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ORIGINAL PAPER

Finding your way in the interdisciplinary forest: notes on educating future conservation practitioners

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Abstract We explore the challenges of educating interdisciplinary thinkers who can address the management of complex socio-ecological systems, such as forests, by sharing our experiences from several perspectives. Five contexts for interdisciplinarity are explored along with examples related to: the department, advising, integrated research collaborations, a graduate working group, an interdisciplinary class, and trans-academic research. These experiences demonstrate the importance of safe space and patience, the need for adequate time to build trust and respect, and the recognition that interdisciplinary thinking is developed and reinforced in multiple contexts. Interdisciplinarity is always a work in progress that differs in its particulars according to the research or management question at hand and the kinds of specializations involved. Thus, there are no hard and fast rules for its creation but only guiding principles that must be adapted in the course of their implementation.

Keywords Collaboration · Graduate education · Interdisciplinarity · Mentoring

Introduction

Forestry has a long history of considering ecological and social factors to achieve desired management outcomes. However, like many other environmental fields, forestry has

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struggled to develop approaches that integrate these disciplinary perspectives and allow a deeper understanding of the socio-ecological systems in which they occur. We, and others (e.g., Öberg 2011; Lyons 2012), argue that our failure to advance truly interdisciplinary frameworks in the environmental sciences is due in large part to the challenge of educating holistic thinkers in antiquated, highly disciplinary academic programs. Thus, a disconnect exists between the education that future forest and other conservation practitioners and researchers typically receive, and the concepts and toolsets they will need to work effectively in complex socio-ecological systems. These systems could include cattle (and therefore, ranchers), redwoods, mycorrhizae, wetlands, Native American basket weavers, spotted owls, venture capital investors and all manner of researchers and instruments collecting data. As emphasized by Lyons (2012), we cannot begin to understand, manage, or make policy about socio-ecological systems, such as forests, without education in rigorous and robust interdisciplinary approaches. Such interdisciplinary education experience might lead to engagement in diverse fields, ranging from mathematics to ethnography, so as to allow the teasing out of hidden connections between and within systems. But where and how does this education occur?

In this paper, we provide a case study of the challenges around educating interdisciplinary thinkers by sharing our experiences. We are a group of interdisciplinary faculty and graduate students from the Department of Environmental Science, Policy, and Management (ESPM) at the University of California, Berkeley. The context from which we write is a 20 year-old multidisciplinary department in a public research university with strong trans-academic (see Table 1 and below) linkages that arise through affiliated institutes and the Cooperative Extension Service. Over its existence (still a work in progress), there has been a gradual, but steady effort in our program to create forums and incentives for engagement and education across disciplines. For example, a weekly departmental seminar recruits a diverse set of speakers and draws a broad audience, though few speakers are prepared to move beyond their discipline's esoteric vocabulary. Within ESPM, faculty have reached across disciplinary lines in the quotidian work of departmental governance, most notably in the graduate program.

Table 1 Key definitions

Interdisciplinary	A mode of thinking and research that involves the crossing between or among disciplines. This crossing can be done at very diverse scales and levels of integration
Trans-academic	Research that engages with individuals and institutions outside of the academia milieu
Biophysical science	Umbrella term for the natural sciences such as ecology, soil science, and physics
Social science	Umbrella term used to refer to disciplines such as, sociology, anthropology, and economics
Epistemology	A philosophical term that refers to the ways knowledge is produced. Disciplines can develop distinct means of knowing and these fundamental philosophical stances can become important when fostering interdisciplinary discussions
Safe space	In this text this is a metaphor to describe any kind of space where students and researchers can step outside their disciplinary comfort zone and take intellectual risks
Socio-ecological systems	A coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner (Redman et al. 2004)

Classes in ESPM have filled with students across the social-biophysical science divide because of a mandated graduate student breadth requirement. In addition, graduate students have been initiated into interdisciplinary work in a required first year course, and have read and critiqued each other's work in their required writing class. Perhaps most importantly, students have access to both social and biophysical science faculty within the walls of the department who make the extra effort to work across disciplinary lines with them. As a result, an increasing number of graduate students are co-advised by faculty in different disciplines. Simultaneously, the number of faculty who make that extra effort has grown, as faculty recruitment has increasingly focused on candidates who are interested in interdisciplinarity approaches to environmental science.

We wish to be absolutely clear: this is not a research article. The observations in this article stem from systematic reflections on the authors' experiences. They are unusual in this genre in that a large proportion of these reflections come from the perspectives of current graduate students. Nor are we arguing that we have "the" answer to interdisciplinary pedagogy, mentoring and practice. Unlike many articles on interdisciplinary approaches in higher education, our experience stems from being embedded in a US research university. Our goal is to share examples of what has worked in our efforts to advance interdisciplinary education and where we have room to grow—with the ultimate hope that other programs and organizations can learn, as we have.

We start by defining the unfamiliar as well as confusingly familiar terms used throughout this article. Our most commonly used terms are summarized in Table 1, but several deserve additional clarification here. We use '*interdisciplinary*' to mean academic research that involves "crossings between or among disciplines" (Lele and Norgaard 2005: 967). We use this umbrella term to avoid unproductive debates over how much integration is required for research to count as interdisciplinary. We use '*transacademic*' (a term from the interdisciplinary Swedish biogeochemist, Gunilla Öberg (2011) to describe research that engages with individuals and institutions *outside* academia. It should be noted that this is distinct from "transdisciplinarity," a term used commonly in Europe. While often employed to describe a similar concept, transdisciplinarity is broader in meaning and a full discussion of this term is beyond the scope of this article. We employ trans-academic (1) to distinguish between the concepts of transcending disciplinary boundaries *within* academia and transcending academic boundaries *entirely*, (2) because some of the skills required to do interdisciplinary work reflect those skills needed to do trans-academic work, and (3) because many of us are motivated to take an interdisciplinary approach because our work is trans-academic. However, a systematic analysis of trans-academic practice and its differences and commonalities with interdisciplinary practice is also beyond the scope of this article. We use '*biophysical science*' as an umbrella term for the natural sciences such as ecology, soil science, and physics. We use '*social science*' to refer to disciplines such as sociology, anthropology, and economics. We note that the divides within social science disciplines can be as deep as those between the biophysical and social sciences (Lele and Norgaard 2005), and careful work can be necessary to bridge those divides. '*Epistemology*' is a philosophical term referring to the ways we produce knowledge. Defining epistemologies intends to addresses the questions, how do we know what we know, and what is a valid way to understand the world around and within us? These fundamental philosophical stances become important when fostering interdisciplinary discussions.

Finally, a frequently invoked aspect of a successful interdisciplinary process or collaboration is the creation of '*safe space*'. The sometimes vague concept of safe space in the academic context has roots in Hall and Sandler's (1982) report on the chilly climate for women, including women students, in the academy. Concerns about safe space for learning

have expanded to include race, ethnicity, religion, and sexual orientation (Lerena-Quinn 2013; Woodford et al. 2014). The metaphor of safe space has come to mean "a description of a classroom climate that allows students to feel secure enough to take risks, honestly express their views, and share and explore their knowledge, attitudes, and behaviors. Safety in this sense does not refer to physical safety. Instead, classroom safe space refers to protection from psychological or emotional harm" (Holley and Steiner 2013:50). Du Preez (2012:59) goes beyond this definition by arguing, "we know a space is safe when risks can be taken in such a space." This second definition is particularly apt in the context of interdisciplinarity, where students and researchers take intellectual risks that require stepping outside their disciplinary comfort zone. Holley and Steiner's (2013) study of social work students found that students considered safe space a very important attribute of a classroom—one that had positive effects on what they were able to learn.

We also employ the concept of *bricolage* as a metaphor to engage and explore the ways in which interdisciplinary research functions through connecting diverse knowledges and modes of knowledge production to understand a given phenomenon. Bricolage is a term from the art world that means the creation or construction of a whole work out of a diverse range of things and/or parts at-hand, and we believe it provides insight into the interdisciplinary approaches described within this article.

Why interdisciplinarity?

In his 1962 work *The Structure of Scientific Revolutions*, physicist, historian and philosopher Thomas Kuhn dubbed familiar conventional science practice "normal science" and characterized it as puzzle solving. Examples of normal science include things such as the genetics of oaks, and the life cycle of spruce budworm. While Kuhn himself was interdisciplinary, the normal science of his time was, by and large, thoroughly disciplinary. But as the problems that science was called upon to address became more complex, and as environmental and conservation scientists increasingly engaged in multi-faceted challenges, the limits of disciplinary science became apparent. Three decades after Kuhn's foundational book, Funtowitcz and Ravetz (1993:744) called for the practice of "post-normal science", that is science practiced in contexts in which "the facts are uncertain, values are in dispute, stakes are high, and decisions are urgent" (Funtowitcz and Ravetz 2003:1). This is precisely the context of today's forest conservation challenges, occurring within highly complex 21st century socio-ecological systems. The agencies, scholars and stakeholders who engage in contemporary forest management integrate disciplines such as soil science, fire science, plant ecology, economics, sociology, and political science, to name only a few.

Interdisciplinary environmental science programs originated with the rise of ecology and environmental movements in the late 1960s (Casey 2010). The broader trend in interdisciplinary education is a reaction against "fragmentary learning" within an increasing number of specialized research fields and "the growing rift between an increasingly compartmentalized university and society" (Apostel et al. 1972:282). In the 1990s, the shift towards interdisciplinary education programs coincided with constructivist and collaborative teaching methods, which "involve working with peers to construct knowledge, invite multiple perspectives as part of the critical examination of solutions, and require analysis and synthesis skills, often leading to an integrative solution" (DeZure 2010, pp. 375–376).

Such interdisciplinary education programs are intended to support a growing need for interdisciplinary research. The first documented use of the word interdisciplinary was in

the 1920s, in social science research and the general education movement (Klein 2010:1). According to a 2004 National Academy of Sciences report, interdisciplinary research today is primarily driven by four factors: the inherent complexity of nature and society; the desire to explore problems and questions that are not confined to a single discipline; the need to solve societal problems; and the power of new technologies (Klein 2010). Many scholars echo the need for research that deals with applied problems that are complex, ambiguous and urgent (Sprain and Timpson 2012; Funtowitcz and Ravetz 1993). The shift towards interdisciplinary research in particular fields has also been facilitated by large-scale government funding for applied interdisciplinary research on complex problems such as national security, disease epidemics, and environmental protection (Miller 2010).

Growing appreciation for the complexity, dynamism and interdisciplinary nature of forest conservation and other environmental challenges has led to serious questions about the education and preparation of future practitioners and scholars. For example, in the last few years, conversations on the need to "rethink" the Ph.D. system in the US have appeared in journals such as *Science* (Benderly, 2012) and *Nature* (McCook 2011). The authors describe the Ph.D. education system as broken and in need of reinvention. For some, interdisciplinary education appears to be a solution that might better prepare students to engage in careers outside of academia. However, none of these articles touches on the changes needed for interdisciplinary programs to be put in place at a larger scale. For instance, they do not discuss where such students would publish, or the mentoring they would need to be successful. "Rethinking PhDs", as these authors claim, requires a large-scale reflection on the processes and institutions around education in general. Though funding agencies in the United States are increasingly rewarding interdisciplinary projects, simply making money available does not automatically guarantee high-quality interdisciplinary work, nor does it address the fundamental and often inhibitory structures of academia. Reform of tenure processes and academic publishing has been extensively discussed elsewhere (Rhoten and Parker 2004; Campbell 2005; Rafols et al. 2012), so while raising the point, we focus instead on the topic with which we collectively have the most experience: how to create interdisciplinary graduate education and research.

Building interdisciplinary programs in higher education

Several authors (e.g., Öberg 2011) have highlighted barriers to interdisciplinary education that are fostered by the isolating and narrow structure of most academic departments. This is particularly problematic for the environmental sciences, where integration across disciplines is necessary for addressing the highly complex and multi-faceted environmental challenges of our day. Environment-themed departments are among the fastest growing programs in North American universities (Chronicle of Higher Education 2012). Yet participants in these programs, from deans to faculty to students, struggle to identify effective top-down (e.g., institutionally-mandated) and bottom-up (e.g. faculty- and student-driven) approaches for fostering interdisciplinary teaching and research. While many departments are quick to adopt interdisciplinary language for their educational programs, they often do so without altering and adapting their disciplinary structures (Klein 2010).

Although there is no single approach to creating interdisciplinary teaching programs in higher education, developing interdisciplinary courses is a common starting point. Introductory courses help engage students with interdisciplinary scholarship at the beginning of their educational programs, and can cover topics ranging from "the basic concepts and methods of reasoning associated with different scientific disciplines" (Apostel et al. 1972:239) to thematic units that focus on specific problem areas (Klein 2010). Courses

may be led by teams of instructors from multiple fields and/or disciplines (Sprain and Timpson 2012; Kaur and Manaan 2013; Newell and Luckie 2013). Yet, as DeZure (2010:382) points out, "having faculty present their disciplinary perspectives in a serial fashion is not sufficient." Rather, an effective interdisciplinary course emphasizes integrative learning, and helps demonstrate how working across disciplines may create something greater than what could be gained through a single, disciplinary framework.

Interdisciplinary teachers employ a diverse set of methods "that support the skills needed to engage in interdisciplinary problem-solving" (DeZure 2010:374). Skill building includes developing a range of cognitive skills such as differentiating, reconciling and synthesizing (Lyall and Meagher 2012), advancing interpersonal competence (Sprain and Timpson 2012), and nurturing students' ability to draw insights from diverse perspectives (Newell and Luckie 2013). Teaching methods are not unique to interdisciplinary teaching programs, and include the use of real world case studies, student group work that fosters teamwork, instructor interactions that model the interrelationships between disciplines, and final capstone projects that create a summative public product (Sprain and Timpson 2012; Kaur and Manaan 2013; Newell 2013). By fostering critical discussion and student reflection, and by creating a safe classroom environment for exploring different viewpoints, teachers can help students learn how to engage with the tensions among and within disciplines, work outside of their disciplinary comfort zones, and build the skills they need for working in interdisciplinary teams (Newell 2013; Lyall and Meagher 2012).

Educating interdisciplinary scholars occurs outside of the classroom, as well. Locating positive mentors is key for interdisciplinary scholars, particularly in their early stages of intellectual development (Klein 2010). Graybill and Shandas (2010:405–410) describe an "initiation" stage of interdisciplinary learning, when students are questioning how to situate their interdisciplinary scholarship within the academy and learning to interact with multiple intellectual communities (both disciplinary and interdisciplinary groups). Establishing a committed and compatible supervisory team that guides interdisciplinary research, while allowing the student to set the boundaries for the work is important (Lyall and Meagher 2012). Networking with other interdisciplinary learning communities is another vital part of interdisciplinary training. As Casey (2010:348) writes, "The community for any interdisciplinary unit is both external and internal," and often requires connecting with relevant faculty across campus or in other institutions, community organizations, businesses, and/or government representatives in order to better understand interdisciplinary problems and create cross-cutting research teams. Social gatherings, both informal and formal, can provide helpful opportunities for interdisciplinary scholars to build collaborations and engage in mutual learning (Klein 2010:148).

Case study: interdisciplinary contexts in a public research university

Building interdisciplinary programs in higher education requires working at multiple scales, including building university-wide institutions and working with faculty and student interests (Klein 2010). We address five contexts for interdisciplinarity which are consistent with many of the approaches for building interdisciplinary programs that are presented above: (1) teaching and learning interdisciplinary thinking, (2) building research collaborations, (3) mentoring interdisciplinary Ph.D. students, (4) linking to and creating interdisciplinary networks, and (5) trans-academic collaborations.

This work reflects our attempts to build interdisciplinary capacity in a department created through the merging of several traditional, disciplinary departments situated within a large US research university. Given the continued importance of public funding to the

University of California, many of our efforts to build more opportunities for interdisciplinary teaching and learning are faculty and student driven, and operate without designated funding. The authors do not claim to have resolved the many challenges of building interdisciplinary programs, and we are learning as we go. Thus, we follow Sprain and Timpson (2012) and Kaur and Manaan (2013) in presenting the range of actions that we have taken thus far, with mixed success. We present our attempts to cultivate "interdisciplinary habits of the mind" (Newell 2013) and "open mindedness" (Apostel et al. 1972) towards multiple research perspectives in our own department. By including graduate student authors, who are deeply involved in building interdisciplinary capacity in our department, we aim to close a gap in the published literature, which typically highlights perspectives of well-established researchers who may not empathize with student experiences (Graybill and Shandas (2010).

Context 1: teaching and learning interdisciplinary thinking

Intellectual diversity is important not just in methods of research and knowledge production (epistemology), but also in approaches to teaching and training (pedagogy). This is particularly the case with interdisciplinary work, because researchers in different fields use widely varying epistemologies and are taught to think differently. For example, those working in labs with physical equipment and samples, those carrying out visual species counts, and those interviewing people all use different methods—as well as different parts of their brains—in doing their work. Thus, a typical interdisciplinary classroom will have students and practitioners benefiting from a wide spectrum of cognitive styles, a variety of research backgrounds, and different epistemologies. This means that best practices in pedagogy should attempt to address this diversity—not just so that students benefit equally from the instruction on an individual level, but also so that they can work together more effectively as a group.

This topic has been highlighted through the issues arising from the increasing internationalization of many college campuses, and the subsequent cultural diversity of their student bodies. As Bradwell (2009:19) puts it, the greater "diversity of students places new demands" on curriculum design, as teachers and lecturers "have to deal with a much greater range of information processing styles, cultural backgrounds and styles of learning. As a result, the ideal for teaching in higher education is now recognized to involve much more than lectures as the means of information provision." For this reason, the growing trend towards methodologically diverse, interdisciplinary work will benefit from pedagogical approaches that acknowledge diverse cognitive styles and intellectual perspectives. Some of these approaches—such as mixing audio/image/text information, as well as using both individual and interdisciplinary group work—were put into practice within our department in a required introductory graduate course, called ESPM 201A.

201A: a multimodal, interdisciplinary classroom

Our department's entering graduate cohort is required to take a course that is taught by faculty from different disciplines (cf. Sprain and Timpson 2012; Kaur and Manaan 2013; Newell 2013) through which students are exposed to interdisciplinary thinking. In the 2012 version of this class, science was presented as a social activity. This contrasted with the received wisdom of the scientific method as a sacred, objective ritual that leads inevitably to "Big 'T' truth". Students learned about Thomas Kuhn's (1962) concepts of normal science and paradigm shift, Bruno Latour's (1987) depiction of the practice of science as

strategic, and Donna Haraway's (1999) concept of situated knowledge (cf Kaur and Manaan 2013). They also practiced interdisciplinary research and interpersonal competence by working in small teams on case studies (cf Kaur and Manaan 2013; Sprain and Timpson 2012, Newell 2013), addressing different environmental issues that they had identified. Depending on the group, students produced a summative public product (Newell and Luckie 2013) in the form of an op ed, a public commentary, or a journal article. The overarching goals were to (a) encourage the students to step back and reflect (Newell 2013; Lyall and Meagher 2012) on what defines "truth" in their field and also their field's fundamental assumptions around knowledge production, and b) expose students to different disciplinary languages.

Making underlying assumptions and differences visible is essential to acknowledging and removing intellectual blind spots and blinders. It is important to begin the process of interdisciplinary collaboration by understanding the borders of one's own mode of knowledge production, and then understanding how one's individual approach can be connected and placed in relationship to others. This process has been emphasized by the Philosopher of Science, Friedrich Wallner, who argues that to successfully conduct interdisciplinary work you must first "strangify" your discipline (Wallner 1992). That is, while learning the vocabularies and concepts of other disciplines is vital, you must also become aware of what you take for granted in your own discipline—methods, concepts, assumptions—everything that seems "normal".

To do this, the ESPM first year graduate cohort class was shown four images. Students were organized in groups and instructed to individually take in each image, and then write down what research questions the image raised for them. Once the students recorded their questions, they discussed the image in interdisciplinary groups, by asking each other questions based on the varying backgrounds of respective group members. This helped the students to recognize their own disciplinary blind spots, and also allowed them to share their knowledge in a safe intellectual environment (Newell and Luckie 2013).

This image (Fig. 1) in particular created an opportunity for a powerful strangification moment. One student, an accomplished wildlife biologist, responded, "I wondered what kind of sheep those are? What do they eat? What diseases do they get? What are their predators?" The student paused, and then said, "I did not even see the girl until I had been looking at the slide for at least a minute". This example is not intended to suggest that the student was unobservant, but rather points out that the student's disciplinary background had led them to focus on the sheep. While this exercise threw off the student's individual blinders, it was also an eye opener to the rest of the class. Students and faculty alike saw that we all have discipline-induced selective attention areas and blind spots about what is and is not important, what should be studied and how. As pointed out by Newell (2013), recognizing your own selective attention and blind spots is essential to doing interdisciplinary work.

Relating interdisciplinary research to 'bricolage' recognizes that taking an interdisciplinary approach to knowledge production can be its own art form. Understanding academic research through the framework of bricolage offers a platform for interdisciplinary collaboration to "examine phenomena from multiple, and sometimes competing, theoretical and methodological perspectives" (Rogers 2012). By pulling from diverse types of knowledge, the strength of interdisciplinary collaboration as bricolage occurs through a shared process of many independent parts working together, and sometimes against each other—functioning much like a robust ecosystem. The understanding gained from the bricolage metaphor is that the end product will be more dynamic as a whole, and greater than its individual parts.

Fig. 1 Photo used in "strangification" exercise

The benefits of bricolage became particularly evident during an interdisciplinary group project in 201A. One group decided to write an op-ed about Yosemite National Park. One student researched flora and fauna; another had regularly visited Yosemite; and others employed their theoretical and methodological tool kits. Taking quantitative and qualitative approaches, they examined race, class, and gender connections to park visitation. All students came away with a better understanding of the social, environmental, and economic pulls and constraints of the park, and the community of people visiting this area. Through interdisciplinary research and collaboration, students learned how their peers approach and navigate research problems and concerns, and how to work outside their own disciplinary comfort zones and understandings.

Interdisciplinary tea: a multi-modal co-learning working group

To facilitate interdisciplinary education and collaboration among graduate students from different disciplinary fields, a core student group created an interdisciplinary working group in 2010 called "IDTEA" (abbreviated from "Interdisciplinary-Tea"—and named after the tea and snacks featured at our meetings). The IDTEA format has changed over the years; it began as a weekly seminar and eventually transitioned to a working group with periodic meetings. Ultimately it serves whatever role is needed by the department's students and faculty in order to facilitate interdisciplinary education and collaboration.

Initially, the IDTEA seminar brought group members together to read and discuss literature about interdisciplinary practice (Newell and Luckie 2013), invited speakers with different perspectives on interdisciplinarity, and went on field trips to see interdisciplinarity in action, which included visiting a non-profit organization focused on biological and culture diversity. Safe space within the IDTEA meetings was important for allowing individuals to stop and ask for clarification, or to admit a lack of understanding. What emerged from these fruitful discussions were common themes and questions about doing interdisciplinary work, especially regarding the process of actually trying to implement an interdisciplinary research project. We elaborate on some of the most important lessons from these seminars in our conclusions below.

One of the most valuable aspects of IDTEA was the opportunity for participants to share their work and receive feedback from a supportive, intellectually diverse group. In this way, IDTEA sometimes functioned as a 'support group' for individuals struggling with posing interdisciplinary dissertation questions and for those in despair after initial attempts to achieve interdisciplinary synthesis in their work, among other issues. In addition, sharing work allowed students and faculty to identify aspects of 'successful' interdisciplinary projects, such as the examples given in Context 3.

One main advantage of the IDTEA working group has been its flexibility; the form of IDTEA has shifted over time to accommodate student needs that are not being met in the other contexts. In some cases, smaller subsets of the group have taken on interdisciplinary projects that were in line with their specific interests. What began as a classroom space, where students and professors could collaboratively learn about interdisciplinary practice, evolved into a working group attempting to enhance interdisciplinary discussion and collaboration within our department's existing structures.

Context 2: building research collaborations

While interdisciplinary courses and working groups may promote broader intellectual experiences for students and faculty, engagement in truly interdisciplinary research efforts provides lessons in holistic thinking that no classroom can match. Many interdisciplinary projects can be enabled by departmental support structures, and are often incentivized by internal or external funding. We provide examples of two projects that authors of this paper are directly involved in. These examples describe research collaborations that have effectively brought together individuals from different disciplines and supported interdisciplinary graduate training.

BHL: building interdisciplinary groups around a tractable research challenge

In 2011, a fledgling interdisciplinary group targeted the Coupled Natural and Human Systems Program at the US. National Science Foundation because it explicitly prioritized interdisciplinary research. The group, comprised of faculty and graduate students from six 'laboratories', met more than a dozen times to share perspectives and find common interests for the multi-year grant proposal. Ultimately, the group proposed an extremely ambitious study to explore how the links among human health, livelihoods and ecology affect sustainability of natural resources.

Funded in 2012, the Biodiversity, Health and Livelihoods (BHL) project (bhl.berkeley.edu) was the result of a 'from-the-gitgo' interdisciplinary effort (as opposed to the last minute inclusion of social or other dimensions often observed in interdisciplinary proposals). The principal investigators include a tropical ecologist, conservation biologist,

public health scientist, a forest management specialist, a natural resource economist, and a rural sociologist. The nine graduate students now engaged in the project all have interdisciplinary backgrounds, even if their research has a disciplinary emphasis. In both the proposal writing and implementation phases of the project, researchers from distinct disciplines discovered and practiced interdisciplinarity through an empirical case study. This engagement is distinctly and importantly different from working through more theoretical or historical concepts of interdisciplinarity in a classroom setting. The field research takes place at rural sites in Ghana, Kenya and Madagascar, and team members share experiences from the field in weekly group meetings at Berkeley—either in person or, when possible, via video conferencing.

A basic principle of the BHL project is "together at the table, together in the field". That is, the group emphasizes integration in all phases of the project, not simply in conception or writing stages. Group participation produces learning that broadens participant understandings, even if group members see their individual role as being more disciplinary. While the pedagogical particulars are beyond the scope of this paper, this approach is increasingly recognized in the field of education, and has often been incorporated into modern classroom best practices (Millis 1997). Thus, where possible, principal investigators and students travel in multidisciplinary groups to multiple sites, in order to share perspectives and learn from local partners. The experiences of travelling together on foot or by dugout canoe, eating from a common pot, and working in difficult field conditions all require that group members must learn to get along. The foremost principle for interdisciplinarity in these and other settings is to work with people who are equally committed to the interdisciplinary enterprise. Much like an ecosystem, group members forge a balance through a rigorous understanding of cooperation, compromise and flexibility.

The daily demands of dealing with dynamic socio-ecological systems, such as those studied in the BHL, reinforces the necessity of moving across disciplines in order to consider the real complexity of natural resource conservation. This often involves going back to disciplinary building blocks in order to get everyone on the same page. However, BHL members have found moving backwards is a small initial cost relative to the gains made later through interdisciplinary synergies.

Early and ongoing interdisciplinary partnerships

Some research collaborations originate from relationships cultivated in the context of the IDTEA graduate working group (described above) or other contexts. For example, after working together as part of the graduate working group, two of the authors of this article, a statistician and rural sociologist, became part of a team studying co-authorship in participatory research publications. Bringing together such different areas of expertise early in the research project allowed the team to make decisions about how to structure the data and select quantitative models through an iterative process, which involved both kinds of experts. By working together closely, the team members ensured that the data collected were appropriate for the intended models, and that the models chosen were appropriate for the questions the group wanted to answer.

This kind of iterative process, involving different skill sets and disciplines from the beginning (or near the beginning), gives rise to higher quality research—by avoiding inappropriate models, inappropriate data, or trivializing the contributing disciplines. This model stands in stark contrast to the model (e.g. in ecology, Wilson 2013) in which researchers consult a statistician only after they have collected data, or the model in which the social scientist is asked to come in late in the process in order to provide 'the social perspective'.

Collaborating from the beginning means that we ask the right questions and obtain data that actually address the questions of greatest interest and value for the issue at hand.

Context 3: mentoring interdisciplinary Ph.D. students

Student and faculty advising relationships range across a wide spectrum. Co-advisors may conduct similar research or may come from disconnected fields. Some students pursue self-guided interdisciplinary study, by tapping knowledge from faculty and fellow students leading and developing a diverse group of people who serve as formal and informal mentors. Engaging with multiple faculty mentors is one way for students to develop their interdisciplinary thinking, as mentors working in a different discipline introduce the students to diverse skill sets and theoretical framings.

It is not surprising that faculty take different approaches to interdisciplinary advising (cf Lyall and Meagher 2012). Some, who are committed to cultivating interdisciplinary practice and thought within the academy, work with individual students to help them broaden their graduate educations. This may involve inviting students from other departments to their group meetings, supporting interdisciplinary graduate seminars and working groups, and encouraging their students to take "coursework for life", not just for the dissertation. Faculty who are less focused on interdisciplinarity in their own research can still encourage students to foster relationships with other advisors and pursue areas of study in other disciplines.

Some students establish formal co-advising arrangements that can be important for providing institutional legitimacy for an interdisciplinary student. In ESPM, the co-advising relationship is formalized by listing both advisors as dissertation co-chairs. This documents the mutual support of the institution, the student, and the two professors for an interdisciplinary dissertation. Formal co-advisors may be identified either before a student is admitted to the program, or later in a student's graduate career. These are all new initiatives; the first formally co-advised doctoral student was admitted in 2006 and graduated in 2012. By gaining an additional advisor, students gain the permission to enter into a new field, and a legitimate place at a *new* seminar table. Examples of different kinds of advising experiences that have facilitated interdisciplinary scholarship follow.

Developing interdisciplinarity mid-stream

Since co-advising is not yet the norm within ESPM or within graduate school in general, some students realize only after they have begun graduate school that the "classical" or mono-disciplinary researcher model is too restrictive, not allowing them to engage in environmental problems as they might wish. For these students, the ability to transition to co-advising contributes to their retention in the graduate program. Having at least one advisor who actively supports interdisciplinarity can help the student sit with and navigate the uncertain, amorphous spaces between disciplines. The transition from one discipline to another is not always easy. It is important that these students find safe spaces that provide validation and promote intellectual courage, which is often needed when moving across disciplinary boundaries and learning the theory and language of new fields. Safe spaces facilitate personal and professional development opportunities, which in turn enrich student learning. Sometimes students need to be supported in visualizing what an interdisciplinary scholar looks like, and in developing a network that will help them identify how their interdisciplinary skills can be seen as an asset and an opportunity. Co-advising can be one such space. Yet the creation of more of these spaces is necessary for interdisciplinarity to grow in higher education (see the "IDTEA" section on creating flexible graduate working groups, above).

A foot in both camps

Some students start their graduate work with formal co-advisors with the intention of developing an interdisciplinary dissertation, but in the end, the final dissertation project may not connect the two disciplines. In this case, the co-advising model supports the student's broader learning goals by providing an entry into different campus learning communities. By working in multiple research groups and with different advisors, students learn how to shift their language and reframe their work to fit the context of those different groups. Even when the research moves out of the disciplinary purview of one co-advisor, that faculty mentor can still help with navigating funding proposals, establishing professional contacts, or providing other advising needs. Maintaining a connection to multiple disciplines through co-advisors can help provide valuable conceptual insights for a "disciplinary" dissertation project, and/or can help expand a student's future job prospects—even when an interdisciplinary dissertation is not the final outcome.

From one-on-one to two-with-one

Some faculty have formed more integrated co-advising relationships. These faculty commit to working together to educate multiple co-advised students in social and biophysical sciences who each pursue interdisciplinary dissertations. For the faculty involved, co-advising has meant adapting the common one-on-one mentoring disciplinary process to a two-with-one process. In developing this new model, both faculty strive to participate equally in student mentoring, in order to help them achieve a broader intellectual foundation and methodological tool-kit. This has involved exploring the balance of disciplinary and interdisciplinary course choices, as well as the realities of doing interdisciplinary research in the context of a dissertation project. In such cases, commitment and compatibility of co-mentors is key. Faculty co-advisors and students must believe they will truly benefit from being challenged with intellectual breadth, and that jobs and careers exist for the students when they complete their degree.

Of course, there are many areas for growth in the co-advising process. Forging the necessary links and being an outsider in a new field can be a challenging experience. There is much work to be done to facilitate co-advising spaces at the department level. For example, there are no set departmental guidelines in ESPM for developing co-advising relationships, and this can contribute to uncertain expectations or divergent understandings between co-advisors regarding what activities constitute a valuable contribution towards a student's education. In some cases, this may leave the student linked to a research group where they are viewed as an outsider, or a sub-par group member who is not producing at the same rate as "disciplinary" students. Still, given that the department's first co-advised student graduated only 2 years before our writing this article, we have yet to experience the multiple opportunities and challenges that will invariably arise from such new "interdisciplinary" models of graduate advising.

Context 4: linking to and creating interdisciplinary networks

Though the organizational and funding structures differ among interdisciplinary environmental science programs in the greater San Francisco Bay Area, where we are based, the many people involved in such programs share a desire to communicate across disciplinary boundaries (cf Lyall and Meagher 2012). From this commonality, a series of Intercampus Workshops on Interdisciplinarity has emerged, beginning in 2012, and primarily involve

interdisciplinary environmental science programs. Workshop hosting has rotated among campuses, which has allowed us to see each program's working environment and facilities. Student leaders have created an email list to broadcast information about interdisciplinary events and opportunities to the larger group. The workshops typically involve a keynote speaker on an interdisciplinary topic and 5 minute 'lightning talks' from students in each program. Some workshops have been organized around a theme, e.g. trans-academics.

Workshop dialogue has led participants from different campuses to identify common practices among their respective programs: (1) the need to create a safe space where people could admit lack of understanding or stop a conversation to ask about a technical term or context, (2) taking notes to record ideas and discussions for absent and future group members, (3) much of the work in these groups is driven by graduate students, and (4) good food is an important factor as a first step in collaboration and sharing. Workshops participants have also discussed ways to further build and strengthen interdisciplinary infrastructure within and between their campuses.

These workshops have been excellent opportunities for networking for all involved. Participants have been able to learn about one another's work, as well to reinforce our collective enthusiasm for interdisciplinarity approaches. Such interdisciplinary collaboration efforts are still developing, but we believe they have great potential to enhance institutional support for interdisciplinarity at a regional scale.

Context 5: trans-academics—engaging with groups outside the academy

Both by definition and design, all trans-academic work and much social science research takes place in concert with non-academic partners in the field. Thus, while many of our students and faculty work with communities, organizations, and individuals outside academia, some of the forms of interdisciplinary engagement described above share a common weakness, in that they fail to expand the activities of interdisciplinary teams beyond the confines of the college campus. An increasing proportion of students seek a graduate education that will prepare them to address conservation and biodiversity issues in a non-academic context. Many of these students search for the tools that interdisciplinarity provides, such as working effectively on a problem with a diverse team, which is often so important in work outside academia. This kind of interdisciplinary problem-solving interface is becoming more common—whether it involves conducting community based participatory research in service of environmental justice, interacting with community practitioners who use academic research, engaging with public participation in scientific research, or addressing a regulatory requirement to involve stakeholders in research projects. Doing work in the realm of sustainable development, for example, means going beyond analytical capabilities and "requires creativity, social competencies and specific communication skills" (Steiner and Alfred 2006). Research questions identified by community partners are rarely framed from disciplinary perspectives, and instead, are often intrinsically interdisciplinary and practical, as well as solution-oriented.

In this context, we note that, while generalization is the goal of science, the actual practice of science is always grounded in the particular. Political scientist, Scott (1998) has observed that "'practical knowledge' that is learned through practice is locally superior to general knowledge that often does not apply well to specific situations". Scott's observation leads us to recognize that working with community members teaches researchers the validity of local epistemologies and the value of local observations—and how these can improve the rigor, relevance and reach of their research (Balazs and Morello-Frosch 2013).

Some of the skills learned in an interdisciplinary seminar, working group or classroom experiences become important here, too. The idea of safe space and the importance of mutual respect and patience are key. Defining technical language and giving critique as a gift—rather than using it as a weapon—are as important here as in an interdisciplinary academic setting. Recognizing a plurality of epistemologies is another key skill. The ability to set expectations at the beginning of a collaboration on who does what work, and who derives what benefits from a given project is also needed in practicing both interdisciplinarity and trans-academics. Finally, consistently reaching out to all parties throughout the life of a project, and checking to make sure individuals do not become marginalized is important for both cases. In both instances, the work takes a lot more time, effort, and patience but the result is, in the authors' opinions, well worth the extra input.

Below, we give some examples of trans-academic projects in our department, some of which were founded by members of the IDTEA seminar and working group members. These projects highlight the importance of problem-oriented learning as a mechanism for furthering interdisciplinary training, and for demonstrating the necessity of holistic research approaches. The three cases we provide present distinct scales of trans-academic engagement, from broad public outreach to a targeted partnership with an important stakeholder group.

The UC Berkeley science shop

The UC Berkeley Science Shop, founded and led by graduate students and faculty in ESPM, is a publicly accessible entity connecting community members with the university's research capacity. Many ESPM students and faculty have a keen interest in partnering with community groups around research. Yet, it has been a challenge for the department to develop mechanisms that facilitate interdisciplinary interactions, while engaging society on a variety of scales. The UC Berkeley Science Shop, the first California-based Science Shop, does this by implementing an initiative that began in Europe in the 1970s to counteract the widespread sentiment that "scientific research is aimed at abstract knowledge or profit and not sufficiently geared towards the needs and concerns of society" (European Commission 2003). The UC Berkeley Science Shop is designed to facilitate high quality research on environmental problems identified by small non-profits, local government and other civic organizations. The UC Berkeley Science Shop funnels these projects to both graduate and undergraduate students seeking environmental research projects. It gives students the opportunity to merge their interest in research with their desire to do community engaged work. It also acts as a permanent entity that groups outside of the University can approach with environmental research questions. The UC Berkeley Science Shop facilitates and supports both the student and the community group through the research process, thereby increasing the likelihood of a successful partnership.

Graduate student cooperative extension program

Our department, in partnership with UC Agricultural and Natural Resources (UC ANR, which includes the University of California's Cooperative Extension division), has designed and funded a program to offer graduate students experience and training in extension and outreach. The program facilitates opportunities for graduate students to network with extension faculty, specialists, advisors, and staff, in order to create a project proposal supported by a year of funding, which is ideally integrated with their dissertation work. The graduate students formed an Extension and Outreach Working Group, and

initially developed the program structure, which later garnered support from the department, college, and UC ANR. As part of this program, executive committee members will develop a curriculum that reflects the skills and competencies needed to conduct community-engaged research and outreach, and focuses on areas not typically covered in an academic graduate program. The skills and experience developed through this program will support students in following non-academic career paths, and allow them to make tangible, applied contribution to pressing environmental problems.

Karuk-UC Berkeley collaborative

Finally, trans-academic interdisciplinary science may often come from targeted efforts by small groups or individuals. For example, one student is working on a community-engaged scholarship project through the Karuk-UC Berkeley Collaborative. This partnership seeks to leverage resources from the academy to support collaborative partnerships, which forward the Karuk Tribe's eco-cultural revitalization goals within its ancestral territory. Working together with Karuk land managers offers an opportunity for students to learn about the environmental issues from a tribal perspective, which includes learning about cultural resource management, contemporary Native American governance institutions, and Indigenous knowledge. The learning that occurs in such a trans-academic endeavor, where students are learning to shift between different terminology and to respect different types of "situated" knowledge systems, applies many of the interdisciplinary learning moments structures discussed in this paper. In addition, this kind of community-engaged scholarship offers students the opportunity to work closely with community research partners in applying research findings to environmental policy challenges.

Conclusions

We began with the question of where and how people learn to be interdisciplinary thinkers. In our answer to this question, we have not posited a single model or set of rules. Interdisciplinarity is a dynamic process that varies, depending on who is in the mix and the nature of the research or management question at hand. Learning as you go is a hallmark of interdisciplinary practice. In what follows, we offer guiding principles that reflect our own experiences—with the hope that some will be useful in the empirical contexts where others who wish to do interdisciplinary work find themselves.

Our answers to "where" include the classroom, but also move beyond it to numerous contexts—most importantly in the field and in trans-academic collaborations. These two contexts force the observant researcher towards interdisciplinarity because complex phenomena on the ground rarely conform to disciplinary boundaries. Our answers to "how" center on patience and respect. Practicing interdisciplinarity in our scholarship and teaching others to do interdisciplinary work is a commitment. We suggest the following as keystones:

(1) Patience is paramount. Allowing time for interdisciplinary processes and relationships to develop is essential. Interdisciplinary processes take time, iteration and adaptation as researchers learn the assumptions and technical languages of other disciplines (and their own!) Working through frustrations, revisiting ideas, adapting to field realities, and developing trust all require time. Tight inflexible schedules may be inappropriate for interdisciplinary and certainly for trans-academic work.

Thus, we recommend working with students to begin interdisciplinary training and research projects early in their academic careers.

(2) You cannot practice interdisciplinarity or trans-academics without respect and trust. Often, interdisciplinary research depends on networks and groups. We have repeatedly mentioned the necessity of safe spaces for interdisciplinary interaction—among disciplines, faculty and students, academic researchers and community researchers. Safe spaces require not only respect for difference, but also a willingness to explore that difference—no matter how odd it may seem at the outset. Questioning is common in safe spaces, while mockery, dismissiveness and humiliation are prohibited. The possibility of interacting without fear opens new possibilities for knowledge formations with many learners experiencing the freedom to push through their disciplinary boundaries, in order to explore other disciplinary and epistemological arenas. Relationships built on mutual respect and trust can be essential when students face the emotional and intellectual challenge of having heretofore 'safe' disciplinary assumptions destabilized. The creation of safe spaces is everyone's responsibility. It is both a bottom-up and top-down process. And while power differentials (between, for example, students and faculty) are a reality, their effects can be minimized through thoughtful practice.

(3) The creation of interdisciplinarity may depend on the cumulative effect of actions across different contexts. While we treat each of the contexts described above separately, it should be clear that they do not exist in isolation, but rather may interact to co-produce each other. For example, as mentioned previously, one of the projects the IDTEA seminar (context 1) took on was to help shape the curriculum in the mandatory 201A course (context 1). As students have completed 201A, they have been exposed to many of the concepts that IDTEA would have previously dealt with, thereby helping some to locate opportunities for interdisciplinary collaborations in their own work (context 2). Thus, IDTEA has adapted by morphing into a working group that has focused on facilitating departmental interdisciplinarity, as well as interdisciplinary connects at a regional level (context 4). Similarly, co-advised students (context 3) can become the links between faculty advisors that give rise to collaborative research grants (context 2), which then create opportunities for other students to be co-mentored (context 3), and also create trans-academic opportunities (context 5).

We have argued throughout this paper that an interdisciplinary education is essential to creating practitioners and researchers who can tackle complex, multi-disciplinary environmental challenges. Few readers will object to this argument, but many will ask if the pursuit of interdisciplinarity comes at a high cost to students and faculty at traditional research universities. We ask this question ourselves and have no simple answer. However, we have noted that explicitly interdisciplinary professors have advanced easily to tenure in our department. Our explicitly interdisciplinary students have been awarded prestigious post docs and earned good jobs, both in and out of the academy. But questions for future research remain as we and other institutions move towards the routinization of interdisciplinary practice, and the career trajectories of interdisciplinary graduates unfold. How do we ensure the quality of interdisciplinary work? What best practices in co-advising will ensure that students do not fall between the cracks? What will persuade more traditional journal editors to accept articles co-authored by researchers from multiple disciplines, or by community researchers in the case of trans-academic work? Only through resolving institutional and historical barriers to interdisciplinarity can our academic programs

educate practitioners capable of working on environmental challenges that are much more than academic pursuits.

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