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Water and Society: Interdisciplinary Education in Natural Resources

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Abstract: Natural resource management and education must account for both the natural and human components of a complex system, yet examples of such interdisciplinary approaches are still relatively rare, especially in education. This study discusses a graduate seminar on water management, developed from an interdisciplinary National Science Foundation (NSF) grant. The seminar applied constructivist pedagogy which is not only best suited for interdisciplinary work, but also allows flexibility to redesign the course components and deliverables after each evaluation cycle. While the seminar was a successful experiment, several challenges remain when implementing such courses. These challenges include not only the organization and assessment of course deliverables, but also fitting such courses into the administrative structure of the university when represented disciplines are located in several colleges across campus.

Keywords: *constructivism, interdisciplinary, groundwater, coupled systems, graduate education*

Water is a primary requirement for successful agricultural production to feed the world's population. Yet, water related stresses such as aquifer depletion and climate change pose threats to food security in both the short- and long-term. Today it is well understood that natural resource management must account for both the natural drivers and the human dimension of such complex systems. However, most academic knowledge has been, and continues to be, produced within isolated disciplines (Miller et al. 2008), and the training of both scholars and professionals still takes place within disciplinary environments. While the recognition that human actions are intertwined with biophysical changes is not new (Marsh 1864), the push for research on these relationships that incorporates knowledge across social and natural sciences has intensified in recent decades (Stern et al. 1992; Lubchenco 1998; Grimm et al. 2000; Kinzig 2001; Redman et al. 2004). This recent effort stems, at least in part, from policy makers' demands for science-based assessments of problems that are outgrowths of coupled human and natural systems. While it is important to learn specific skills and perspectives accumulated by various disciplines, it is equally important to gain a comprehensive understanding of coupled natural and human systems to find the best responses to complex challenges that emerge.

Funding agencies such as the National Science Foundation (NSF) have sought to accelerate research integrating the social and natural sciences by creating new streams of research funding, with 2011-2016 Strategic Goals to "Transform the Frontiers" and to "Innovate for Society." Within the last decade, the NSF funded research grants under new crosscutting programs such as Dynamics of Coupled Human-Natural Systems (CNH), Urban Long-Term Research Areas (ULTRA), Integrative Graduate Education and Research Traineeship (IGERT), NSF Research Traineeship (NRT), Water, Society, and Climate (WSC), and the National Ecological Observatory Network

(NEON). Developments in both the philosophy of scientific inquiry and the funding responses from national agencies point toward the integration of research and education within an interdisciplinary framework. While almost all challenges societies face are complex, spanning several disciplines and requiring multidisciplinary solutions, certain fields are better suited for such initiatives.

This study discusses experiences and lessons learned from an experimental graduate course, "Water and Society," an outgrowth of NSF funded interdisciplinary activities on water resources connecting research and education. Constructivist pedagogy was heavily emphasized and focused on the use of water resources in an agricultural setting. The importance of this approach lies in the central component of constructivist pedagogy, which redefines the role of the student to become an active learner, contributing to the delivery of the content. This approach works particularly well for interdisciplinary learning where disciplinary knowledge is not only presented and synthesized, but also actively negotiated throughout the entire course. The class was taught by a team of instructors who themselves had to negotiate this knowledge, producing a dynamic and balanced classroom environment in contrast to the typical strictly separated roles between teachers and learners.

The pedagogical and administrative experiences and challenges of this five year project are discussed in this paper. Since academic knowledge has been advancing toward interdisciplinary perspectives and applications, graduate courses like this one will likely be increasingly important components of higher education, working toward the societal goal of training professionals capable of responding to sustainability challenges in natural resource management.

Conceptual Background

Miller et al. (2008) argue that the main limitation to interdisciplinary research is not that scholars fail to recognize the inherent cross-disciplinary nature of researchable issues, but rather that their disciplinary training exposed them to particular epistemologies, or theories of knowledge. While essential to the progression of knowledge within disciplines, different epistemologies across disciplines are incongruent and cannot be seamlessly merged when scholars in these fields work independently on the same problem. For example, the "knowledge as mechanism" metaphor common in the natural sciences and engineering leads to a very different form of argumentation than the "knowledge as narrative" metaphor that is typical of the humanities and certain social sciences (Miller et al. 2008).

In order for future scholars to meaningfully integrate knowledge across disciplines, they must be exposed to different disciplinary approaches, preferably during their graduate training while their conceptions of knowledge are still being developed. Institutions of higher education have been challenged to reform curriculum and instruction that leads to the preparation of students with the skills, attitudes, and dispositions necessary for the 21st century. No longer is it acceptable for students to graduate from college with only domain specific knowledge from their major; but rather, students are expected to create innovative applications of content knowledge while working collaboratively with others to solve complex real-world problems. Unfortunately, the very structure of universities may hinder such knowledge creation or skill acquisition, as shown by our example where the challenges were as much administrative as conceptual. Nonetheless, interdisciplinary initiatives in graduate education and the general approach of constructivist learning are best suited to shape such initiatives, due to their emphasis on active learning (Yarrow and Millwater 1995).

The fundamental characteristic that makes the constructivist teaching method effective is the idea that learning is an iterative and integrative process where the student builds upon extant knowledge by taking an active role in the construction of knowledge formation (Piaget 1977). This reasoning has been incorporated by educators in constructivist learning environments which are student-centered and learner controlled, orienting instruction towards the active student learner and away from the passive information gatherer (Yarrow and Millwater 1995; Mara 2005). This constructivist learning paradigm has also been effectively extended to include technological innovations available in the contemporary classroom (Jonassen et al. 1999).

Interdisciplinary courses are based on the idea that real world problems are broad, complex, and require tools and information from a variety of different disciplines to formulate solutions. Courses are usually designed around a central topic, and then coursework incorporating different disciplines relevant to that topic is employed. Hollenbeck (2006) gives the example of the Dust Bowl of the 1930s, which is typically confined to a history class. The interdisciplinary class incorporates the historical components of the Dust Bowl, but also includes many scientific disciplines such as climatology, meteorology, ecology, and geology, which are all relevant to the event, but typically would not be incorporated. Students learn the effects, causes, and overall difference in life before and after this historically significant event using multiple disciplinary approaches.

Interdisciplinary learning integrates knowledge from multiple disciplines across a central program theme or focus (Ivanitskya et al. 2002) and requires understanding higher-order relationships and organizing principles (Goldsmith et al. 1991). The principles of constructivist learning theories applied in interdisciplinary courses support the development of student learning outcomes desired for the 21st century. The constructivist approach uses real world examples, and is built around the student designing pertinent questions and actively seeking answers, while the instructor operates as a resource to help the student find the information needed. Constructivist pedagogy also has students practice self-evaluation and extend learning concepts outside the classroom, and fosters the ability of students to apply concepts and skills to new situations (Yager 1991).

The Water and Society Course

Societal problems in natural resource management offer excellent opportunities for interdisciplinary collaboration. They usually combine the two aspects necessary to understand the greater picture: 1) the physical characteristics of a natural phenomenon, and 2) the social and economic drivers of human decision making. Supported by a grant from the CNH program of the National Science Foundation, an instructor team used water resource management as the theme of an experimental graduate course. The objective was to facilitate a constructivist learning experience in which students develop their understanding of the subject through a number of group assignments. Teamwork was emphasized based on the recognition that professionals will increasingly need to work in interdisciplinary teams to solve natural resource challenges.

The course has been offered five times (2006, 2007, 2008, 2011, and 2013) to small groups of master's and doctoral students, and was co-taught by an interdisciplinary team of six faculty from four different colleges. The course was open to any students, but targeted recruitment was employed via the disciplinary networks of the faculty involved. While the general topic remained the same, class assignments, deliverables, and assessment methods were occasionally changed from one year to another, following the annual evaluation results (Tables 1 and 2).

Water and Society started as a one credit hour class. Soon it became clear this hindered the interaction between students as well as between students and instructors due to limited class

Table 1. Basic course characteristics.

Year	Credit Hours	Weekly Meeting Times	Number of Faculty	Number of Students
2006	1	One hour weekly for 16 weeks	5	7
2007	1	One hour weekly for 16 weeks	5	6
2008	1	Two hours weekly for 8 weeks	6	7
2011	3	Three hours weekly for 16 weeks	6	5
2013	3	Three hours weekly for 16 weeks	6	9

Table 2. Disciplinary components and learning outcomes.

Year	Disciplines of Participating Students	Main Learning Outcomes	Main Student Deliverable
2006	Agricultural Economics Agronomy Civil Engineering Landscape Architecture Sociology	• Increasing understanding of water resources systems as coupled human and natural systems • The ability to explicate features of the system from multiple disciplinary viewpoints	Collaborative paper explaining the complexity of a water resource system
2007	Civil Engineering Landscape Architecture Sociology	• Increasing understanding of water resources systems as coupled human and natural systems • The ability to explicate features of the system from multiple disciplinary viewpoints	Collaborative paper explaining the complexity of a water resource system with a stakeholder role-play exercise
2008	Agricultural Economics Agronomy Civil Engineering Landscape Architecture Sociology	• Increasing understanding of water resources systems as coupled human and natural systems • The ability to explicate features of the system from multiple disciplinary viewpoints • The ability to quantitatively analyze interactions among various features of water resources systems	A spreadsheet demonstrating the interplay of various factors in a water resource system with a stakeholder scenario game
2011	Agronomy Civil Engineering Political Science	• Increasing understanding of water resources systems as coupled human and natural systems • The ability to explicate features of the system from multiple disciplinary viewpoints • The ability to quantitatively analyze interactions among various features of water resources systems • The ability to use a variety of analytical aids to develop a complex model of system interactions	Interdisciplinary computer model simulating the complexity of a water resource system
2013	Agricultural Economics Civil Engineering Landscape Architecture Sociology Political Science	• Increasing understanding of water resources systems as coupled human and natural systems • The ability to explicate features of the system from multiple disciplinary viewpoints • The ability to quantitatively analyze interactions among various features of water resources systems • The ability to use a variety of analytical aids to develop a complex model of system interactions	Interdisciplinary computer model simulating the complexity of a water resource system with stakeholder interaction

time. The adjustment in 2008 was to combine two class hours and have the course taught for eight weeks as opposed to sixteen. It helped the learning experience, but as the final deliverable became more complex, the credit hour number was eventually increased to three. At the same time the class returned to the 16 week teaching schedule. This helped facilitate student teamwork outside the class setting.

The class started with five faculty from various fields: agronomy, agricultural economics, civil engineering, landscape architecture, and sociology. Faculty turnover resulted in adding political science and computer science, and losing landscape architecture. The impact these changes had on the course could easily be accommodated by the constructivist pedagogy. With a few exceptions, all faculty members participated in all class sessions, with different professors serving as the main instructor depending on the topic of the day. Faculty participation in class discussion was intensive in the first few weeks to give as much collective background to the conceptualization process as possible, but more limited later when students were tasked to synthesize and extend what they had previously learned. This allowed a natural student transition from disciplinary learner to interdisciplinary problem-solver. The following overview provides a sample on how each discipline approached this main subject.

The *agronomic sciences* cover a broad range from basic research into biological, chemical, and physical aspects of plant and soil systems to applied studies and delivery of new technologies in soil tillage and amendment; crop breeding, genetics, and improved varieties; and integrated best management practices for crop production. The agronomy section in this class described the roles of plants as economic products of an agricultural system and also, at the physiological level, important valves both controlling water transport and creating the need for groundwater exploitation. For example, irrigation to meet plant transpiration needs comprises 95^{+} % of groundwater use in the geographic areas focused on by the class. In one year there was a felicitous synchronization between class scheduling and agricultural field research. It was possible to bring to class samples of experimental sorghum lines being bred for biofuels applications. These plants were visually striking (being over 12 feet tall) and provided an exceptional vehicle for explaining plant processes ranging from growth, development, water relations, plant genetic controls, and their manipulation via breeding.

Plant processes such as these have been the subject of computer simulation efforts for half a century. As the course incorporated more computer simulation, it was also possible to leverage this section to present "how to" information on modeling. This involved steps ranging from the identification of basic system components, to the mathematical description of the relationships governing their behavior, to the computer implementation of those equations, and ending with a systematic evaluation of model characteristics (e.g., stability and sensitivity) and verisimilitude to reality.

For *hydrology* the important properties that control hydrologic processes are mass, flux, pathways, and residence time. Across the globe, the mass of water resides in stores including surface water, glaciers, the atmosphere, and groundwater. Water fluxes occur within each store and pathways exist between the stores (e.g., a portion of precipitation seeps downward in soils past the root zone and eventually recharges groundwater). The residence time in each store varies on the order of hours/days in the atmosphere to years/millennia in glaciers and groundwater.

The *groundwater* component of the hydrologic cycle was illustrated in class using a sandbox demonstration. In this, recharge entered layers of alternating granular porous media, layers of clay that retarded the movement of water, and underlying limestone where water flowed through fractures. Mass was computed by multiplying the volume of media containing water times the porosity (volume of pores/total volume). Flux and pathways were visualized by injecting dye and observing travel times, and the impacts of human forcers, such as pumping water from wells. It was also observed that groundwater has a much larger residence time when traveling through pores between granular media than when traveling through fractures in limestone. The sandbox demonstration helped students visualize hydrologic processes and properties and taught the

differences between porous and fractured media flow, and basic concepts such as head (groundwater elevation) and discharge (pumping rates). These variables controlled the quantity of groundwater that was available for use as well as the flow rates that were available for extraction/diversion.

The *economics* section involved an integrative lecture and an experiential activity. The lecture portion provided an overview of the subdiscipline of environmental and natural resource economics with an emphasis on the types of questions commonly addressed in the field. The inherent links between economic, socio-cultural, and biophysical phenomena were discussed. An example of integrative cross-disciplinary research (Steward et al. 2009) was presented in which economic analysis was coupled with hydrologic modeling to address groundwater decline issues.

The experiential activity was a classroom experiment commonly used by experimental economists called the "common property game." In this exercise the subjects were joint owners of a resource and could make individual decisions about how much of the resource to extract. The game can be presented in various forms, but in our case the property owned was a (hypothetical) shared bank account with an initial balance of \$10 x *N*, where *N* was the number of students. Each student decided to withdraw an amount up to \$10. The remaining balance in the account after the combined withdrawals was multiplied by an interest rate and the final balance was divided equally among the students. Thus, each student's earnings were the amount initially withdrawn and his or her share of the final balance. The maximum group earnings occurred when everyone withdrew zero dollars and the full initial balance accrued interest. At the same time, the individual incentive was to withdraw at least some of the funds initially. As is typical of the results from literature, students chose to withdraw nonzero amounts initially, reducing the group gain. These results and the similarity of the incentives in this game to those of pumping water from a common pool aquifer were discussed.

The *political science* section of the course provided an introduction to the study in policy analysis and policy sciences. Given that most of the students enrolled came from engineering or agronomy backgrounds, this section emphasized the social scientific nature of this field of study. The purpose was to make sure that students understand there is a disciplinary framework for the integration of knowledge from several fields of study to help study and resolve water policy issues.

The section began by noting that political science entails search for systematic explanations for political phenomena. In the field of political science, aggregate patterns of behavior are studied rather than individuals or singular events, and theoretical models are probabilistic and nomothetic. The next part of the discussion covered the differences among policy studies, policy analysis, and policy sciences. *Policy studies* focus narrowly on one policy area using methods from primarily one academic discipline, such as cost-benefit analysis from economics. By contrast, the subfield of *policy analysis* is the process of multidisciplinary inquiry designed to create, critically assess, and communicate information that is useful for understanding, developing, and/or improving policies. *Policy science* is a holistic, multidisciplinary approach, which focuses on solving problems by integrating both qualitative and quantitative information from all disciplines to design policy solutions.

The *sociology* component focused on the conceptualization of natural resource management, the power and inequality inherent to extractive industries, and the social demography of water resource systems via labor market outcomes. A brief lecture on social change and population dynamics illustrated the relationship between the two, and examples from various counties were used to demonstrate the impact of fertility, mortality, and migration on long-term population trends and population composition. The lecture included a discussion of sustainability at various levels of geography from local to global.

Following the lecture, students were given an introduction to population projections, discussing the two most commonly used methods: mathematical extrapolation and cohort component projection. It was demonstrated how various projections could differ based on the time period used for constructing the baseline assumptions. This was followed by a group exercise of a cohort component projection model. The students

discussed assumptions about fertility, mortality, and migration that were entered in the model in class, based on the 2000 population of a randomly selected rural county. The results of the population models were discussed with the objective of comparing the relative weight of each component in the final outcome. The discussion was then connected to potential policy initiatives addressing economic development options (based on the availability of water) and predicted population dynamics.

Two additional disciplines, landscape architecture and computer sciences, were used for additional technical insights in the course. *Landscape architecture* focused on the use of GIS tools in modeling various layers of the land from topography to human interactions. In addition, a unique game was developed around the various perspectives and elements of the water resource system in the state. The goal was to model how communities, with often contradicting perspectives within the community, deal with water allocation in an over appropriated water area. This game was crucial to add the land use perspective in scenario design and decision making.

The *computer science* section introduced the students to the practice of integrated modeling through a combination of group discussion and hands-on experimentation. A short lecture initiated the discussion and outlined the process of formalizing conceptual domain-level process interactions into concrete data exchanges between models. The discussion highlighted the primary challenges of model integration (e.g., resolving differences in programming languages) and the broad spectrum of approaches (e.g., linking models vs. combining them), with emphasis on the additional complexity involved in integrating multidisciplinary models. An integrated computer model that was part of an ongoing research study served as an applied case study of how disciplinary models for groundwater, economics-based crop decision making, and crop production can be linked together using the Open Modeling Interface (OpenMI) (Gregersen et al. 2007). The linked model provided the students with a context for both learning about the OpenMI and learning how to utilize an integrated model. Lab training on executing the linked model and inspecting the simulation output for different input data sets enabled the students to later utilize this model outside of class as part of the final class deliverable.

The number of students taking the course was small, although not unusually so for graduate seminars. Recruitment efforts were focused on getting a relatively even representation from the various disciplines. This worked best in 2006, 2008, and 2013, and created significant challenges in 2007 and 2011.

The main deliverable changed each time the course was taught. In the first year, which was a learning experience for the faculty as much as it was for the students, the course ended with a collaborative paper describing the interaction between the components of a complex water resource system. In the second year, a stakeholder roleplaying exercise was added when students had to present the findings as members of various stakeholder groups, arguing for individual interests while keeping the interdisciplinary perspective. This proved to be very useful, so the third year task was to develop a comprehensive game around these various interests and perspectives. The game included a complex spreadsheet modeling the interactions based on stakeholder decisions. During the final presentation, the students played the game on a sample county landscape game board representing an area with an aquifer. In the fourth year, the emphasis was on computer modeling which integrated a number of existing disciplinary components. In the last iteration, the computer model was supplemented by a live video presentation to faculty and students of a community college in the state (many of them stakeholders outside the classroom) who interacted with the graduate students on campus via videoconferences. That way the final deliverable was not only evaluated by the faculty, but also a stakeholder group in the region. The deliverables therefore evolved from developing a simple conceptual model to writing a more complex computer tool.

The course had three major modules, covering an approximately equal share of the 17 week course. The first module was the period of contrasting the students' own disciplinary perspectives on water resource management systems with a cross-disciplinary vision on the same issue. In this module, students developed an individual

diagram of a water resource system based on their own disciplinary training and background. Once completed, they were instructed to work as a group (which is why keeping the class size small was very important) to create a collective understanding of the issue. This was required to incorporate all disciplinary perspectives.

In the second module the students were exposed to various stakeholder interests and discipline-specific lectures in water resource management. These were highly interactive with discussions and reflective writing components on fundamental literature in each discipline. The purpose was to deepen each student's knowledge regarding the various fields represented in the course.

After the disciplinary perspectives, the third major module of the course focused on the synthesis of the material and developing the main student deliverable for the class. This module varied according to what the main deliverable in a given year was. In the first and second years, it was mostly group discussions. From the third year onward when computer modeling was involved, there was a more comprehensive work not only focusing on the conceptual links, but also on how these could be translated into actual calculations. In the fifth year when the interactive video presentation was added, the final module included a follow-up presentation to the distance stakeholders based on their questions and comments during the first session. A constructivist approach to teaching helped keep the third module flexible enough to revisit any particular fields that proved challenging to the students. The practice of all faculty being present in all sessions maximized the ability to respond to student inquiries and discuss tangents if needed.

The case study for the class in each year was the depleting groundwater of the Ogallala Aquifer. After learning about the disciplinary perspectives, students were required to develop a conceptual model of how various components of the water resource system interact with each other. To connect this model to applied questions, the dynamics had to follow the farmer's decision making considerations from both the natural and the socioeconomic systems (such as water availability and economic incentives).

Once the conceptual model was in place, students were required to collect data on the dynamics of the system, such as recharge rates, water used for irrigation, crop choices, employment structure, and demographic trends. Selecting one study county, students applied the collected data on the conceptual model, and integrated the two using the OpenMI framework. Finally, they were required to demonstrate various policy changing scenarios and their impact on the combined model. Part of this demonstration was done in a live videoconferencing situation where students and faculty from a community college in the study county had the opportunity to ask validating questions about the application of the model on that specific location.

The assessment of student work was as complex as the material covered in class. While there were minor changes for each new iteration of the course, the basic assessment structure remained the same and included both individual and team assessments. Disciplinary components were evaluated through reflective writing assignments that were graded by standard rubrics using Bloom's taxonomy of learning domains. Conceptual work was assessed through the individual and collective diagram of the water resource system, graded separately. The grading emphasis was on the inclusion of various elements of the system as well as on demonstrating the causal and non-causal mechanisms between those elements. Interdisciplinary data projection and model application were assessed as a team project by providing students a specific scenario which they had to apply in the model. Finally, the term paper and its oral presentation were assessed using a revised version of Bloom's taxonomy, putting more emphasis on application and self-evaluation at the team level.

An external evaluator was hired to document the process and the impact of using a constructivist approach (discovery-based, problem-based, cooperative learning, interdisciplinary) to teach the Water and Society course. The major evaluation questions focused on the process of implementation, the constructivist principals that were used, and the application of constructivist components.

A mixed methods evaluation design using both qualitative and quantitative data collection and analysis was implemented. On several occasions

evaluators were present during classroom discussions and other activities. A multi-case study (the student as unit of analysis) was used to explore the relationships among the following student variables: preferences for learning, performance, interaction, and perceptions of the extent to which teaching and learning elements of the constructivist classroom enhanced student's personal learning. Data collection techniques included document review, surveys, performance assessments, and interviews. The evaluation plan included a system of recursive review, analysis, and reporting to allow the instructors to make necessary modifications to the course during the duration of the semester. At the end of each year, the evaluator provided an annual review from which the team made modifications for the next installment of the course.

Discussion and Conclusions

The Water and Society course was taught five times between 2006 and 2013, using constructivist pedagogy to address complex interdisciplinary issues. The external evaluation revealed five themes as the noted benefits of this approach: 1) increased interest in the subject, 2) increased knowledge of water management issues, 3) utilization and communication of multiple perspectives, 4) enhanced problem-solving skills, and 5) improved communication and leadership skills. Most of these would probably apply to any other topic under the same pedagogy. In addition, among the benefits of this learning experience, students emphasized not only the content of the course, but also the applied learning methodology. This indicates a type of knowledge transfer which shows that constructivist pedagogy supports a sustained educational experience.

The constructivist approach provided significant flexibility for the instructors to accommodate not only the different disciplinary processes of graduate education, but also the differences in student background and training. In addition, this approach made it possible to adjust the course schedule and activities if students needed additional time to complete a team assignment or were looking for more in-depth explanation about a particular module or disciplinary context. Given that both the student background and the deliverable were different each year, constructivism was a necessary cornerstone of the instructional methods.

Based on external evaluations and feedback from faculty, an integrated interdisciplinary class setup further enhances the understanding of complex issues, and better prepares students for professional positions. It is widely understood that insights from other disciplines improve understanding of the big picture. Some of these insights can be acquired by taking classes in other academic fields, but putting teams of instructors and students from different fields together to work on a complex problem promotes learning new material and requires applying it at the same time. Such simultaneous knowledge acquisition and application is the best formula for retaining new information and skills.

This course brought up several challenges regarding interdisciplinary education at the graduate level, in addition to its successes. Some of these challenges were anticipated by the instructor team, while others emerged unexpectedly. We believe that these were general enough to merit a discussion and recommendations about course development in an interdisciplinary setting.

One challenge was to find students who could most benefit from the particular knowledge and skills offered in the class. The practice and understanding of interdisciplinary work varies across disciplines, therefore students in various fields had different expectations about the usefulness of the course. At the same time, an interdisciplinary student body was crucial for the success of the course. Recruitment was eventually done through individual faculty efforts where discipline-specific messages were used to target students in various programs. This was one aspect where the constructivist method was as much an obstacle as an advantage. The course structure was kept flexible, which meant that in the recruitment phase little information was available to give to the students, especially in the first years. The experience over the five years was that as the course moved from a conceptual to a more practical application, it was easier to advertise its benefits for students. The more personal, network-based student recruitment could overcome the lack of early information, but this would not allow marketing the class in the traditional manner.

A typical recruitment challenge was that it was not always possible to have students from every pertinent discipline each year. The success of the final deliverable, as well as the general understanding of the course material given the strong emphasis on student teamwork, was contingent upon having a variety of fields represented among the students. It was clearly visible how certain components of the final deliverable were weaker if a particular discipline was not represented. This challenge emerged in the second year, and the instructor response was the introduction of disciplinary modules. However, this could not fully address the problem as a student in one field cannot become an expert in another field after a few in-depth classes. This was particularly true across the natural sciences and social sciences division, and regarding fields that have substantial training in mathematics, such as engineering and computer science. Moreover, having a student from a particular program was not an assurance for successfully completing a given disciplinary task, as students were quite different even if they came from the same field. This was especially true for the social sciences where graduate education could take various forms toward the advanced degree. For example, a sociologist with an emphasis on demography would result in a different final deliverable than a sociologist with training in rural development and inequalities.

Interdisciplinary instruction is easier to imagine than to implement, and the first requirement is that the faculty team agrees on what constitutes knowledge that is transferrable across disciplines and which scientific vocabulary to use in education. Even simple terms such as 'theory' or 'models' mean vastly different things in different disciplines. In this case, the instructor team had been working together for years by the time the course was first offered, and there was a general agreement on how to develop the course. However, teaching this class was as much a learning experience for faculty as it was for the students. Certain aspects of the class, especially assessment, proved very difficult to administer with students used to different evaluation practices. One example of this was the balance between reflective writing assignments and computational exercises. The former was easier for students in social sciences, while the latter came more naturally to those in STEM fields. The relative weights of such assignments had to be carefully designed and evaluated so that a student would not fall behind because his or her discipline has less emphasis on a certain type of assessment.

Faculty members taught this course on an overload basis, without any financial compensation. While this is feasible for a single offering or a short series of offerings, its sustainability is questionable. For example, it was not possible to obtain a course number, because the university structure did not have one available. In the first few years, students took the class as independent study courses within their own disciplines. Since Water and Society not only cut across departments but also colleges, it was a long administrative process to develop a structure which made cross-listing the course with the 'GRAD' prefix possible. Questions to be solved included the allocation of credit hours, tuition income, and the distribution of various fees and expenses related to equipment use.

The growing emphasis on online education brought up the possibility of having both on campus and distance students in the class. In 2011 and 2013, the class had distance students as well. One challenge the team was not able to solve was the successful incorporation of distance students. The technical part of this challenge was less of a problem as the team utilized various technologies, such as a data repository for readings, recorded interactions for those missing class and working in distance mode, a message board to foster communications, and videoconference meetings. However, the intensive face to face teamwork with collective assignments that required several meetings outside of the class made it very difficult to involve distance students in class work. Despite the availability of various communication tools, this aspect is yet to be solved.

Finally, it is important to note the impact of interdisciplinary education on the students' future career. We know little about how interdisciplinary graduate training affects individuals once they enter the workforce. There are, of course, a number of reasons to expect it would be beneficial. Likely in response to the funding models at NSF and other agencies, there are a growing number of research and teaching jobs posted with "interdisciplinary" as a key word.

Presumably students with coursework like Water and Society are better positioned to obtain these jobs and should be better trained to meet the interdisciplinary expectations once they take them. However, support for interdisciplinary scholarship is highly developed in only a handful of institutions. Accordingly, some of the students who find themselves in purportedly interdisciplinary jobs still face a number of obstacles (limited publication opportunities, high startup costs and long learning times, lack of appreciation for interdisciplinary work in promotion and tenure decisions, etc.). Overall the effect of such coursework on future employment and success is unclear, and this calls for future research on tracking those students who participated in interdisciplinary education.

The Water and Society course has been a successful experiment in interdisciplinary graduate education. Student response to the evaluation was overwhelmingly positive. Being challenged to think outside the box and develop a collaborative deliverable more than compensated for the requirements of learning about fields that a student would not normally know much about. The course helped deconstruct the artificial barriers between academic disciplines, as well as stimulate further interdisciplinary collaboration. In addition, senior faculty with many years of experience in various academic fields were challenged to advance their own knowledge, which in turn could open up new opportunities for future research projects.

While the topic of the course focused on the use of water resources, many aspects of this experience could be generalized to advance interdisciplinary courses covering other subjects. The scholarly environment fostered in Water and Society would suit any pedagogy which moves from knowledge acquisition to knowledge construction. None of the challenges we observed are insurmountable. Since academic knowledge has been advancing toward interdisciplinary perspectives and applications, graduate courses like this one are likely to be increasingly important components of higher education.

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