faculty members from around the US who share a passion for infrastructure education. CIT-E intends to transform the way that civil and environmental engineering topics are taught. One major initiative for this community of practice is to create a "model" introductory infrastructure course to be delivered to first- and second-year civil and environmental engineering students. The intent of the model introductory course is to provide instructors with the tools needed to help change the way students view and approach infrastructure topics.

The CIT-E model course contains complete lesson materials for an entire one-semester course. The course introduces first or second year civil and environmental engineering students to infrastructure and helps students see infrastructure as the system that it truly is. Consequently, it provides students with the knowledge, skills, and attitudes needed to effectively design, build, manage, and maintain our public works by considering social, economic, environmental, and political impacts in addition to the technical considerations.

The course developers (that is, the members of the CIT-E community of practice) recognize that many first- or second-year students have very little knowledge of infrastructure and have designed the course with this in mind. Complex mathematics is not needed in the course as the focus is to provide students with a holistic view of infrastructure. In addition, real-world examples are integrated into the lessons that emphasize the concepts of interconnectivity of different systems. The course learning outcomes were developed collaboratively by members of the CIT-E community of practice in 2015. The process is described by Parker et al. [1]. A course outline, specifying 43 lessons that will support the outcomes, was also developed collaboratively by the community of practice (Table 1). The CIT-E community of practice decided to categorize infrastructure into three categories: One Water, Transportation, and Energy, and each of these are supported with a single "module", as shown in Table 1. A Fundamentals module was created to introduce students to the basic concepts, and the Capstone module is intended to tie the entire course together with case studies. Note that in Table 1, the lessons in the One Water module, which is the focus of this paper, are highlighted.

Table 1: Overview of CIT-E Introductory Infrastructure Course

Fundamentals Module	1	What is infrastructure and why do we care?		**Transportation Module**	22	Transportation I
	2	Basic infrastructure functions			23	Introduction to rail, water, roads, air, and pipelines
	3	Systems/network analysis			24	Bridges - life cycle
	4	Triple Bottom Line/Sustainability			25	Roadways
	5	Social impacts of infrastructure			26	Complete streets
	6	Teamwork			27	Parking
	7	Ethics I			28	Mass transit
	8	Ethics II			29	Route analysis and layout
	9	Traits of effective written and oral communication			30	Hoover Dam bypass
	10	Financing infrastructure				
	11	Safety/licensure		**Energy Module**	31	Society and energy
	12	Infrastructure Planning			32	Electricity use
	13	Resilience and risk			33	Generation
					34	Transmission
One Water Module	14	Introduction to One Water			35	Distribution
	15	Drinking water supply and treatment			36	Renewable energy
	16	Wastewater sources and treatment			37	Air pollution
	17	Stormwater infrastructure			38	Energy/food and energy/transportation nexi
	18	Green infrastructure			39	Water/energy nexus
	19	Water security				
	20	Water re-use and conservation		**Capston**	40	Cross Harbor Freight Program Case Study
	21	Global water topics			41	Infrastructure user fee or other
					42	Dams

					43	Hazardville case study

Each lesson contains all the materials necessary for delivery: background readings for the instructor; pre-class materials for the student, including original screen casts; complete set of instructor notes including supporting PowerPoints and detailed active learning exercises; homework assignments, and solutions. The active-learning strategies used in the lessons encourage teamwork, which is essential in practice.

The lessons in the One Water module, as well as the individual learning outcomes in each lesson, were defined by the CIT-E community of practice. This process was carried out by 13 faculty and staff members at 12 universities. In the summer of 2017, CIT-E members met at the National Academies of Engineering in Washington D.C. to further develop the lessons in the One Water, Transportation, and Energy modules. 7 workshop participants worked on the One Water module lessons in a very collaborative manner following the steps outlined below.

- Participants worked together to refine lesson outcomes for all One Water lessons
- Participants completed an "Alignment Grid" in which they aligned pre-class activities, in-class activities, post-class activities, and assessment methods with the learning outcomes. This is based on the "backwards" lesson design process popularized by L. Dee Fink [2].
- Completing the Alignment Grid was an iterative process, with participants working independently for periods of time and then reconvening as a group to refine their ideas.
- Following the workshops, participants continued to work on the modules and submit them to internal (that is, within the One Water module team) peer review. In Spring of 2018, these lessons will be submitted to external peer review and will be published on the CIT-E website (www.cit-e.org) in the Summer of 2018.

In the next sections, a description of the One Water lessons (those that are ready for external peer review) and their impact on the environmental engineering curriculum are provided.

14. Introduction to One Water

This lesson is intended to introduce students to the concept of "One Water" and set them up for the remaining lessons in the One Water module. As such, the lesson outcomes are:

1. Describe the water cycle and explain the importance of managing wastewater, stormwater, and water supply as "One Water"
2. Compare demands for the major water use categories
3. Calculate water footprint and explain how it is affected by embedded water

Like all lessons in the CIT-E model introductory infrastructure course, outcomes are achieved with a variety of pre-class activities, in-class activities, and post-class activities. Pre-class activities are designed to present facts and concepts, enabling class time to focus on higher-order processes such as analysis and evaluation, leaning on the best practices found in a "flipped" classroom. Pre-class activities for Lesson 14 require students to calculate their water footprint with an online tool, answer some questions about this tool, and watch a brief video from the Kahn Academy on the water cycle. An answer key for the water footprint portion of the pre-class activities is provided for instructors.

In class, the students build on their pre-class activities. Class begins with a brief video on the "water crisis", and then a guided discussion ensues to lead students to a more nuanced understanding of the water problems we are facing. The pre-class video on the water cycle is quickly reviewed, and then students are presented with a diagram that shows the urban water cycle and uses this to open up a key concept of "one water" – i.e. that groundwater, fresh surface water, saltwater, wastewater, recycled water, and stormwater, are all possible sources of potable water. Barriers to implementing this holistic view are discussed, and then the class wraps up by revisiting the concept of water footprint.

Not only does this lesson introduce students to the remainder of the One Water module, but it will hopefully help them be more educated "consumers" of materials in their ensuing classes, such as their introductory environmental engineering course and their applied design courses on stormwater, drinking water, wastewater, etc.

15 Drinking Water Supply and Treatment

The learning outcomes for this lesson are:

1. List the main sources of drinking water
2. Describe the infrastructure that supports drinking water supply, treatment and distribution
3. Explain the basic treatment processes for municipal water
4. Explain the relationship between drinking water standards and risk

The pre-class activity for this lesson require students to research the source of drinking water for their hometown. Students compare potential differences in drinking water sources and examine if sources could potentially impact water treatment. Students also watch a video about drinking water treatment plant where basic infrastructure components and treatment processes are introduced.

The in-class activities include a discussion of the responses to pre-class activities and generation of a list drinking water sources. A discussion on how the source water type impacts drinking water treatment is supplemented with a discussion of the treatment processes used at a local water treatment facility. In addition, in-class activities include a video presentation to describe infrastructure that supports drinking water supply, treatment, and distribution. This is followed by a guided discussion on the video and the relationship between water standards and risks.

This lesson is intended to help students better understand the basic concepts involved with drinking water treatment and distribution. This lesson will provide fundamental knowledge on drinking water sources along with information on the basic infrastructure components that support drinking water supply, treatment, and distribution.

16 Wastewater Sources and Treatment

This lesson introduces the students to wastewater, strategies for wastewater collection, and the processes involved in wastewater treatment through the following learning outcomes:

1. List the sources of wastewater and the common constituents found therein
2. Describe the infrastructure that supports wastewater collection and treatment
3. List and explain the basic treatment processes for wastewater
4. Explain how wastewater standards differ from drinking water treatment standards

A pre-class screencast is utilized to introduce different types of wastewater and the students are assigned a preliminary task of identifying the constituents found in wastewaters based on their source. The students are also introduced to the different infrastructure components that are used for wastewater collection such as the types of sewers (gravity, low-pressure and vacuum) and sewer systems (combined, separate). In addition, the students are also introduced to the processes involved in conventional wastewater treatment processes (primary, secondary & tertiary). The lesson also describes the standards for wastewater and drinking water treatment. The pre-class screencast concludes with the importance of energy in collection and treatment, and the costs associated with the increasing requirement for energy.

The in-class lesson begins with a discussion about the constituents in wastewaters based on their source. The students will use the information from the preliminary task and compare with the instructor's solution. In addition, the in-class lesson is used to enlighten the students about sustainable and low-cost alternatives for wastewater treatment, their advantages and disadvantages. The in-class activity focuses on the treatment facilities required for three different types of communities.

This lesson is used to introduce basic concepts involved in wastewater collection and treatment techniques. The lesson provides a fundamental introduction to an environmental engineering course where the students learn further information about water treatment and wastewater treatment and broaden their scope in designing these facilities.

18 Green Infrastructure

The lesson outcomes for the Green Infrastructure lesson are:

1. Explain the motivation for green infrastructure
2. Suggest candidate green infrastructure to integrate into a new or existing site
3. Design a green infrastructure plan using EPA National Stormwater Calculator
4. Reflect on how green infrastructure can affect quality of life

Pre-class activities require students to watch a screencast developed by the lesson authors, to watch a background video on the benefits of green infrastructure, and to familiarize themselves with the National Stormwater Calculator. This software program, developed by the US EPA, has the following purpose [3]:

> The National Stormwater Calculator is a simple to use tool for computing small site hydrology for any location within the US. It estimates the amount of stormwater runoff generated from a site under different development and control scenarios over a long term period of historical rainfall. The analysis takes into account local soil conditions, slope, land cover and meteorology. Different types of low impact development (LID) practices (also known as green infrastructure) can be employed to help capture and retain rainfall on-site. Future climate change scenarios taken from internationally recognized climate change projections can also be considered.

The in-class activities lead students to a better understanding of green infrastructure, and then helps them understand how to apply the National Stormwater Calculator to a local site. Students start on this project in class and complete it for homework.

19 Water Security

This lesson aims to engage students in the importance of water supply, and thus the importance of security measures through the following learning outcomes:

1. List the threats to drinking water supply, treatment and distribution systems
2. Describe the ways in which drinking water systems are vulnerable
3. Apply resilience concepts to a water system

A pre-class screencast identifies critical assets, categorize threats (malicious acts, natural disasters, unintentional acts, dependency/proximity hazards, or aging infrastructure), and identify vulnerabilities with respect to water quantity and water quality. Additionally, a preliminary risk assessment procedure is introduced which informs prioritization. Seven brief case studies are provided as optional screencasts to demonstrate a variety of recent and historical water crises with respect to quantity and quality.

The in-class lesson provides additional examples of water system threats and prompts student discussion of the potential consequences of these threats. Lack of redundancy (single point of failure) examples are provided. Several water supply scenarios are presented in which student workgroups are tasked with identifying potential risks and proposing countermeasures to improve resilience. Homework problems include an analysis of the New York City water supply reservoir system, and further evaluation of one on the in-class examples.

This lesson builds upon a basic understanding of water supply, treatment and distribution infrastructure helping students to comprehend overall system interdependence. The lesson provides foundational skills for water security and resilience in upper-level environmental engineering courses and highlights an emerging concern among water resource managers. The lesson is based on the J-100 Standard of the American Water Works Association.

20 Water Re-Use and Conservation

This lesson provides an introduction to water conservation and re-use including the motivation, strategies, and barriers, through the following learning outcomes:

1. Explain the motivation for re-use and conservation
2. Describe how water can be re-used and conserved in municipal systems
3. Discuss the barriers to the implementation of water re-use programs
4. Describe the treatment requirements for re-used water

This lesson is designed to facilitate an active learning or flipped classroom approach. A pre-class screencast presents growing demand and supply constraints as the motivation for water re-use and conservation. The screencast introduces conservation strategies such as pricing, educational campaigns and building codes. Students are also introduced to the categories of wastewater (e.g. graywater) and the levels of water quality required for different re-use applications (e.g. potable). A brief reading assignment provides greater depth on the water quality for re-use.

During class, students are asked to examine water use on their campus and to identify water quality needed for each type of use and the quality of the wastewater generated by each use. They are then asked to identify opportunities for conservation and re-use. Then students are asked to examine their personal water use behavior and willingness to use reclaimed wastewater in various applications to spark a discussion on barriers to re-use and conservation. The lesson wraps up with a case study on the city of San Diego to present the opportunities and challenges of scaling water reuse up to the city scale. For homework, students are first asked to evaluate their own water consumption using a water use calculator and to assess the impact of replacing individual fixtures in their home or residence hall. Then students are asked to look up their local water utility and its implementation (or not) of water re-use and conservation before answering a set of questions about the opportunities for and barriers to water re-use and conservation locally.

The lesson provides motivation for courses later in the environmental engineering curriculum including courses on water and wastewater treatment and hydraulics and highlights the role of environmental engineers in providing sustainable and reliable water supplies.

21 Global Water Topics

This lesson introduces the students to global water. It has a pre-class activity, an in-class PowerPoint presentation, an in-class facilitated group discussion, and three homework problems to achieve four learning outcomes:

1. Identify the prevalence and importance of present and future water scarcity and flooding
2. Describe the water food nexus
3. List potential sources of conflict over water
4. Describe the need for, and progress toward reaching UN Sustainable Development Goals for water and sanitation

To achieve outcomes 1 and 3, students work with the Aqueduct online tool and they also review case studies published on Aquapedia. Aqueduct online tool (http://www.wri.org/our-work/project/aqueduct/) is Water Resources Institute’s web based interactive platform for mapping water risks at the global scale. The platform has numerous water risk metrics. However, to keep it simple, the lesson focuses on analyzing the following five risk topics

- Baseline water stress
- Overall water risk
- Flood occurrence
- Drought severity
- Access to water

In the pre-class activity, each student uses the tool to bring to class a global map that shows the level of risk for one of the above topics. During class, students use these maps to analyze three countries: Bangladesh, Palestine, and the United States. They summarize their findings in a table. They then take it one step further and use case studies published in Aquapedia to analyze the conflicts in these countries that resulted from these risks.

To achieve outcome 2, students are presented water footprint data in class using PowerPoint slides. The slides show the water footprint for different food items and dives deeper into a case study of almonds where students can see geospatially that almonds are grown in the most drought stricken areas in California. The students follow up on these concepts in a homework problem where they use the water footprint product summaries to determine which food items they can swap in their own diets.

Outcome 4 is introduced in class using PowerPoint slides. Students are shown how the Millennium Development Goals have been updated in the more recently developed UN Sustainable Development Goals. Students are also shown the progress in these goals. A homework problem requires students to revisit these concepts and report it back in writing.

One innovative aspect of the module is that it exposes students to geospatial analysis of data and further interpretation of this data using case studies. The module also shows students that different types of water data are now incorporated in web based tools. Both the Aquapedia and the Water Footprint tools are very user friendly that make it easy for students to learn.

Another innovative aspect of the module is to scaffold activities to get deeper into the concepts. For example, students first utilize Aquapedia to learn about water risk. They discuss these topics in class with their peers. They summarize the information in a table. They then relate these quantitative data to case studies. This way, the data has some context on why these conflicts occur.

Conclusions

Environmental engineering should be modified to reflect the growing complexity of infrastructure. The One Water module of the CIT-E model introductory infrastructure course provides fundamental knowledge of not only components and systems, but also challenges, constraints and potential solutions. With this foundation, first and second year students are better prepared for upper-level courses and ultimately their careers. The learning outcomes of each lesson from the One Water module are a vital step in establishing the framework for the necessity of sustainable infrastructure that supports community needs. This is established through pre and in-class activities, and discussions involving real-world case-studies.

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