ISSUES IN INTEGRATIVE STUDIES
No. 29, pp. 118-143 (2011)

INTERDISCIPLINARY METHODS IN WATER RESOURCES[1]

by

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Abstract: In the face of a myriad of complex water resource issues, traditional disciplinary separation is ineffective in developing approaches to promote a sustainable water future. As part of a new graduate program in water resources, faculty at the University of Idaho have developed a course on interdisciplinary methods designed to prepare students for team-based interdisciplinary research. The course introduces the steps required for interdisciplinary research outlined by scholars of interdisciplinary research, but focuses on the key step of integration. Over four years of course development, faculty found that the initial barriers to effective integration are differences in language, methodology, values, and goals across disciplines, and misperceptions about those factors in other disciplines. Thus, initial class discussions focus on the methods and problems encountered with communicating and integrating across disciplines. Students then learn to use simplified versions of tools for integration, requiring them to first develop a conceptual understanding of linkages between disciplines, then to explore those linkages. The introduction to tools for integration is achieved through three projects that span physical, biological and behavioral sciences, political science, and law. Students on interdisciplinary teams are tasked with being the expert/teacher in their discipline, but must achieve sufficient understanding of the other disciplines reflected in the problem to understand and articulate their relation to the problem and how integration with their

[1] The authors would like to thank the students who have participated in our experiment with Water Resources 506, helping to bring it to a new level of integration.

primary discipline alters the process or outcome. From this initial preparation students in the water resources program are better prepared to go on to effective interdisciplinary research.

Introduction

In the face of a myriad of complex water resource issues, traditional disciplinary separation is ineffective in developing tools to promote a sustainable water future. University of Idaho faculty have developed a graduate degree and research program in water resources called Waters of the West. The program trains students to integrate aspects of disciplines relevant to current water resource problems. The unique program focuses on developing innovative interdisciplinary strategies and solutions to the world's critical water shortages and associated water quality issues. To accomplish this broad objective, the program offers three overlapping degree focus areas: (1) Water Resources Engineering & Science; (2) Water Resources Science & Management; and (3) Water Resources Law, Management & Policy. Additionally, concurrent JD/MS and JD/PhD degree options are available with any of the three option areas. The program is based on three key principles: (1) for students to effectively integrate across disciplines, their faculty must model that behavior; (2) while integration across disciplines to address complex problems is in part an intuitive process learned by doing, it is possible and desirable to develop and teach a set of tools and processes to aid in integration; and (3) the major water resource problems facing the world require approaches that combine disciplinary depth with disciplinary breadth and thus are best addressed through teamwork to integrate across disciplines. By using these three principles as the foundation of the Waters of the West graduate course in Interdisciplinary Methods in Water Resources, now entering its fifth year as the core course in the program, students are better prepared to begin interdisciplinary research.

The course begins with an introduction to the steps necessary for interdisciplinary research, relying on processes outlined by Klein (1990); Newell (2001); Szostak (2002); Repko (2008); Szostak, (2011). However, to address the limitations of a one semester course and to focus on what faculty identified as the crucial step of integration (referred to as the "black box of integration" by Repko, 2007, p. 8), students are given team-based projects in which the underlying problem, the disciplines to be used, and the literature and data required are provided. In the initial two years of teaching the course, faculty and students found that differences in language, methodology, values, and goals across disciplines; misperceptions about those factors in other disciplines; and basic interpersonal interaction and group dynamics were the initial barriers to effective team-based interdisciplinary research and applied problem solving (Eigenbrode et al., 2007; Repko, 2008). Each of these barriers was most pronounced during the key step of integration across disciplines. Consistent with the concept of finding common ground discussed by Repko (2007) and Szostak (2011), addressing these issues required the addition of communication and team-building exercises and specific focus on the differences between qualitative and quantitative research, thus creating the dialogue necessary to identify common ground within the relevant disciplinary concepts, assumptions, and theories. Only after resolving these initial issues does the course move to an introduction to techniques for integration across disciplines. The following paragraphs present the approach used to improve interdisciplinary communication, the development of tools for facilitation of integration, and the three team-based projects that give students an opportunity to apply and experiment with these tools and with interdisciplinary communication.

Interdisciplinary Communication Skills

The term "disciplines" can be defined as "scholarly communities that define which problems should be studied, advance certain central concepts and organizing theories, embrace certain methods of investigation, provide forums for sharing research and insights, and offer career paths for scholars" (Repko 2008, p. 4). "Interdisciplinary" as taught in the course, requires not only "bringing together in some fashion distinctive components of two or more disciplines" (Nissani, 1995, p. 119), but also integrating the insights from the different disciplinary perspectives to address complex problems or to develop a broader understanding of a problem (Klein & Newell, 1997; Repko, 2007). Thus, by definition, team-based interdisciplinary research brings together people with different goals, concepts, theories, methodologies, personal experiences, and values and challenges them to find common ground (Eigenbrode et al., 2007; Repko, 2007). In this setting, conflict is unavoidable and effective communication is essential.

Development of communication skills begins with a session on team building. Students are presented with a view of conflict as an inevitable, normal, and even necessary aspect of team-based research, whether disciplinary or interdisciplinary. The only issue with which they are confronted is whether to approach conflict as a destructive or constructive aspect of team dynamics (Deutsch, 1973). Students are asked first to identify the relevant perspectives, methods, assumptions, and important questions of their own discipline, then

explore the differences and commonalities among their disciplines that may lead to conflict (Fisher, 2006; Eigenbrode et al., 2007). Students entering graduate school may not be fully grounded in the relevant perspectives, methods, assumptions, and important questions of their undergraduate discipline, thus faculty from the water resources program also participate in this dialogue. The discussion then broadens to conflict that may arise in any group setting whether due to disciplinary or personal differences (Stulberg & Love, 2009, pp. 33-37). Skills taught include active listening, removing defensive language from statements, and establishing and enforcing ground rules for teamwork (Horn, 1996; Gomes de Matos, 2006).

Once students have completed at least one team project, the course deals more directly with disciplinary divides involving the difference in values, methods, assumptions, handling of uncertainty, and consideration of which questions are important and appropriate for research. Faculty observation of students in the course through four semesters suggests that there is a strong correlation between issues created by disciplinary differences and those created by group dynamics. This may be simply because people tend to choose a discipline, consciously or not, that fits their world view. Thus, the methods for addressing team conflict are equally applicable here. However, we find a more specific focus on the differences among disciplines serves the purpose of further team building and sets the stage for discussion of methods for integration of research from different disciplines, as well as increasing understanding of other disciplines. Recognizing the barrier this might pose to effective interdisciplinary research, colleagues at the University of Idaho have developed a "toolbox for philosophical dialogue" (Eigenbrode et al., 2007). Students are exposed to a toolbox session prior to completion of their final group project. Similar to the team building class, we ask students to consider the constructive aspects of disciplinary differences emphasizing, as noted by Newell (2001), that one of the best means to test the assumptions of one discipline is to view them through the lens of another discipline.

The disciplinary divide we find most prevalent in graduate students starting an interdisciplinary program is that between qualitative and quantitative methodologies (Lele & Norgaard, 2005). While most students, regardless of their background, find quantitative methods to be credible, a strong lack of understanding of and therefore prejudice against qualitative research exists. We use a qualitative research assignment to address this issue. Students must each develop a photo essay using 12 photos to describe themselves on a single poster. The posters are displayed in the water resources office for all students to use as the sole source of information to describe water resources students as a group. Descriptions generally show striking similarities, and this exercise illustrates to students the replicability of information obtained through qualitative methods. Through two years of doing this assignment it appears that water resources students love the outdoors and, in particular, water in any form. They ski, they kayak, they garden, and they fish. The visual display and discussion of highly personal and nuanced facets of their fellow students also facilitates team bonding. It is with the qualitative research project that a transformation in the ability of students to come together as creative, productive teams occurs. Quite simply, they begin to have fun working together.

The second step in our approach to teaching interdisciplinary communication skills is to initiate the development of disciplinary adequacy in the supporting disciplines that will play a role in their research (Repko, 2008; Szostak, 2011). The term "disciplinary adequacy" recognizes the reality that it is impossible or at least highly unlikely that individuals can become experts and keep up with publication and emerging concepts in more than one discipline. At the same time reliance on other team members as experts in a field, while leading to adequate multidisciplinary research, will not yield the level of integration sought. Disciplinary adequacy requires, at a minimum, understanding the methodology, assumptions, basic terminology, perspective, and major research questions identified with the discipline in which one is not trained (Repko, 2008, pp. 43-44, 143). To achieve this, the course relies on a series of disciplinary lectures, readings, and problems in the disciplines the students will encounter in the team-based projects. Faculty make it clear to students that exposure to a new discipline in a single class period will not produce disciplinary adequacy. Instead, this provides an opportunity to introduce students to disciplines and associated water resource faculty at a stage when they are formulating their study plan, choosing a committee, and developing a thesis/dissertation proposal. An additional element that accommodates the time limitation is the focus of disciplinary lectures on aspects of the discipline most relevant to the team-based projects. This limits the material covered, and gives students a second opportunity to apply their knowledge of the new discipline in completing the project.

As part of the disciplinary coverage, each student must submit an assignment in each discipline to assure they are not merely relying on teammates as experts. Assignments are developed that introduce basic concepts within a discipline while challenging their problem-solving skills and ability to handle complexity. Fortuitously, in the four years of the course, class enrollment has been divided fairly evenly among students with undergraduate degrees in each of the disciplines covered in the course. To

avoid having students with existing expertise in a particular discipline do what to them would be a simplistic assignment, we use them as teaching assistants for that assignment. Students within a discipline assist the faculty member in developing and delivering a lecture, evaluating the assignment, and providing oral feedback to students on the assignment. This is a component of the third prong of our approach to interdisciplinary communication skills.

The use of students with baseline disciplinary adequacy to evaluate assignments and give feedback necessitates that students communicate their knowledge to someone outside their field. The ability to communicate complex concepts to someone with no background in a discipline requires both a heightened understanding of the concept and the ability to translate that concept into appropriate language. Students are encouraged to use analogies and metaphors drawn from common experiences (i.e., they must find common ground), and to provide real world examples.

Tools for Facilitation of Integration

Scholarship on the process of interdisciplinary research often lists a series of steps beginning with problem identification, discipline identification, development of disciplinary adequacy, and at some point "integration" (Newell, 2001; Szostak, 2002, 2007; Repko, 2007, 2008; Klein, 2011). Describing what is meant by the step labeled "integration" to students is no easy task. It begins with the activities described above involving identification of common ground (Repko, 2007) and conflict among disciplinary insights, but now as applied to the specific problem. It is in part a process that students learn by doing. Thus the choice of projects described below that cannot be solved without integration. Many interdisciplinary scholars also describe it as requiring a substantial role for intuition (Repko, 2008). However, faculty found that students' development in this area can be facilitated through the use of tools to facilitate or add to the "intuitive" process.

Through development of team-based research projects as part of the Waters of the West Program, faculty developed, or relied on, four tools for integration that are introduced to students in the course: (1) integrating questions; (2) conceptual modeling; (3) systems modeling; and (4) participatory GIS (Geographic Information Systems).

Research in general begins with the formulation of a question, or in some disciplines, a hypothesis. Integrating questions bring together at least two avenues of inquiry. This appears simple until integration across multiple disciplines is considered. In Waters of the West research, faculty and graduate student teams have found that the added complexity imposed by integrating insights from multiple disciplines can be approached by breaking the process down into integration by twos. The process starts with two disciplines that are similar in methodology and views (e.g., hydrology and aquatic biology), develops an integrating question for those disciplines, and then the process continues until we have a single umbrella question. The more disciplines, the more vague and seemingly useless to beginning a research agenda the umbrella question appears. However, the mere process of developing the question raises and resolves upfront many of the disciplinary barriers that would have been encountered in the course of research and sets the stage for a more intuitive approach to integration. In addition, the initial questions integrating a smaller number of disciplines form the basis for subgroups that work more closely together to develop common methodologies in research projects. In the introductory course we assign development of an integrating question in the first team-based project, leaving students to choose the approach to use in subsequent projects. Examples of integrating questions are provided with the description below of the declining aquifer and the steelhead spawning problems.

The second tool we teach students is conceptual modeling (Heemskerk, Wilson, & Pavao-Zuckerman, 2003). Conceptual modeling is a qualitative, visual or graphic approach with the same goal as developing the integrating question, but goes further in developing a map of the interactions among various aspects of the problem. Students use a single poster board to set out the elements of and relationships within the problem. For example, in our problem involving conjunctive management of an aquifer connected to a river described below, we may have various stocks (surface reservoirs and aquifer storage) and flows based on supply (precipitation, recharge), and demand (irrigation water use). Both recharge and water uses affect aquifer storage. On further study, irrigation water use of ground and surface water both removes water from the aquifer and may recharge it with surface water. Additional variables might be added—e.g., climate change affects both supply and demand; conversion of agricultural land to subdivisions may increase or reduce demand depending on state policies on domestic water use. The resulting diagram is shown in Figure 1 (next page). The final product is a map of relationships that illustrates to team members how the information they gather in their research might rely on or be useful in understanding the information that other team members gather. It provides a visual representation of how they might integrate their work.

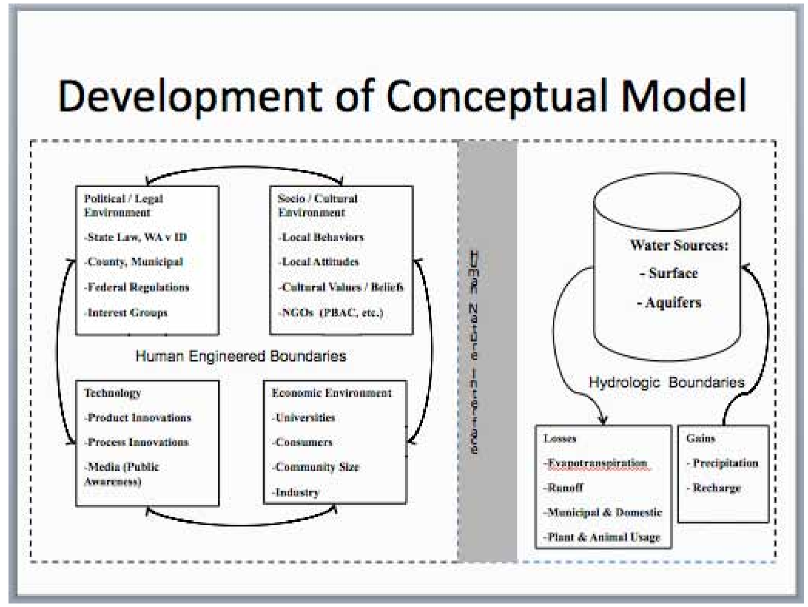

Figure 1: Conceptual model developed by water resources students Phil Dennis, Joey Machala, Nick Sackman, and Scott Struhs for a class presentation in 2007.

We find that students from text-based disciplines (e.g., law) are more comfortable with integrating questions, whereas students more accustomed to graphical representation of information (e.g., most sciences) are more comfortable with conceptual modeling. (The common statement: "I can see that your little arrow between boxes indicates that recharge and precipitation are related, but wouldn't it be easier and more precise to just say that?" or "You wrote a whole page on what I can illustrate with two boxes and an arrow.") Rather than suggesting either approach is better or worse, these differences provide further opportunity to discuss the differences in how people view the world and how they learn. It provides an opportunity for students to consciously recognize their own strengths and to appreciate those of others. Finally, it provides an opportunity to discuss the fact that a person you are presenting research to, whether a client, funding agency, or team member, may understand things better if presented in a different way. Learning to experiment with different techniques to convey information may enhance the student's ability to function effectively in an interdisciplinary environment.

The third tool we expose students to is systems modeling (Ford, 1999). Systems modeling is a means for quantitatively exploring temporal interactions and feedbacks between stocks and flows that compose a system. Systems are modeled by developing mathematical relationships between the same stocks and flows that can be illustrated in a conceptual model. Although originally developed in the management of corporations (Forrester, 1961), systems modeling is increasingly used in natural resource problems (Ford, 1999; Langsdale, Beale, Carmichael, Cohen, & Forster, 2007) and more recently used in participatory contexts to aid decision making (Tidwell, Passell, Conrad, & Thomas, 2004; Beall & Zeoli, 2008; Beall & Ford, 2009). The power in using systems dynamics as an integrating tool is that anything that can be cast in terms of stocks and flows can be modeled. It is not possible to teach students the intricacies of model development in a single class session. Instead, we provide students with a simplified version of the systems model developed for the research that the declining aquifer problem described below is based on and have them use it to explore certain questions. The goal is to introduce students to the capabilities of the tool, in particular its value in illustrating the complex results of feedbacks, and the types of integrated questions the tool might be useful in addressing. Students may then decide whether to take more in-depth coursework in systems modeling. The application of the tool will be described more fully in description of the declining aquifer problem below.

GIS is a powerful tool for relating data from various disciplines to geographic locations and has proven useful in water resource research (Rohdea, Hostmannb, Peter, & Ewald, 2006; Zhoua, Gonga, & Liub, 2008). Some obstacles facing resource management across multiple disciplines likely exist because of lack of transparency in existing data. In interdisciplinary research, both qualitative and quantitative data can be linked to the same geographic setting allowing researchers to explore links in a spatial context that might not otherwise emerge. We emphasize participatory GIS, a relatively new field within the GIS discipline, which encourages stakeholder participation and collaborative governance in the decision-making process (Elwood, 2006; Dunn 2007). Similar to the introduction to systems modeling, students cannot learn GIS in a single classroom session. Students with disciplinary expertise in GIS are, as part of their graduate project, building a GIS service for watersheds of interest, easily accessible via the Internet. Applying principles of participatory GIS and survey methodology throughout the development process, students, faculty, and community stakeholder groups are invited to provide direction in the development, display, and functionality of the geographic databases. Once again, we illustrate the capabilities of the tool, the types of questions it might be useful in addressing, and a specific application described below in the steelhead spawning watershed problem. Students are left to decide whether to pursue it further in coursework or use it in their research.

These four tools complement each other in a way that gives students a solid foundation to build their research and interdisciplinary careers. Integrating questions are a logical, and necessary, first step, and students both struggle and engage with what can be a daunting task. Conceptual modeling precedes systems modeling, and exposure to both helps to link qualitative and quantitative approaches. While the systems modeling exercise works well to illustrate changes over time, GIS is particularly suited to exploring spatial issues.

Team-based Projects

To apply the tools learned and to begin the "intuitive" process of learning to integrate, students are required to do two to three team-based projects. (Faculty are currently experimenting with using only two of the three problems to allow more time to reflect on the process.) Choice of projects must balance the fact that to require an interdisciplinary approach, a problem must have at least some complexity (Newell, 2001; Klein, 2004), with the reality of the length of a semester being a limiting factor. Each problem described below is a simplified version of a research project that student-faculty teams in Waters of the West are working on. The problems are simplified to allow completion in the course time period and to emphasize integration between key disciplinary insights. Faculty learned from the initial course offering in which students collected information within their own discipline in addition to working as a team to integrate the information, that both time constraints and the natural tendency to retreat to their own discipline will lead to a multidisciplinary approach with little emphasis on integration of disciplinary insights. The problem packet now includes the basic disciplinary information produced by the faculty/student research team, and the assignment asks questions that call for integration of that material. Students work in teams and are required to produce a group report and presentation. Students are instructed that while solving the particular problem is a goal, we will place greater emphasis in assessment on their description of the methods of integration used to get there. Presentations are followed by a class period devoted to de-briefing the problem including methods used by teams to integrate across disciplines and the problems encountered. Problems given to students become increasingly complex as the semester proceeds.

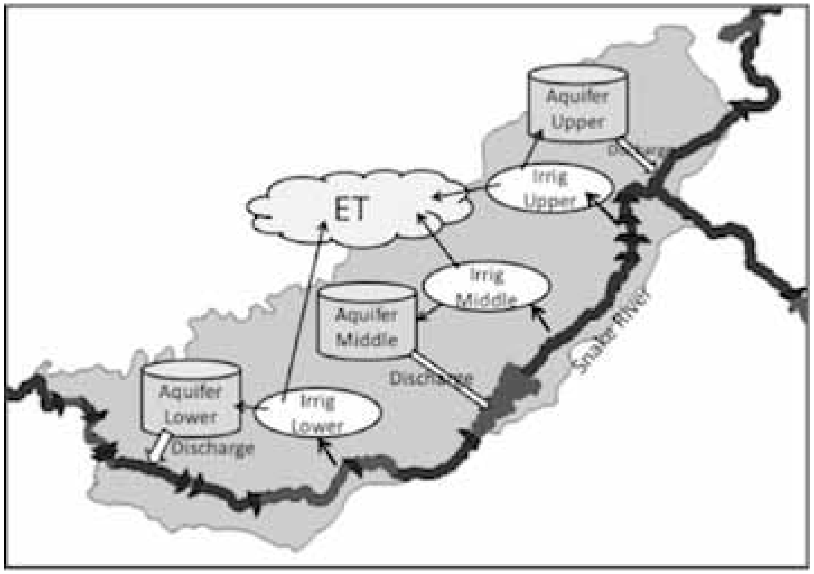

Figure 2: Conceptual model of ground and surface water interaction in the Eastern Snake Plain, Idaho. Kristyn Scott, water resources student.

Conjunctive Management

The first problem is based on conjunctive management of ground and surface water using a case study on the Eastern Snake Plain Aquifer (ESPA) and the Snake River in southern Idaho (illustrated in Figure 2). This problem focuses on the interrelationship between the legal doctrine of prior appropriation and the technical difficulties of determining the relationship between groundwater pumping and river flows to the degree of specificity required to curtail junior (i.e., the last to develop) groundwater pumpers to protect senior (i.e., the first to develop) surface water users. Students work with both administrative rules promulgated for conjunctive management, and output from a model being used to identify which groundwater pumping to curtail. The following paragraph describes the underlying problem, followed by the hydrologic setting of the ESPA; the development of a groundwater model to analyze and quantify the impact of groundwater pumping on

surface water use; the legal setting; and the reliance of the Idaho Department of Water Resources (IDWR) on the model to issue a legal ruling.

On April 19, 2005, Karl Dreher, former director of the IDWR, the entity charged with enforcing water rights in Idaho (Idaho Code §42-602), issued the first order requiring curtailment of groundwater pumping pursuant to water rights with a priority date of February 27, 1979, and later. Curtailment could be avoided if a plan to provide mitigation water in the amount of 133,400 acre-feet to senior surface water users is developed (IDWR Order, April 19, 2005, as amended May 2, 2005). This unprecedented effort to enforce the seniority of surface water rights against junior groundwater use required a thorough understanding of the water resource; in particular, the hydrologic connection between surface and groundwater in the Eastern Snake River Plain (ESRP).

The ESRP is a plain covering roughly 200 by 60 miles in southeastern Idaho underlain by thick basalt flows and interbedded sediments (Johnson et al., 1998). The basalt layers and sediments host the Eastern Snake River Plain Aquifer, a designated sole source aquifer (Idaho Administrative Code 37.03.11.050). Groundwater flow in the contact zones between basalt flows may be substantial. Discharge from the aquifer along these contact zones can amount to the majority of the flow of the Snake River below Milner Dam in summer (Johnson et al., 1998).

With an annual precipitation of only 8-14 inches, this rich agricultural region relies on irrigation. Under the doctrine of prior appropriation, surface water rights from the Snake River and its tributaries, established before the now extensive development of the aquifer, take precedence. Interaction between surface and groundwater is often highly complex. Some of the water spread over the surface of the land by precipitation and irrigation will seep into the groundwater. Seepage will vary with the permeability of surface soils and geologic units, with rate of precipitation or application of water, and with the existing soil moisture content. Surface streams may lose water to groundwater or gain water from groundwater. Flow rates vary within an aquifer. Many streams lose water in some stretches while gaining in others (Winter, Harvey, Franke, & Alley, 1998). As a result of these and other variables, the impact of groundwater use on surface water is not direct, immediate, or one-to-one. Because of this complex interaction, a team of scientists had begun developing a groundwater model four years before its use by IDWR to issue the 2005 Order to aid in management of the aquifer and the development of plans to mitigate the impact of its use on surface water.

The scientists faced problems in modeling at appropriate spatial and temporal scales to allow the detailed analysis sought. Recharge to the aquifer is complex, coming from sources as diffuse as precipitation, irrigation, and rivers. GIS and Fortran-based programs were developed to calculate aquifer recharge from complex land surface water budget analyses. The aquifer recharge estimates were used in a USGS Modflow model of the aquifer that included interactions between the aquifer and the Snake River.

Idaho follows the doctrine of prior appropriation for both surface and ground water (Idaho Constitution Art. XV §3, Idaho Code §42-106). But until now, IDWR had not enforced water rights as if surface and groundwater were one resource (referred to as "conjunctive management"). In 1994, the Idaho Supreme Court ruled that IDWR must enforce a call by senior surface water users against junior groundwater pumpers (*Musser v. Higginson,* 1994). That same year, IDWR promulgated the Conjunctive Management Rules (CMR) to provide uniform guidelines and procedures for enforcing a surface-ground water call. Use of these rules in the problem requires students to learn about the role of administrative agencies and the limits of their authority. The CMRs walk the line between prior appropriation and the legal and real need for efficient use of water in an arid region by basing enforcement of a call on a finding by IDWR of material injury (Idaho Administrative Code 37.03.11.010.07). IDWR may consider a number of variables in determining if material injury exists including factors that reflect water supply, investment, efficiency, availability of reasonable alternative means of diversion, and the use of meters (Idaho Administrative Code 37.03.11.042.01). The CMRs have survived both a facial constitutional challenge (*American Falls Reservoir Dist. v. IDWR,*), and recently a challenge to the IDWR application of the rules (*Clear Springs Foods v. Spackman*, March 17, 2011).

In addition to the complexity of the surface to ground water connection, among the pronouncements in Idaho law that IDWR and the students must deal with are: (1) Idaho law states that the doctrine of prior appropriation, while applicable to groundwater, "shall not block full economic development of underground water resources" (Idaho Code §42-226); (2) the Idaho Supreme Court has repeatedly declared that the public policy of the state prohibits waste in the use of water (*Glenn Dale Ranches, Inc. v. Shaub*, 1972); and (3) Idaho law prevents a futile call, defined in the conjunctive management rules as a call that, "for physical and hydrologic reasons, cannot be satisfied within a reasonable time of the call by immediately curtailing diversions under junior-priority groundwater rights or that would result in waste of the water resource" (Idaho Administrative Code 37.03.11.010.08).

This first project requires students to integrate methods and insights from two disciplines: law and groundwater hydrology. We make the assumption that non-law students have no background in administrative law or process, or in western water law. Similarly, we make the assumption that non-groundwater hydrology students have no concept of what lies beneath the surface of the ground, and that qualitative scientists experience a desire to curl into the fetal position when faced with math. As a simplification of the problem, we ask students to focus on the use of a hydrologic model in a legal process and to understand and be able to argue the various disciplinary insights on whether the degree of uncertainty in the particular model renders it inadequate for the purpose of issuing a legal order curtailing specific groundwater pumping. In doing so, they must also understand the legal process. Emphasis in this project is placed on interpersonal skills, group dynamics, communication across disciplines, and an introduction to the development of an integrating question.

Declining Aquifer Problem

The second problem addresses management of water supply for a community relying on a declining aquifer, based on the Palouse Basin Aquifer that serves the University of Idaho, Washington State University, and surrounding communities. This problem uses a participatory systems approach to characterize the long-term behavior of a basalt aquifer, and to compare the effects of conservation versus new source development with a goal of aquifer stabilization within a 50-year timeframe. Students work with population and hydrogeologic data to conceptualize the problem, conceptual engineering design of new surface water sources, conservation methods, and social science data on public attitudes toward conservation. They are exposed to the use of a systems model to compare different approaches. The following paragraphs describe the difficulties faced by citizens of the Palouse Basin. For purposes of simplifying the problem, students are told to ignore the complicating legal issues associated with the Idaho-Washington border dissecting the resource.

Residents in the Palouse Basin rely on a sole-source, declining aquifer system for their water supply. The deeper and primary aquifer, the Grande Rhonde, is thought to receive little if any natural recharge, as indicated by isotope age dating, which estimates that the water is "fossil" ranging from 12,000 to 30,000 years old (Crosby & Chatters, 1965; Larson, 1997; Douglas et al., 2006), and by the fact that water levels have consistently declined for over 100 years (PBAC, 1992). A shallower and secondary aquifer, the Wanapum, receives an uncertain amount of recharge (Reeves, 2009), and was in rapid decline prior to development of the deeper aquifer in the 1950s and 1960s (PBAC, 1992). The Palouse Basin Aquifer Committee (PBAC) was comprised of representatives of municipal and institutional entities dependent on the aquifer, formed in 1967 (under a different name and slightly different make-up and authority) to coordinate efforts to understand the multi-state water supply and to engage in water planning. PBAC has no decision-making authority, and political leadership in the basin has allowed uncertainty in the understanding of the aquifer to polarize public opinion while few active management decisions have been made in the 40+ years since the formation of PBAC. The following example of an integrating question is based on data on aquifer decline with a high level of uncertainty regarding recharge, and data showing a wide range of public views on the problem and the solution: How does uncertainty in the understanding of the groundwater resource affect public discourse and willingness to take action? A team of Waters of the West faculty and student researchers, who represent the disciplines of hydrology, social science, engineering and law, are conducting an interdisciplinary analysis of this coupled natural-human system to identify barriers to and opportunities for sustainable management. Several key factors have been identified, including: (1) The legal disconnect between both state water allocation and local management of growth (Marchant, 2010), and between water allocation by the two states (Darrington, 2010), prevents consideration of water supply in planning for community growth; (2) Uncertainty in physical parameters such as storativity and recharge is difficult to quantify and communicate, and can potentially lead to paralysis in which decisions are delayed in the hope that more study will end arguments (Reeves, 2009); and (3) The values of local residents, such as their willingness to pay for water to support conservation and/or supply augmentation, are both unknown and under-appreciated by local officials (Bilodeau, 2009).

The focus of the simplified problem used for the class is the use of a systems model developed in the project with the participation and funding of PBAC and review by experts on hydrology and water conservation in the basin (Beall et al., 2011). Of particular importance to student understanding of the value of the model is the participatory process to help managers develop a common understanding of the aquifers and how they are related to human use and decisions, despite a high level of uncertainty. In addition, students must integrate social data to understand how scientific uncertainty

can both distort and be used purposely to distort natural resource decision making. Interestingly, although students are not required to recommend further use of the model, a similar participatory process to move the public off its current polarization is often the first recommendation made.

The second project requires students to integrate groundwater hydrology, conservation and reservoir engineering, geographic information on population, growth and water demand, and social data on willingness to conserve water. In addition to the skills developed in the first project, students are introduced to the use of systems modeling to integrate across disciplines.

Steelhead Spawning Watershed

The third problem is based on steelhead recovery efforts on Lapwai Creek, a tributary to the Clearwater River within the Nez Perce Indian Reservation. The problem requires integration of quantitative and qualitative information across multiple disciplines. Students are exposed to the use of GIS to compare diverse datasets and to look for otherwise hidden relationships.

Lapwai Creek is designated critical habitat for steelhead (Oncorhynchus mykiss) under the Endangered Species Act (ESA), and provides essential fish habitat for chinook and coho salmon. It is listed by the State of Idaho under §303(d) of the Clean Water Act (CWA) for failure to support cold-water biota and salmonid spawning. The Lapwai watershed provides a representative example of widespread water resource conflict in the Pacific Northwest. Despite its relatively small size, and perhaps because of this, the Lapwai Basin serves as a meeting place for nearly all of the contentious and complicated water resource issues that students across a broad spectrum of disciplines can expect to face in the upcoming decades. Physical obstacles to fisheries/water quality restoration include: reduction of viable aquatic habitat due to channelization; water quality degradation from septic systems and agricultural runoff; riparian habitat viability; diminished stream flow. Management obstacles include multiple political jurisdictions and management agencies and "checkerboard" ownership pattern of tribal and private land. Legal obstacles include ongoing litigation concerning an out-of-watershed diversion by the U.S. Bureau of Reclamation. Political and social obstacles include: application of management goals across jurisdictional/demographic divides; poverty and access to resources; and local movement to diminish tribal sovereignty.

The entire watershed lies within the boundaries of the Nez Perce Indian

Reservation established in 1855. Following the discovery of gold within the Reservation boundaries, a new treaty was negotiated with the Nez Perce in 1863, dramatically reducing the reservation to approximately 750,000 acres. Most of the Lapwai watershed remains within these new boundaries. Allotment and opening of surplus land to homesteading in 1893 resulted in a checkerboard mixture of trust, individual trust, and private land. Only 17% of the land within the Lapwai watershed remains in trust status, complicating the jurisdictional issues associated with implementation of any effort for steelhead recovery. Figure 3 (next page) illustrates the process of developing an integrating question by dividing topics into pairs initially. As discussed above, the final integrating question shown in the middle of the figure is vague and does not form a basis for identifying the next steps in research. However, the process of developing the question facilitated a dialogue that addressed many of the communication issues that might have plagued the research effort.

To narrow the focus of the problem for purposes of the course, we ask students to focus on the relation between the immediate floodplain and steelhead spawning. Recently, a successful lawsuit in Washington held that designation of floodplains by the Federal Emergency Management Agency (FEMA) for traditional risk purposes without regard to the impact of allowed floodplain development on critical habitat for listed species is a violation of the consultation requirements of Section 7 of the ESA (*National Wildlife Federation v. FEMA,* 2004), and a similar suit in Oregon led to settlement (*Audubon v. FEMA*, 2010). Waters of the West researchers believe this is the tip of the iceberg and that development of a methodology for integrating habitat information with floodplain mapping is needed. Students in the course use the preliminary approaches being developed by student researchers in the program. Steelhead data have been collected by students under a grant from the U.S. Bureau of Reclamation. Developing floodplain maps at several flood levels and integrating steelhead data in a GIS database, as is done in the research project, would be beyond the scope of what students in the introductory course can accomplish, thus they rely on developed maps. Students must nevertheless understand how this information was created and how the ESA leads to its need.

Recognizing that social conflict may overshadow all other issues in the Lapwai watershed, the faculty-student research team conducted a situation assessment (also referred to as social assessment and stakeholder assessment in the literature—see for example Prell, Hubacek, & Reed,

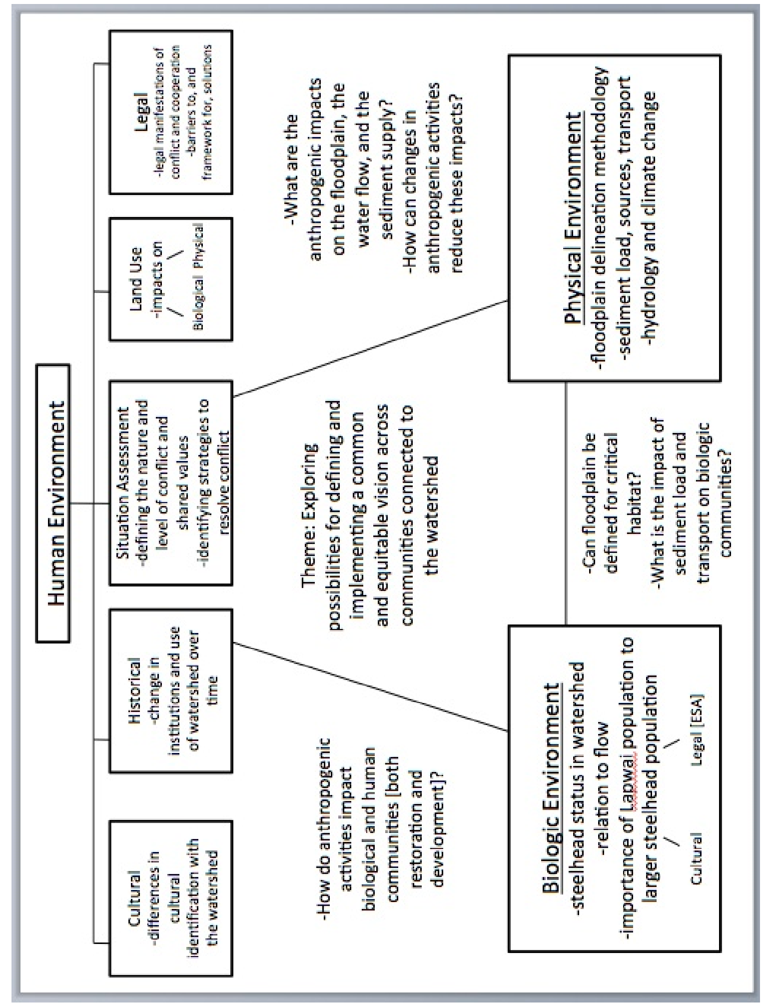

Figure 3: Integrating questions developed by the faculty/student team working on the Lapwai Watershed Project, a research project of Waters of the West, University of Idaho.

2006; Tanaka, 2006). The assessment is based on a series of face-to-face and telephone interviews with watershed stakeholders, including local residents, the Nez Perce Tribe, Nez Perce County, the City of Lapwai, Lewiston Orchards Irrigation District, the Nez Perce Soil Conservation District, Lewiston Chamber of Commerce, Lewiston Orchard residents, riparian landowners, and other stakeholders that were identified in the course of the assessment. A "snowball" sampling method was used to identify interviewees. That is, interviews with key players in each stakeholder group were asked to recommend others who should also be interviewed. Interviews continued until no new information was anticipated from additional interviews and no new key stakeholders were recommended by assessment participants. In this case, 27 interviews were completed. These interviews resulted in a report that: 1) describes the origin and purpose of the Lapwai Creek assessment and related research efforts; 2) summarizes the range of concerns, issues and ideas identified by participants in the assessment; and 3) makes recommendations for process structure and design. Interviewee comments focused on the needs of fish, historical changes in land and water use and their impacts on the ecological health of the watershed and opportunities for cooperative learning and decision-making. The report identifies a range of processes that might be appropriate for achieving shared goals, with a recommendation to begin to develop collaborative relationships that include local residents and landowners. Several issues, including levee placement and maintenance, upland forest management and flood plain zoning were offered as a good starting point for such collaboration. Additional products of the assessment might be descriptions of the Lapwai Creek watershed, including what is known about its life history, existing research documents related to the watershed and its complex social and political history, as well as an extensive collation of existing documents related to projects and research by UI faculty, Nez Perce Tribe, natural resource agencies and other entities. Students in the course must use this additional information in analyzing the social barriers and avenues to floodplain protection for steelhead spawning.

The third project requires students to understand the integration of floodplain delineation and steelhead habitat data, to overlay an understanding of the legal requirements of the ESA and to integrate social data in developing solutions. Students are exposed to the use of GIS as a tool for comparison of diverse datasets.

Conclusion

Interdisciplinary work is difficult and time consuming, confirmed by observations of students by faculty in this course. A passion to solve complex problems is needed to carry students through the difficult maze of information coming at them from multiple disciplines. Yet in entering the fifth year of experience with trying to capture interdisciplinary research in defined methods, it is clear that there are steps a student can follow to ease the process. The process is informed by the concept of development of disciplinary adequacy in other disciplines, and use of tools for integration including integrating questions, conceptual modeling, systems modeling and participatory GIS.

Discussion of disciplinary adequacy helps students understand that simply relying on experts from other fields is insufficient for integration even in team-based projects. Communication is a fundamental integrating tool. By first leading students to better understand differences in language and methodology through discussion of interdisciplinary adequacy, while concomitantly improving basic interpersonal and teamwork skills, we found that they were better able to apply the integrative process that has evolved through work by Klein (1990), Newell (2001), Szostak (2002), Repko (2008). In particular, focusing on the differences and commonalities between quantitative and qualitative approaches (without regard to particular disciplines that tend to rely on one or the other) facilitates communication and thus integration by people with disparate backgrounds. Of course, creating a fun working environment and allowing for bonding—interestingly, by way of a qualitative research assignment in the course—greatly improves interdisciplinary collaboration. This process is mimicked at the programmatic level in Waters of the West by reasonably frequent social gatherings.

We chose to teach and employ a set of integrating tools based on what is suggested in the literature and personal experience. The use of integrating questions is not new, but we discovered that their utility improved with prior explicit instruction in communication. The communication toolbox (Eigenbrode et al., 2007) is particularly useful in this regard. Integration by twos is a useful method to help guide students in their development. Conceptual and systems modeling are complementary, as they are qualitative-quantitative analogs. While most people can immediately jump into conceptual modeling, systems modeling takes some time to learn and is thus less useful for integration over a semester course unless the models have already been developed. GIS allows for integration of spatially oriented information from multiple disciplines, including qualitative data. Similar to systems modeling, use of GIS requires special skills that are not amenable to teaching within the course, so either a pre-developed GIS analysis or use of an in-class expert is necessary. Importantly, by requiring the interdisciplinary methods course in the students' first semester of graduate school they can identify tools that may be useful in their own research and take further courses in that area. Other tools may be equally viable, but the key point is this: When people with disparate backgrounds must use or build or solve something together with a common technique or process, integration occurs.

One of the important lessons we learned is that student and faculty teams are inclined to approach problems in a multidisciplinary manner: problems are divided into disciplinary components, experts in those areas conduct the work in those components, and everyone gets together at the end to integrate. While integrating questions help teams stay focused, their development does not necessarily preclude fallback to a multidisciplinary approach. One means of avoiding it in the classroom is to provide students with problems for which much of the disciplinary work has been completed, so that the primary remaining task is integration. By requiring students to describe and evaluate their method(s) of integration in the project report, increased attention is given to using a systematic approach to integration. We have also experimented with having the students first do a small project in a more traditional, multidisciplinary fashion, followed by another small project in which they continuously work together and integrate. This approach explicitly illustrates the differences.

Finally, we have observed that it is useful for faculty to model the interdisciplinary process, whether within the classroom in the form of discussions involving faculty from several disciplines, or outside of the classroom by using projects derived from ongoing research. The former is difficult to sustain, as time and management constraints usually do not allow multiple faculty to routinely attend a single class.

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Gary Johnson is a Professor of Geological Sciences at the University of Idaho, a faculty member of the Waters of the West Program, and has been a member of the team teaching the course in Interdisciplinary Methods in Water Resources. His teaching and research focus mostly on groundwater hydraulics, regional scale modeling, and surface and groundwater interactions, and aquifer management. The need for interdisciplinarity has emerged in several of these topics where science, economics, policy, and law are all needed to implement the changes necessary for flexible and efficient use of our resources. His off-campus work location in southern Idaho integrates him heavily into distance education and places him in close contact with water users and managers.

Brian Kennedy has been an assistant professor at the University of Idaho in the Departments of Fish and Wildlife and Biological Sciences for the past five years. He is an aquatic ecologist with interests in the biogeochemistry, community ecology, and fish biology of fluvial environments. He teaches fish ecology, stream ecology and population ecology. The current research in his laboratory focuses on community interactions in streams; how biotic and abiotic relationships create energetic opportunities and challenges for freshwater fishes; and in salmonids, specifically the impacts and consequences that this has for migratory decisions and, more broadly, the evolution of unique life history patterns. In the process, the lab explores novel ways of approaching these questions through the development of biogeochemical tracers and isotopic approaches. Before moving to Idaho, Brian was a postdoc in the University of Michigan's Department of Geological Sciences (2001-2005), a graduate student in Dartmouth College's Ecology and Evolution program (1995-2001), and an undergraduate at Colgate University (BS, 1991).

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