

# Training Water Resources Systems Engineers to Communicate: Acting on Observations from On-the-Job Practitioners

Meghna Babbar-Sebens, Ph.D., A.M.ASCE<sup>1</sup>; Elizabeth Root, Ph.D.<sup>2</sup>;  
David E. Rosenberg, Ph.D., A.M.ASCE<sup>3</sup>; David Watkins, Ph.D., P.E., M.ASCE<sup>4</sup>;  
Ali Mirchi, Ph.D., A.M.ASCE<sup>5</sup>; Marcio Giacomoni, Ph.D., A.M.ASCE<sup>6</sup>;  
and Kaveh Madani, Ph.D., A.M.ASCE<sup>7</sup>

**Abstract:** Engineers face the ongoing challenge to effectively communicate for diverse purposes and audiences across multiple settings. The authors interviewed 10 practicing water resources systems engineers to collect their lived experiences of the use of water resources systems analysis in their workplaces. Thematic analysis was used to identify three key communications hurdles practitioners face: stakeholder influence over the communication process, engineers as central to communication and decision making, and communication as an opportunity to educate stakeholders and engineers. Practitioners recommended classroom activities to overcome these hurdles and better integrate communications training into curricula. Recommendations include (1) expanding the use of case studies, (2) adding opportunities for role plays and team activities, (3) providing students with more practice on how to hold effective discussions, facilitate teamwork, and resolve conflicts, and (4) providing students with the broader contexts for class problems, including how political/institutional constraints, bureaucracies, and social issues may constrain communication and technical solutions. This study shares 22 example activities as online educational resources in a free, open, searchable repository and shows how activities can serve as a bottom-up approach to integrate communications training into the engineering curriculum. DOI: [10.1061/\(ASCE\)EI.1943-5541.0000427](https://doi.org/10.1061/(ASCE)EI.1943-5541.0000427). © 2019 American Society of Civil Engineers.

**Author keywords:** Water resources systems engineering; Civil engineering; Engineering communication; Thematic analysis.

## Introduction

A crucial role for engineering faculty working in colleges and universities is to prepare the next generation of engineering students

<sup>1</sup>Associate Professor, School of Civil and Construction Engineering, Oregon State Univ., Owen 211, Campus Way, Corvallis, OR 97331. Email: [meghna@oregonstate.edu](mailto:meghna@oregonstate.edu)

<sup>2</sup>Associate Professor, Speech Communication, School of Arts and Communication, Oregon State Univ., 104 Shepard Hall, Corvallis, OR 97331. Email: [elizabeth.root@oregonstate.edu](mailto:elizabeth.root@oregonstate.edu)

<sup>3</sup>Associate Professor, Dept. of Civil and Environmental Engineering and Utah Water Research Laboratory, Utah State Univ., 4110 Old Main Hill, Logan, UT 84322-4110 (corresponding author). ORCID: <https://orcid.org/0000-0003-2163-2907>. Email: [david.rosenberg@usu.edu](mailto:david.rosenberg@usu.edu)

<sup>4</sup>Professor, Dept. of Civil and Environmental Engineering, Michigan Technological Univ., Houghton, MI 49931. ORCID: <https://orcid.org/0000-0002-0978-2710>. Email: [dwatkins@mtu.edu](mailto:dwatkins@mtu.edu)

<sup>5</sup>Assistant Professor, Dept. of Biosystems and Agricultural Engineering, Oklahoma State Univ., 111 Agricultural Hall, Stillwater, OK 74078. ORCID: <https://orcid.org/0000-0002-9649-2964>. Email: [amirchi@okstate.edu](mailto:amirchi@okstate.edu)

<sup>6</sup>Assistant Professor, Dept. of Civil and Environmental Engineering, Univ. of Texas at San Antonio, One UTSA Circle, San Antonio, TX 78249. Email: [marcio.giacomoni@utsa.edu](mailto:marcio.giacomoni@utsa.edu)

<sup>7</sup>Researcher, Dept. of Physical Geography, Stockholm Univ., Stockholm, Sweden; Visiting Professor, Centre for Environmental Policy, Imperial College London, London SW7 2AZ, UK. Email: [kaveh.madani@natgeo.su.se](mailto:kaveh.madani@natgeo.su.se)

Note. This manuscript was submitted on December 12, 2018; approved on June 26, 2019; published online on August 9, 2019. Discussion period open until January 9, 2020; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Professional Issues in Engineering Education and Practice*, © ASCE, ISSN 1052-3928.

to meet the demands of their future jobs. Training the next generation of engineers is a long-running responsibility (ASCE Task Committee on Water Resources Education and Training 1990; Walker and Bridgeman 1985), and today's educators must prepare their students to meet new and evolving job conditions that require engineers to work and communicate through more numerous channels in more varied environments and with broader clientele (ASCE 2018; Craig et al. 2008; Dannels et al. 2003; Darling and Dannels 2003; Ford and Riley 2003). In the water resources systems engineering field in which the authors practice and teach, engineers have to integrate knowledge from multiple disciplines, including physical sciences, engineering, and social sciences (Loucks and van Beek 2016).

Water resources systems engineers often use a spectrum of simulation and optimization modeling and visualization tools to identify solutions to societal water problems. Systems analysis offers a holistic framework to help solve water problems by describing and quantifying interrelationships between natural and engineered system components, formulating alternative solutions to problems, and establishing formal and reproducible methods to assess benefits of alternatives while considering uncertainties. These integrative engineering skills are also common to other engineering fields. It can be challenging to communicate methods, results, and the accuracy and reliability of analysis across multiple disciplines with technical and non-technical audiences.

There are several ways to ensure engineering students are trained in communication skills, such as via curriculum development, exposure to technical writing programs, federal and state accreditation programs, and by involving advisory boards composed of practitioners in university department planning. Additionally, classroom exercises like serious gaming (Hockaday et al. 2017;

Madani et al. 2017; Pierce and Madani 2013), modular components (Nazzal et al. 2015), role play (Kasprzyk 2017; Rosenberg 2016), or internship opportunities set up by individual faculty or programs [e.g., Huntly (2019)] can help students practice different communication strategies. Specific approaches tend to be implemented by individual faculty members, programs, or departments at a given institution.

Despite the wide recognition of the importance of communication in engineering, the field of water resources systems engineering has been challenged to train students in the communication skills needed for practice. For example, the ASCE Task Committee on Water Resources Education and Training (1990) surveyed 563 engineering professionals and identified the need to improve the oral and written communication skills of students at multiple levels. But the study did not identify the communication hurdles engineers experience on the job nor provide strategies to overcome these hurdles.

Since 2014, an ASCE Task Committee has worked across institutions and degree programs to identify, share, and promote excellent and innovative practices in water resources systems analysis education and communication (Rosenberg et al. 2017). The ASCE Task Committee gathered 40 syllabi for water resource systems analysis courses from 28 institutions in the United States and Asia, interviewed 10 professionals who practice water resources systems analysis to learn their lived, on-the-job experiences, and established a repository of innovative water resources systems analysis teaching and communication materials (Rosenberg 2019); hereafter called the Ecstatic repository. This paper analyzes responses from the 10 semistructured interviews, identifies commonly occurring communication hurdles practitioners faced in their jobs, presents classroom activities to improve communication training for students, and shows the impact of disseminating these communication training activities as open educational resources across the globe.

## Science and Engineering Communication and Challenges

The broader context for engineering communication is science communication, which focuses on ways to disseminate scientific research to the general public and decision makers (Fischhoff 2013). According to Fischhoff (2013, p. 14033), “effective science communications inform people about the benefits, risks, and other costs of their decisions, thereby allowing them to make sound decisions.” Effective science communication can be hindered by the way science is popularized, use of inaccessible language (i.e., technical jargon), the limited scientific literacy of the general population (Weigold 2001), antiscience attitudes (e.g., Scheufele 2013), and the difficulty of educating the public about uncertainty (Scheufele 2013). Ahteensuu (2012) proposed a deficit model of science communication in which the general public is characterized as being largely ignorant of science and therefore needs to be educated about how to process scientific information. The deficit model of science communication is intuitive, and many scientists and practitioners subscribe to it even though the model has become unpopular recently (Cortassa 2016; Luisa et al. 2017; Simis et al. 2016; Suldovsky 2016).

More recent models of science and engineering communication emphasize communication as interactional or two-way (Bray et al. 2012; Burns et al. 2003; van der Sanden and Meijman 2008). For example, professionals should recognize different goals for communication, engage the audience to develop mutual understandings, use methods specific to the communication goal, and be empathetic to the audience (Bray et al. 2012; Burns et al. 2003; van der Sanden

and Meijman 2008). Additionally, professionals should measure success to determine whether the communication achieved the goal and how to improve for the next communication (Grubert and Cook 2017).

There are challenges to train scientists, engineers, and practitioners to communicate according to the tenets of these communication models. One challenge is to create actual activities that “resemble the more advanced challenges of engineering communication that occur in the practice of *doing* engineering” (Craig et al. 2008, p. 280, emphasis in original). Another serious challenge is current attitudes toward these skills (Dannels et al. 2003; Wisniewski 2018). For example, students seem to distinguish writing or communication tasks as separate from the real work, included in engineering, resulting in students placing low priority on communication skills. Similarly, communication skills are often labeled as soft skills, which seems to designate them as less important (Bjekić et al. 2015). Although communicative competence is a crucial component to any engineer’s work, students may pick up on attitudes regarding the importance of communication from their professors (Bjekić et al. 2015).

Likewise, Jamison et al. (2014) described a specific division in attitudes regarding what content should exist in an engineering curriculum. Some educators consider the inclusion of such courses that cover communication, marketing, and business as essential to aiding students in a global marketplace, whereas other educators worry that such courses distract or detract from the core engineering curriculum. Even though courses exist to teach communication skills to engineering students (Bjekić et al. 2015; Dannels et al. 2003; Ford and Riley 2003), and students who take these courses end up with interaction skills “at the same level as older and more experienced active engineers” (Bjekić et al. 2015, p. 374), there is an impression that engineering graduates lack communication skills (Wisniewski 2018). There is still the need to identify what specific communication skills students need as they enter the workforce and ways an engineering curriculum can help students develop these skills.

Subsequent sections describe the interviews held with 10 practicing water resources systems engineers and identify key themes vocalized in those interviews that involve communications challenges practitioners face in their work. Practitioners’ suggestions are shared regarding the communication skills and techniques universities should teach to effectively prepare new practitioners. Recommendations are made for classroom activities that university instructors can use to foster development of communication skills. Finally, it is discussed how sharing these activities on a repository as open education resources (Caswell et al. 2008) can encourage their use and dissemination across the globe.

## Interview Methods

Interviews were held with 10 water resources systems analysis professionals over a span of 13 months between September 2014 and November 2015. The purpose of the interviews was to collect the lived experiences of water resource engineers regarding their use of water resources systems analysis and communication challenges in their workplace. Initial interview questions included basic demographic questions regarding job positions and titles, length of work experience, and a summary of formal training. The main focus of the interviews was to collect descriptions of current job activities, including specific systems analysis techniques and software or tools used in projects. The practitioners were asked how they applied systems analysis methods, such as multiobjective decision-making techniques, to evaluate tradeoffs and select a preferred design or

solution from the set of alternatives. Practitioners were also asked how they analyzed and communicated uncertainty, tradeoffs, and simulation and optimization model results. Toward the end of each interview, practitioners were asked to provide their advice regarding how systems analysis could be employed more effectively in the future, including what skills and techniques universities should teach to effectively prepare new practitioners as they join the profession.

In this study, all interviewees were solicited from the roster of the ~100 member standing ASCE Environmental and Water Resources Systems (EWRS) Committee of which the authors are also members, or were recommended by a member of the EWRS committee. All interviewees were male, worked at either consulting firms ( $n = 6$ ), water utilities ( $n = 2$ ), or an agency ( $n = 2$ ), but represent a diversity of ethnicities. The combined life experience in the workplace ranged from 4 to over 40 years on the job. All participants either had a MS or Ph.D. in engineering, including graduate work in water resources systems analysis. Six participants had P.E. licenses. Job titles ranged from Chief Modeler, Hydrologist, or Principal Engineer to Owner and President of a consulting firm. The number of interviews was cut off at 10 people because by that point, responses started to repeat and interviewees recommended additional people that had already been interviewed. Careful notes were taken during the interviews that resulted in a collected pool of data. With interviewees' consent, the interview questions and all raw interview notes were posted on the Ecstatic repository (Rosenberg 2019) under the heading "Interviews."

Thematic analysis was used to search for meanings across all of the data, and then search for structural relationships between the meanings (Åkerlind 2012, p. 117). Originally from the field of education (Baillie and Douglas 2014), thematic analysis is a qualitative method built on the epistemological foundations that learning and knowledge are negotiated between learner and teacher, in this case a negotiation between the engineer and audience. The thematic analysis examines and combines the life experiences (Åkerlind 2005; Daly et al. 2012) articulated in the interviews.

To achieve this, two authors first combined all the interview transcripts and read through each closely to enact a "selection procedure based on criteria of relevance" (Åkerlind 2012, p. 118). This resulted in a specific focus of all the communication issues and challenges mentioned by the research participants; the outcome was a combined collection of selected quotes from the interviews. These quotes were then seen as the data pool for this study. Next, the combined quotes were further explored based on similarities. Distinct categories were created based on the grouping of distinct similarities from the narrowed pool of data (Åkerlind 2012). The first two authors performed this analysis as a team, and dialogic reliability checks were conducted through team discussions. According to Åkerlind (2012, p. 125), a dialogic reliability check is "where agreement between researchers is reached through discussion and mutual critique of the data and of each researcher's interpretive hypothesis." The resulting themes thus represent the combined feedback of all the interviewees.

## Interview Results

The thematic data analysis provides insight into how the work of practicing water resources systems engineers is communicated in the field. Within this communication process, three themes and five categories within the themes surfaced from the data (Table 1). In the following subsections, each theme and subtheme is highlighted with specific details from the qualitative data.

### **Impact of the Stakeholder in the Communication Process**

The first theme emphasizes the important role that stakeholders play in the communication process. Communication is not one-way from the engineer to the stakeholder; rather, there is back-and-forth and iterative communication among engineers, stakeholders, experts, and nonexperts during a project. Three specific categories within this theme emphasize the relational aspect of the communication and associated decision-making process.

#### **Difficulty in Communicating Results**

During the interviews, practitioners provided many statements explaining how it can be challenging to explain certain technical analyses to their clients. Examples from the data include statements regarding how it is difficult to communicate results of uncertainty analysis, convey ideas of probability distributions, and explain statistics, as well as how stakeholders can be averse to recognizing the benefits of optimization studies. Another practitioner also explained how it can be challenging to translate from frequency to probability.

#### **Limitations Based on What Stakeholders Can/Cannot Understand**

Because it can be difficult to communicate certain results or analyses to the clients, water resources systems engineers need to consider how their clients will process and understand results. Study data show how this limitation of understanding, as a result, impacts the specific techniques engineers are likely to employ, and the type and manner of results reported. For example, one research participant described that it is easier and more accessible to explain ranking or prioritization systems over pure optimization. Another participant said that it is more accessible for stakeholders and the public to understand sensitivity analysis and trade-offs between goals in comparison with optimization techniques. Another practitioner highlighted that, in his experience, stakeholders prefer scenario-based approaches.

#### **Communication Process Is Time-Consuming**

The two previous categories support this third category under the theme of the impact of the stakeholder in the communication process. Challenges in communicating results, and limits of possible strategies because of clients' previous level of understanding, can make communication a time-consuming process. One practitioner specifically explained that he found visualization techniques to require a significant amount of time to communicate, and another practitioner highlighted the need for additional time that allows iterative feedback between stakeholders and analysts throughout the duration of the project.

Theme 1 highlights the concern that if engineering students are only taught specific analysis tools or techniques, they might miss out on important roles that engineers are expected to play during the communication process. Working with clients or stakeholders is a relational communication process, and each project, situation, and analysis depends not only on the engineering analysis, but also on the people involved in the project. Computing solutions does not happen in a neutral vacuum, for example, in a sterile exam environment in a classroom. Instead, solution generation and analysis is part of a potentially complex interaction. Data from this study demonstrate the impact that stakeholders have on how engineering analyses are performed, and analyses should be disseminated for the purpose of improving situational awareness of all involved parties. This theme emphasizes communication as a two-way relay that can be complicated by the techniques and channels, information exchanged, and persons involved.

**Table 1.** Themes, categories, and example communication challenges described by water resources engineers on use of water resources systems analysis in the workplace

Theme	Categories and example communication challenges
1	<p><b>Impact of stakeholder in communication process: know your audience.</b> <i>Emphasizes the role the stakeholders play in the calculation process; ultimately, there is a communication relationship between engineers and stakeholders through the duration of the project</i></p> <p>A. Difficulty communicating results and report certain results to stakeholders</p> <ul style="list-style-type: none"> <li>• Difficult to communicate results of uncertainty analysis</li> <li>• Challenging to convey ideas of probability distributions</li> <li>• Stakeholders adverse to pure optimization in practice</li> <li>• Difficult to communicate statistics</li> <li>• Hard to translate from frequency to probability</li> </ul> <p>B. Limitations based on what stakeholders can/cannot understand. Engineers need to consider how stakeholders will process and understand results; this impacts the techniques they use and the results they report</p> <ul style="list-style-type: none"> <li>• Easy to explain ranking or prioritization systems</li> <li>• Stakeholders can understand need of multiobjective analysis</li> <li>• Stakeholders prefer scenario-based approaches</li> <li>• Easy for stakeholders and public to understand sensitivity and trade-off analyses</li> <li>• Convey trade-offs, even though most stakeholders prefer least-cost solution</li> </ul> <p>C. Communication process is time-consuming</p> <ul style="list-style-type: none"> <li>• Visualization techniques take time to communicate</li> <li>• Need time for feedback between stakeholders and analysts over project duration</li> </ul>
2	<p><b>Role of engineer in decision-making process:</b> <i>ongoing two-way communication between engineers and stakeholders throughout the project. Engineers need communication skills beyond merely reporting results to stakeholders; the communication process includes facilitating decision making</i></p> <p>A. Communication to build and facilitate consensus</p> <ul style="list-style-type: none"> <li>• Group meetings can be unproductive unless approval from all stakeholders is gained</li> <li>• Meet with stakeholders, respond with simplifying models</li> <li>• Use optimization models to build consensus if stakeholders do not concur on trade-offs</li> <li>• Important to be able to integrate issues, stakeholders' concerns, and conflict resolution</li> </ul> <p>B. Communication as integral to decision-making process</p> <ul style="list-style-type: none"> <li>• Should be more active in decision-making process</li> <li>• Decision making is a power and political process</li> <li>• Interactions with decision makers needs to improve, both with listening (to know what is the right question) and also talking to people</li> <li>• Keep stakeholders involved in the whole process, not just at the last step</li> <li>• Challenging to use uncertainty bounds on alternatives and incorporate into decision making</li> </ul>
3	<p><b>Communicate to educate emphasizes the possibility that engineers might consider themselves as 'educators' with their stakeholders;</b> <i>the effectiveness of the project could rely on an ability to teach stakeholders about the necessity of certain techniques</i></p> <p>A. Communication between engineers is not the same as with nontechnical people</p> <p>B. Need to boil down information from analysis to presentation slides, a unique skill</p> <p>C. Sensitivity analysis was new to participants; people had to be taught and cajoled</p> <p>D. Stakeholders do not see value of alternative techniques, such as uncertainty analysis</p>

### Role of Engineer in the Decision-Making Process

Not only do the study data emphasize the important effect of the communication processes on water resources systems engineering, they also depict how engineers play an important role in the decision-making process. This second theme highlights how engineers need communication skills beyond merely reporting technical methods and results to stakeholders. Communication with stakeholders and clients can also help facilitate decision making. Two categories surfaced from the data under this theme.

#### Communication to Build and Facilitate Consensus

As part of the decision-making process, water resources engineers might be called on to work to build consensus between disparate groups involved in the project. For example, one research participant described how group meetings can be unproductive unless approval from all stakeholders can be gained; the engineer might work to facilitate this approval. Another practitioner described that one aspect of the communication process includes meeting with stakeholders to ascertain their specific needs, then developing simplified models to respond to those needs. Another practitioner described how he uses optimization models to build consensus if the stakeholders do not initially concur on trade-offs.

Another aspect of the decision-making process involves the engineer acting as facilitator if the communication process becomes problematic. One research participant explained how it is crucial to be able to integrate issues, address stakeholders' concerns, and resolve conflicts. These results identify how diverse communication goals, including to resolve conflicts, influence the techniques and channels used, and information relayed.

#### Communication as Integral to the Decision-Making Process

The research participants in this study explained many ways in which they would advise new graduates on how to be involved in decisions with clients and stakeholders. For example, one practitioner directly stated that water resource engineers need to be more active in the decision-making process; the act of decision making is a political process, and many factors influence the final results. Because of this, engineers need to keep stakeholders involved in the entire process, not just at the last step of sharing their results. All interactions with decision makers in the process need continuous improvement, including listening skills, identifying the right question that should be pursued, identifying when additional questions should be pursued, and identifying additional stakeholders and experts (e.g., professional facilitators) to include in the communication process. One practitioner specifically described how it

has been challenging to communicate the implications of uncertainty bounds on alternatives and how this uncertainty should be incorporated into decision making.

This second theme of how the water resources engineer acts as part of the decision-making process builds on the first theme. Although the stakeholders and clients impact the communication process, the engineer also has an important role in facilitating complex decision-making processes.

### **Communicating for Education**

This final theme emphasizes the need for the water resource engineer to play a role as an educator as well as a learner within the process, specifically to help professionals and project stakeholders exchange information during a project. The effectiveness of a project can depend on the ability to teach stakeholders about the need of certain analytical techniques, how an analysis is done, and what results and insights are gained from the analysis. For example, one practitioner stated that the education of stakeholders is a crucial issue to consider because it directly impacts outcomes. Another participant explained that when communication between engineers themselves is different than with nontechnical people, it is necessary to address this difference with distinct communication tools and strategies. Specifically, stakeholders may not have had any formal training or experience with the technical methods used in the project.

Another participant explained that an important aspect of his job is to convey background and underlying assumptions on how the trade-offs between conflicting stakeholder objectives are quantified. Stakeholders may not have seen the value of alternative techniques that engineers may have in their toolbox, such as different types of numerical techniques for conducting uncertainty analysis. Another practitioner described how sensitivity analysis was new to clients, and they had to be taught and encouraged before methods for sensitivity analysis were integrated in project activities. One other specific issue that was mentioned is the need to boil down information from the analysis to a clear and concise presentation format in order to aid the stakeholders' learning of complex technical methods. All of these examples from the data stress that water resource professionals need to work on educating those involved in the project to reach an effective and satisfactory outcome.

At the same time, engineers need to listen carefully to their clients and stakeholders to learn more about the problem, stakeholder goals, available data, opportunities, and constraints. Engineers also have to learn how to best present information in an accessible and timely manner. Education of all involved stakeholders and participating engineers necessitates two-way interactions where stakeholders educate the engineer, and vice versa. Results from this subtheme show rich interactions and connections among communication goals, techniques, information types, participants, and setting, and they emphasize the need for two-way relay.

Together, the three themes highlight multiple communication hurdles that water resources systems engineers face in their jobs. These hurdles include explaining computational results, explaining effects of decision outcomes on stakeholders, and educating stakeholders on the usefulness of certain techniques. Interviewees also noted that clients, stakeholders, and others often do not understand what water resources systems analysis is or what systems analysts do. Additionally, systems analysts often focus on use of computational tools (rather than the problem context that determines which tools to use), whereas stakeholders tend to focus on contextual complexities and sometimes narrowly on the worst-case scenario.

## **Suggestions to Bolster Communication Training**

To start addressing these communication challenges, several ways are suggested to bolster communication training in small, manageable increments within an individual water resources systems analysis course or throughout an engineering program and curriculum so that practitioners and stakeholders can better benefit from systems analysis work. These suggestions come from the practitioners themselves, in the form of advice they offered at the end of interviews on skills and techniques universities should teach to effectively prepare new practitioners to join the profession. The six recommendations are presented in the following subsections.

### **Use Case-Study Examples and Projects in the Classroom**

The benefits of using case studies include providing students with opportunities to understand broader perspectives and contextual details, acknowledge situations involving multiple stakeholders, weigh tradeoffs among stakeholder objectives, and describe the complexity and evolution of problems. In analyzing case studies, students can consider how communication plays a role in the decision-making process and the outcomes. Case studies also foster an ability to consider and explain complex issues. Examples of engineering case studies and suggestions for classroom use include those from Baillie and Moore (2004), Bhatt et al. (2009), Elleithy et al. (2016), Lawson and Brady (2011), Sankar et al. (2008), Swatuk and Motsholapheko (2008), and Watkins (2013). Case studies can help students communicate for more diverse goals and techniques, relay different types of information, and see problems from different participant's perspectives.

### **Allow Students to Role Play Different Roles in a Case-Study Decision-Making Process**

Role play allows students to overtly practice different forms of communication, negotiation, teamwork, conflict, and conflict resolution based on the realistic details in the case study. Both Darling and Dannels (2003) and Sageev and Romanowski (2001) also found that developing communication skills in meetings and teamwork situations is one of the most common and effective skills needed for engineers; role plays allow students to practice these informal communication skills as opposed to solely focusing on public speaking skills. Pierce and Madani (2013) found that students cooperated, built trust, shared information, communicated, and engaged in social learning while role playing villagers choosing to irrigate fields with groundwater, surface water, and rainwater in the online game Irrigania (Seibert and Vis 2012). Further, these skills also contributed to students more sustainably managing resources within the game (Pierce 2013).

Jamison et al. (2014, p. 266) highlighted how engineering education should allow students to experience, engage, and interact in such a way that their "own learning process . . . will include awareness and understanding of the people that are going to use the technology that the students learn about." Role-play assignments and team activities encourage students to look at the situation from another perspective (such as from the position of a stakeholder), instead of only considering communication from the position of engineer. At the same time, role playing can sometimes make students feel uncomfortable (Jackson and Back 2011); instructors must monitor role playing exercises, engage with students, and check on their emotional well-being. Role play addresses all three themes that emerged from this study's interview analysis. Realistic case studies offer students opportunities to examine the role of stakeholders and clients in projects, facilitate decisions regarding

which tools and solutions to consider, and learn more deeply about the case.

### **Guide Students to Develop the Ability to Simplify a Problem and Explain It**

One practitioner suggested that for all projects and assignments, students or teams need to explicitly write down and document the specific questions and problems they seek to answer. This activity can help students write clearly and identify and understand the relevant problems (Craig et al. 2008; Ford and Riley 2003; Jamison et al. 2014). This attention to problems and associated questions can help students develop skills in problem definition and selection of the modeling, analysis, and uncertainty methods to use to solve the problem and communicate with stakeholders. To determine which tools to use, water resources systems analysts must develop problem-definition skills to simplify a problem, explain it, and identify the issues that constrain technical solutions.

Bish et al. (2014) highlighted problem solving skills for engineering asset management as including the ability to combine pieces of the puzzle, analytical thinking skills to break down issues into smaller concepts, and the ability to seek out information. This overt recommendation from one practitioner connects with all three themes from this study's analysis because effective problem definition will impact communication with clients, including ways in which analysts will impact decisions and step up to educate stakeholders regarding the most effective way to address problems.

### **Encourage Students to Develop Facilitation and Conflict-Resolution Skills**

Multiple interviewees suggested that training to help students develop facilitation and conflict-resolution skills will benefit graduates once they enter the workforce. Certain practitioners advocated for additional training to help students to learn to listen to people. Connected to listening is enacting comprehension checks to make sure that the right question is being addressed, which might require further communication and discussion with stakeholders than that suggested from simply reading the project contract or scope of work. Encouraging students to develop facilitation and conflict-resolution skills ties most directly to the second theme of considering the role of engineers in the decision-making process. Having the ability to facilitate effective discussions among a variety of stakeholders is beneficial to the overall systems analysis process.

Support for this recommendation is also found in the literature. Pierce (2013) reported that students communicated in efforts to resolve groundwater conflicts while playing the Irrigania game. Bjekić et al. (2015) stressed the importance of developing conflict-resolution skills for engineering students, and Darling and Dannels (2003) highlighted that listening, negotiation, and clarity are crucial job skills because engineers work with diverse audiences.

### **Cross Pollinate with Other Fields Such as Ecology, Public Health, and Economics**

Practitioners recommend offering students the opportunity to consider a situation from broader perspectives, including ecology, public health, economics, and others. Broader perspectives will encourage students to think about the problem scope and simplifications typically assumed in water resources systems analysis and confront the technical jargon used in the field. Cross pollinating with other fields may also introduce students to different ways to frame a problem, new technical approaches (e.g., treatment of uncertainty), and alternative ways to present results. This suggestion links to all three interview themes to help students communicate to

a broader group of stakeholders and clients, reach consensus among wider groups of people, and help educate stakeholders and clients about the different dimensions of a problem. Dannels et al. (2003) and Ford and Riley (2003) suggested ways to group students in multidisciplinary teams to learn communication skills.

### **Include Broader Contexts of Problems, Such as How Political/Institutional Constraints, Bureaucracies, and Social Issues May Constrain Technical Solutions**

This recommendation highlights the need to use case studies (Recommendation 1) that are rich in background context—including political/institutional constraints, bureaucracies, social issues, and laws—to illustrate the relational and contextual factors that affect on-the-job communication. Jamison et al. (2014) also argued for the need for contextual knowledge for engineers. In the same vein, when discussing this recommendation in the area of chemical engineering, Tuerk and Lee (2014, p. 1957) stated, “understanding the nature of relevant political and social issues is a prerequisite to good engineering design, thus requiring an appreciation for, and competence in, basic policy, social science, and cultural studies among engineers.” Engineering students who only find solutions in controlled classroom environments will never see the important roles stakeholders play to impact the decision-making process or the need to educate stakeholders during a contractual relationship.

The practitioners interviewed for this study highlighted the need for students to be prepared for a broad set of constraints, bureaucracies, social issues, laws, and other factors that affect their water resources systems engineering work. Including the broader context that constrains technical solutions will help students communicate for more diverse goals, relay information, and identify appropriate communication settings.

### **Activities to Integrate Practitioners' Suggestions into Curriculum**

This study also provides 22 classroom activities that integrate the practitioners' six recommendations to improve communication training for engineers into curriculum (Table 2). For example, the Fairweather Planning (Palmer 2013) and Choose a Manager (Kasprzyk 2017) activities present students with case studies where they must work in groups and communicate to solve a water management problem. The online Irrigania computer game (Madani 2018; Rosenberg 2016; Seibert and Vis 2012), Fairweather team-building exercise (Palmer 2013), and Milwaukee, Wisconsin stormwater/sewer water management problem (Watkins 2018) allow students to role play as farmers, managers, consultants, planners, citizens, and other stakeholders working to solve water management problems like preventing aquifer drawdown, providing a reliable water supply to a city, or preventing combined sewer overflows. The serious game activities (Hockaday et al. 2017; Madani et al. 2017; Pierce and Madani 2014) further allow student role players to work together to resolve conflicts.

Causal loop diagramming, one-page written summaries, and 3-min pop-up presentations help students simplify and explain a problem. Similarly, the Fairweather team-building (Palmer 2013), water allocation with seasonal forecasts (Brown et al. 2010), and game-based learning (Madani et al. 2017; Pierce and Madani 2013) activities help students negotiate and resolve water resources conflicts. Nine other activities further use water resources course syllabi, practitioner interviews, causal-loop diagramming, planning activities, and a field trip to help students cross pollinate across related fields and identify the broader context for water resources problems. These activities also involve community members and

**Table 2.** Example classroom activities to improve communication skills

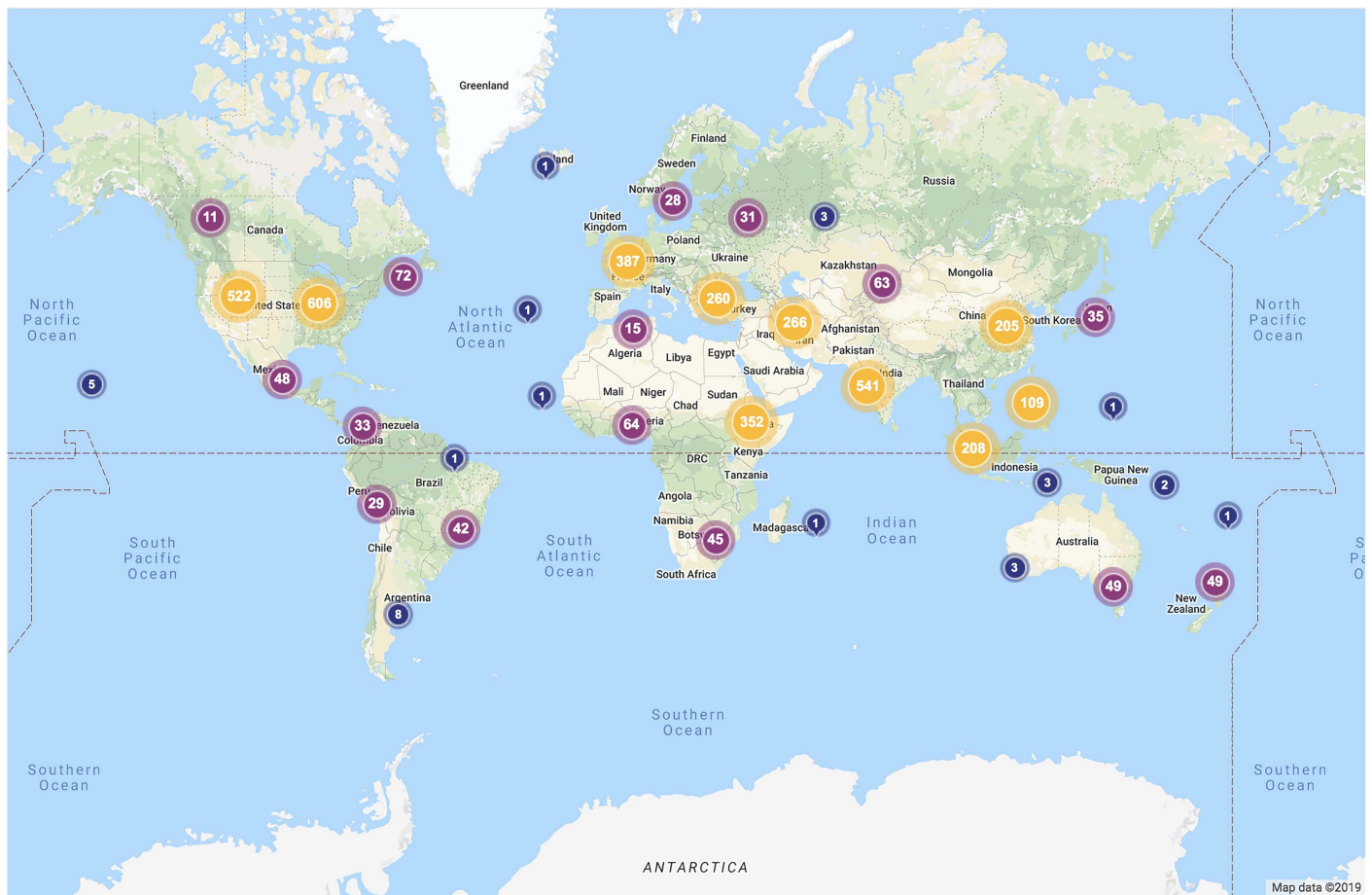
Skill	Class activity	Institution	Date	References
Case studies	Fairweather planning Exercise 1	UMass	Fall 2013	Palmer (2013)
	Choose a manager to illustrate multicriteria decision analysis	University of Colorado Boulder	Fall 2017	Kasprzyk (2017)
Role play	Irrigania computer game	Politecnico di Milano, USU, UCF, and Lund University	2013–2018	Madani (2018), Pierce (2013), Rosenberg (2016), and Seibert and Vis (2012)
	Fairweather team-building Exercise 2	UMass	Fall 2013	Palmer (2013)
	Students role play as an engineering consultant tasked with developing a cost-effective plan to upgrade Milwaukee's sanitary and combined sewer systems	MTU	Fall 2018	Watkins (2018)
	Students role play a lead diplomat or politician negotiating a deal over transboundary water and environmental problems [e.g., sharing the Nile River and Caspian Sea, agreeing over a global declaration on water/environment, or setting up a regional initiative/center to deal with water and dust problems in the Middle East and North Africa (MENA) region]	UCF, Imperial College London, Polytechnic University of Valencia, and Yale University	2013–2019	—
	Encourage students to use effective listening skills, optimistic tone during games	—	—	—
Simplify and explain a problem	Serious board and computer games	—	—	Hockaday et al. (2017)
	Causal loop diagram (CLD) drawing activity to visualize water management system structure and facilitate consensus on management strategies	UT El Paso	Spring 2018	Mirchi (2018)
	Students write a proposal to solve a water problem using a systems analysis technique. Next, students develop the project and present a preliminary and a final report	UT San Antonio and USU	2015–2018	—
	Students make 3-min pop-up talk on class projects midway through the semester	USU	Fall 2018	—
	Students write a one-page summary of a systems analysis paper or problem to identify the problem, importance, modeling approach, main findings, and limitations	UT San Antonio and USU	2012–2018	—
Conflict resolution	Invite local politicians and decision makers to student presentations and have visitors ask questions	—	—	—
	Fairweather team building Exercise 2	UMass	Fall 2013	Palmer (2013)
	Students negotiate reservoir water allocations given uncertain seasonal forecasts	MTU	Fall 2018	Brown et al. (2010)
Cross pollinate across fields	Game-based learning and serious games	—	—	Hockaday et al. (2017), Madani et al. (2017), and Pierce and Madani (2014)
	Use Ecstatic materials to structure syllabi to include a breadth of topics (Rosenberg 2019, Ecstatic_syllabi)	University of California Davis	Fall 2017	—
	Students attend multidisciplinary symposiums and training involving formal and informal oral communication of water science, engineering, law, business, and policy	—	—	—
Include broader context for problems	Hold competitions (e.g., USEPA Campus Rainworks Challenge). Multidisciplinary student teams jointly work on problems	—	—	—
	CLD drawing activity to visualize water management system structure and facilitate consensus on management strategies	UT El Paso	Spring 2018	Mirchi (2018)
	Fairweather planning activity Exercise 2	UMass	Fall 2013	Palmer (2013)
	Read practitioner interviews on what constrains use of systems analysis in practice and discuss	USU	Fall 2018	Grayman (2015) and Loucks (2015)
	Economic and full value of water module	MTU and UT El Paso	Fall 2016–Spring 2017	Gyawali et al. (2018)
	4-day/3-night field trip to Glen Canyon Dam where students met with stakeholders and managers	USU	Spring 2018	—
	Have different community members present on various aspects of an assigned problem	—	—	—

Note: UMass = University of Massachusetts Amherst; USU = Utah State University; UCF = University of Central Florida; MTU = Michigan Tech University; and UT = University of Texas.

encourage students to attend multidisciplinary symposiums and trainings.

Feedback for students is built into each of the communication activities. For example, students who play serious or role-play games can observe their own and other students' performance during the

game and afterwards. Judges of student competitions can provide feedback, and instructors can constructively critique student work in the other communication activities as part of regular student reflection and grading. Further, communication activities can be combined to enhance feedback for students. For example, local

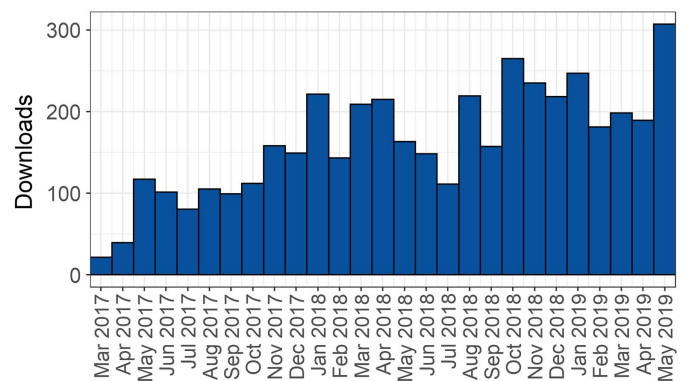


**Fig. 1.** Total downloads from the ECSTATIC repository by location through May 2019. (Map data © 2019 Google.)

politicians and decision makers can be invited to observe role play activities and share their observations of the role play with students. At public presentations by students, local stakeholders and decision makers can share reactions afterwards during questions and answers.

Each skill and its associated activities in Table 2 address the three communication themes identified in Table 1. For example, Theme 2 on ongoing two-way communication between engineers and stakeholders is very prominent in the activities and reinforced by a repeated cycle of student communication and instructor feedback. These cycles offer students the opportunity to communicate through multiple mediums, be receptive to others' ideas, listen to the needs and requirements of others, adapt project scope and methods over time, and experience communication as an on-going and long-term process.

The authors and other engineering faculty have already led many of these communication training activities in university courses across the United States and Europe in recent years (Table 2, third and fourth columns). Many of these activities have also been shared on the Ecstatic repository as open educational resources that educators throughout the world can access, adopt, and extend (Caswell et al. 2008). Through the end of May 2019, 78 Ecstatic resources have been downloaded 4,407 times by individuals on six continents (Fig. 1). A full 70% of downloads have come from educational institutions, with the remainder from commercial, governmental, organizational, library, and military institutions. Monthly download rates have grown since the repository was established in February 2017 (Fig. 2). The Ecstatic repository includes a Submit New



**Fig. 2.** Monthly downloads from the ECSTATIC repository since March 2017.

Material link so the Repository can grow over time (Rosenberg 2019).

Posting and sharing these teaching materials serves as a bottom-up approach to integrate practitioners' recommendations for communication training into curriculum. Posting activities on the Ecstatic repository encourages and empowers individual instructors to make changes in their own classes. This bottom-up approach to integrate communication into curriculum is sustainable and scalable because it requires little effort for an educator to add a new or existing communication activity to the Ecstatic repository.



At the same time, other educators and students can freely access activities as open educational resources. This bottom-up approach to enhance communication training in water resources systems engineering can be replicated by other engineering disciplines.

## Conclusions

An important role for engineering faculty working in colleges and universities is to prepare the next generation of engineers to address complex problems with diverse groups of stakeholders. This study moves beyond simply emphasizing the importance of communication skills in engineering (Donnell et al. 2011) by identifying where current water resources systems analysis programs sometimes fall short in teaching professional communication skills and how programs can be improved.

Ten practicing water resources systems engineers were interviewed to identify, share, and promote effective practices in water resources systems analysis education and communication. The interviews highlighted three themes of communication challenges that exist on the job: stakeholders' impact the communication process, the role of the engineer in the decision-making process, and communication as a means to educate stakeholders. Practitioners also suggested several ways to better prepare students to meet these communication challenges. These suggestions include using case studies in the classroom; encourage students to role play; guiding students to develop the ability to simplify problems and describe them; encouraging facilitation and conflict-resolution skills; cross pollinating examples with content from public health, economics, and other disciplines; and including broader political, institutional, and social considerations and constraints in example problems. Together, these practitioner recommendations can help water resources systems analysts better communicate with and listen to stakeholders, develop a vision and intuition for the work they will undertake, develop conflict-resolution skills, and humbly recognize that systems analysis techniques cannot solve every problem.

In addition, 22 classroom activities are shared that integrate the practitioners' six recommendations to improve communication training for engineers into curriculum. The authors have implemented these activities in university classrooms in the United States and Europe and shared them as open educational resources on the Ecstatic repository for other instructors and students to download, use, share, and adapt. This bottom-up approach to integrate communication into the water resources systems analysis curriculum is sustainable and scalable and can be replicated by other engineering disciplines.

## Appendix. Themes, Categories, and Example Communication Challenges Described by Water Resources Engineers on Use of Water Resources Systems Analysis in the Workplace

### *Theme 1. Impact of Stakeholder in the Communication Process: Know Your Audience*

This theme emphasizes the role the stakeholders play in the calculation process; ultimately, there is a communication relationship between engineers and stakeholders through the duration of the project. Aspects of this theme are as follows:

1. Difficulty communicating results and reporting certain results to stakeholders:
  - difficult to communicate results of uncertainty analysis;
  - challenging to convey ideas of probability distributions;
  - stakeholders adverse to pure optimization in practice;

- difficult to communicate statistics; and
  - hard to translate from frequency to probability.
2. Limitations based on what stakeholders can/cannot understand. Engineers need to consider how stakeholders will process and understand results; this impacts the techniques they use and the results they report:
    - easy to explain ranking or prioritization systems;
    - stakeholders can understand need of multiobjective analysis;
    - stakeholders prefer scenario-based approaches;
    - easy for stakeholders and public to understand sensitivity and trade-off analyses; and
    - convey trade-offs, even though most stakeholders prefer least-cost solution.
  3. Communication process is time-consuming:
    - visualization techniques take time to communicate; and
    - need time for feedback between stakeholders and analysts over project duration.

### *Theme 2. Role of Engineer in Decision-Making Process*

This theme concerns ongoing two-way communication between engineers and stakeholders throughout the project. Engineers need communication skills beyond merely reporting results to stakeholders; the communication process includes facilitating decision making. Specific areas of this theme are as follows:

1. Communication to build and facilitate consensus:
  - group meetings can be unproductive unless approval from all stakeholders is gained;
  - meet with stakeholders, respond with simplifying models;
  - use optimization models to build consensus if stakeholders do not concur on trade-offs; and
  - important to be able to integrate issues, stakeholders' concerns, and conflict resolution.
2. Communication as integral to the decision-making process:
  - should be more active in decision-making process;
  - decision making is a power and political process;
  - interactions with decision makers needs to improve, both with listening (to know what is the right question) and also talking to people;
  - keep stakeholders involved in the whole process, not just at the last step; and
  - challenging to use uncertainty bounds on alternatives and incorporate into decision making.

### *Theme 3. Communicate to Educate*

This theme emphasizes the possibility that engineers might consider themselves as educators with their stakeholders and how the effectiveness of the project could rely on an ability to teach stakeholders about the necessity of certain techniques. Specific areas in this theme are as follows:

1. communication between engineers is not the same as with non-technical people;
2. need to boil down information from analysis to presentation slides, a unique skill;
3. sensitivity analysis was new to participants; people had to be taught and cajoled; and
4. stakeholders do not see value of alternative techniques, such as uncertainty analysis.

## Data Availability Statement

All interview questions and notes from the interviews with practitioners are available online as open educational resources on the

Ecstatic Repository provided by Rosenberg (2019) under the heading “Interviews.” Example classroom activities cited in this article are also available on the same Ecstatic repository.

## Acknowledgments

This work was supported by the Environmental & Water Resources Institute of the American Society of Civil Engineers as part of the Excellence in Systems Analysis Education and Innovative Communication (ECSTATIC) task committee. The authors thank the 10 interviewees and Shane Brown for constructive feedback on an earlier draft.

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