Title: Transdisciplinary graduate education in marine resource science and management

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Abstract: In this article we consider the current educational needs for science and policy in marine resource management and we propose a way to address them. The existing literature on cross-disciplinary education that responds to pressing environmental problems is vast, particularly in conservation biology. However, actual changes in doctoral-level marine science programs lag behind this literature considerably. This is in part due to concerns about the time

investment in cross-disciplinary education and about the job prospects offered by such programs. There is also a more fundamental divide between educational programs that focus on knowledge generation and those that focus on professional development, which can reinforce the gap in communication between scientists and marine resource managers. Ultimately, transdisciplinary graduate education programs need not only to bridge the divide between disciplines but also between types of knowledge. Our proposed curriculum aligns well with these needs because it does not sacrifice depth for breadth and it emphasizes collaboration and communication among diverse group of students, in addition to their individual knowledge and skills development.

Key words: transdisciplinary, graduate education, professional skills, experiential learning

Introduction

The need for broader scientific perspectives to address complex marine resource management problems has recently led to increased support for integrated marine resource science (Perry *et al.*, 2012) and participatory management (Armitage *et al.*, 2009). While this push has advanced the development of cross-disciplinary tools and approaches (e.g., Paterson *et al.*, 2010), a growing number of scientists are concerned that current models for educating doctoral-level marine scientists do not address the social-ecological complexity of marine systems (Langholz and Abeles, 2014). At the same time, graduate students are forced to contemplate the time investment in cross-disciplinary education and the job prospects offered by such degrees. Although there are already a number of successful MSc-level programs that are implementing curricula that cross sociological, ecological and policy boundaries, PhD-level programs in marine science needs to extend further in order to develop the collaboration and communication skills needed to pursue truly transformative science that has lasting policy implications (e.g., reports from the Intergovernmental Panel on Climate Change). There is, in fact, a separation in scientific education between academic programs that focus on basic and applied science. This separation reverberates through the professional life of students that graduate from either type of program and perpetuates the existing gaps among managers, policy makers and scientists. In this article, we consider the current educational needs for applied marine science and propose a structure for a short-term, intensive training academy for early career marine scientists to address such needs. Our proposed approach increases opportunities for collaborative work that cross not only disciplinary but epistemological boundaries as well.

Educational needs in applied marine science

The call for integrated and participatory approaches recognizes that marine resource management not only requires information about organisms and their environments, but must also include social, cultural, and historical perspectives to understand what motivates human actions (Berkes, 2011). Even the assessment of management success or failure depends on the disciplinary lens through which it is examined (Loring, 2012). Thus, complex natural resource management issues need solutions that bridge the natural and social sciences. This need has been well recognized by funding agencies nationally and internationally. The U.S. National Science Foundation (NSF), for example, has implemented a series of grants aimed at revamping research and education in sustainability (e.g., Science, Engineering and Education for Sustainability (SEES) investment area).

Moving into transdisciplinarity

We refer to cross-disciplinary approaches as those research and educational activities that span two or more traditional disciplines (e.g., ecology and economics). Rosenfield (1992) distinguishes three types of cross-disciplinary research: multidisciplinary, interdisciplinary and transdisciplinary (Fig. 1). It is instructive to examine this taxonomy in the context of future needs in marine resource management. In multidisciplinary and interdisciplinary settings, individuals work in parallel to address a common problem (e.g., status of fisheries) with no integration (multidisciplinary) or some integration (interdisciplinary) of their respective disciplines. This approach may fall short of developing an integrated course of action to address the original problem (Rosenfield 1992). Transdisciplinarity is the deepest level of collaboration achieved by a team of different experts (Fig. 1), who may be joined by stakeholders with local knowledge of the system. In a transdisciplinary framework, researchers with varied expertise work jointly to address a problem they define under a shared conceptual framework; this approach essentially breaks down disciplinary boundaries as shared language and problem-solving approaches are developed (Rosenfield 1992).

Reports by various governmental agencies to document the status of fish stocks and propose new management measures are good examples of the multi- and interdisciplinary collaborations inherent in fisheries science. These reports include chapters on stock assessment, habitat and other ecosystem considerations, oceanography, and socioeconomics of fishing communities, each prepared by a group of experts in the respective fields. However, these separate frameworks are often poorly integrated when formulating policy decisions, which are still heavily based on intradisciplinary considerations (Hollowed *et al.*, 2011). Coastal marine spatial planning initiatives provide a good example of both the need and implementation of transdisciplinary research approaches applied to marine resource science and management (Galparsoro *et al.*, 2012). We argue that this level of cross-disciplinary collaboration is needed to integrate ecological and social sciences in ways that can address complex policy needs, but such exercises are only likely to be successful if participants are able to synthesize information from all of the relevant disciplines.

Transdisciplinary needs in graduate training

Many PhD-level marine science graduate programs are already cross-disciplinary and individual students acquire some depth of knowledge in several fields. For example, fisheries scientists are typically well versed in biology, ecology, statistics, mathematics, and policy. However, professionals in marine science are now asked to cross an even greater number of disciplinary boundaries when dealing with resource management problems, including resource economics, welfare economics, and institutional analysis (Paterson *et al.*, 2010). More importantly, scientists and managers need to work in integrated teams with members whose professional mandates range from the generation of new scientific knowledge through research to policy development for natural resource governance. Thus, what appears undeveloped in PhD-level graduate programs focusing on conservation of marine resources is the horizontal connectedness among students with different disciplinary and educational backgrounds—we are not helping our students become efficient collaborators and members of creative, transdisciplinary research teams (McBride *et al.*, 2012). This occurs because current PhD-level programs are, in spite of several specific cross-disciplinary graduate programs such as the NSF Integrative Graduate Education and Research Traineeship (IGERT), still largely aimed at individual achievement within a student's primary discipline. Students are ultimately asked to independently write a research dissertation, which directs graduate education towards individual rather than interpersonal achievement (Campbell *et al.*, 2005, Goring et al. 2014). Even cross-disciplinary graduate programs such as the IGERT may stop short of reaching transdisciplinary outcomes (Morse *et al.*, 2007). A research and disciplinary focus is necessary for developing competence as a scientist; however, it fails to provide the communication, collaboration, and other transdisciplinary skills that students will ideally require for success as practicing professionals (Borrego and Newswander, 2010). We teach doctoral students to be good scientists, but not to work well as a team on a larger picture. A metaphor for these programs is that individual students master the preparation of different cuisines, but do not gain practice in collectively cooking a great gourmet meal.

Teaching transdisciplinary skills in graduate programs through group problem solving

Pedagogy has long acknowledged that truly transformative educational experiences must include a dispositional outcome (Dewey, 1916; Colby, 2003). Development of dispositional outcomes for future marine conservation scientists involves training for working effectively in cross-disciplinary team settings (Langholz and Abeles, 2014). This view contrasts with traditional doctoral program curricula, where the acquisition of specific knowledge and methodologies is at the forefront of learning outcomes (Fig. 2). Individuals do not need to be polymaths or sacrifice depth for breadth of knowledge; however, they do need interpersonal skills that will enable them to be good collaborators, such as communication and group facilitation. One way to foster these dispositional changes in marine conservation students is through short-courses or training academies (3−5 weeks) in which graduate students interact with cross-disciplinary peers and stakeholders while addressing real-world problems as a team (Cannon *et al.*, 1996). Short-courses also give students and stakeholders opportunities to interact in an educational setting while alleviating their concerns about the time investments of longer transdisciplinary programs (Rhoten and Parker, 2004).

There are three aspects of knowledge integration in cross-disciplinary research teams: defining a problem, developing a methodology, and proposing a tactical solution (Fig. 1). Often there is not one best or optimal solution, but a set of possible solutions to the collectively defined problem. To work effectively in teams, members of transdisciplinary educational programs require cross-disciplinary literacy, and constant interaction in defining a shared vision of the problem, addressing it and mapping out solutions through an iterative process. Such outcome may not automatically translate into a policy change, but it offers an integrated view to a multifaceted problem. A practical way to implement these elements in a short-course is by organizing students in cross-disciplinary clusters, each working on a specific project commissioned by a stakeholder (client). In marine resource management, managers or policy makers from federal and lower levels of government are often the most suitable clients because they can provide case studies that have clear policy implications. The projects could be part of larger policy initiatives (e.g., regional-level coastal marine spatial planning), but should have focused and clear objectives (e.g., environmental, economic and social impacts of marine renewable energy infrastructure). Defining focused and achievable targets will help students see the immediate relevance and application of their collaboration. This is an important trait that distinguishes transdisciplinary from intradisciplinary courses, where students have limited opportunities to propose integrated approaches to address real-world problems.

To facilitate knowledge integration at all three levels of transdisciplinary collaboration, we envision a graduate training academy that is organized in three phases. In the first phase, students are introduced to a particular case study from multiple disciplinary and client perspectives and create a shared knowledge platform that allows participants to understand the different facets of the case study. Short teaching modules precede the academy (e.g., one to three days), which students attend based on their [lack of] prior expertise; for example, those in social science will gain natural science background and vice-versa. These modules are an effective way to promote a common language and, ultimately, promote transdisciplinary literacy (Vale *et al.*, 2012). With an emphasis on reading and discussion, students are encouraged to offer their own perspectives on marine resource science and management issues. During the second phase, participants work together on a commissioned project, starting with the task of defining a shared vision of the problem and ending with a consensus on operational solutions to resolve that problem. In the third phase, participants present a report to the client and revise their work based on feedback. Revisions can be done following the short course via online meetings and discussion boards; however, providing students with funding to meet with clients and present their work at professional meetings would facilitate long-lasting interactions and provide motivation for continued collaboration among team members. Throughout all phases of the course, it is important that student clusters have dual mentorship by professionals in the social and natural sciences. Doctoral students in their second or higher year of education are best poised to take advantage of transdisciplinary educational programs, because they are well versed in their own disciplinary fields, and at the same time, ready to participate in professional activities in which collaborative skill sets are most needed.

Some aspects of the short-course module that we propose have already been successfully implemented in a variety of academic programs. For example, the Monterey Area Institutions' Network for Education (MARINE) initiative of the Center for Ocean Solutions (http://www.centerforoceansolutions.org/education/marine) offers opportunities for students from seven different campuses in the Monterey area (California, USA) to get together and engage in addressing real-world management problems. To meet learning outcomes and justify the use of faculty and student time and resources, exercises such as this must be accompanied by academic rewards for both students and instructors. Opportunities to publish the results of team efforts and to include them in the dissertations of each participant is essential, however the latter will require a break from traditional individual-based academic expectations.

Conclusions

Calls to improve transdisciplinary research skills of current graduate educational models to address complex environmental issues are not new, but the implementation of such programs in marine science lags behind. Here we identified a number of challenges, including time investment, reward systems for collaborative efforts, and job prospects of interdisciplinary training. There is also a more fundamental divide between educational programs that focus on knowledge generation (e.g., scientific and academic degrees) and those that focus on professional development (e.g., management and professional degrees). Neither of these two programs, taken in isolation, can adequately address the current educational needs for pressing management issues in marine science. The *status quo* of letting people who are good at generating knowledge continue to do it, and letting the people who are good at fast-paced group problem solving take that knowledge to the real-world problem space does not foster the development of science-based and long-lasting policy solutions to pressing management problems. It actually widens the gap between scientists and managers. We do not advocate making managers out of scientists, but rather increase opportunities for collaborative work that cross not only disciplinary boundaries but epistemological boundaries as well. The hope is that doing so will lead to more rapid, long-lasting and sustainable innovative solutions to pressing management issues. The opportunity for PhD students to work in a transdisciplinary setting will benefit them (and their advisors) directly by improving their understanding of their own disciplinary work. This may result in benefits such as better-focused research questions or more articulate motivations for the disciplinary work. So, the direction of impact of transdisciplinary work is not only from the basic towards the applied, but also from the applied back towards the basic.

Is academia ready to embrace these new opportunities? While the job market for students with various levels of cross-disciplinary training can be strong in NGOs and government agencies (Blickley *et al.*, 2012), the future of cross-disciplinary PhDs in academia is still in question (Rhoten and Parker, 2004). In many universities the current reward systems of students and educators alike, such as advancement in graduate programs and promotion/tenure decisions, are based on individual and disciplinary achievements (Noss, 1997, Goring et al., 2014). At this point the students see the opportunity for integrating across disciplines more clearly than the academic world does (Vinhateiro *et al.*, 2012). We thus have a paradox: practitioners, managers and students recognize the importance of transdisciplinary skills to address current management issues but universities are lagging behind in hiring and promoting faculty with the necessary background to teach these skills. Revisiting the cooking metaphor, perhaps one of the problems is that we are not placing students in the kitchen with master chefs.

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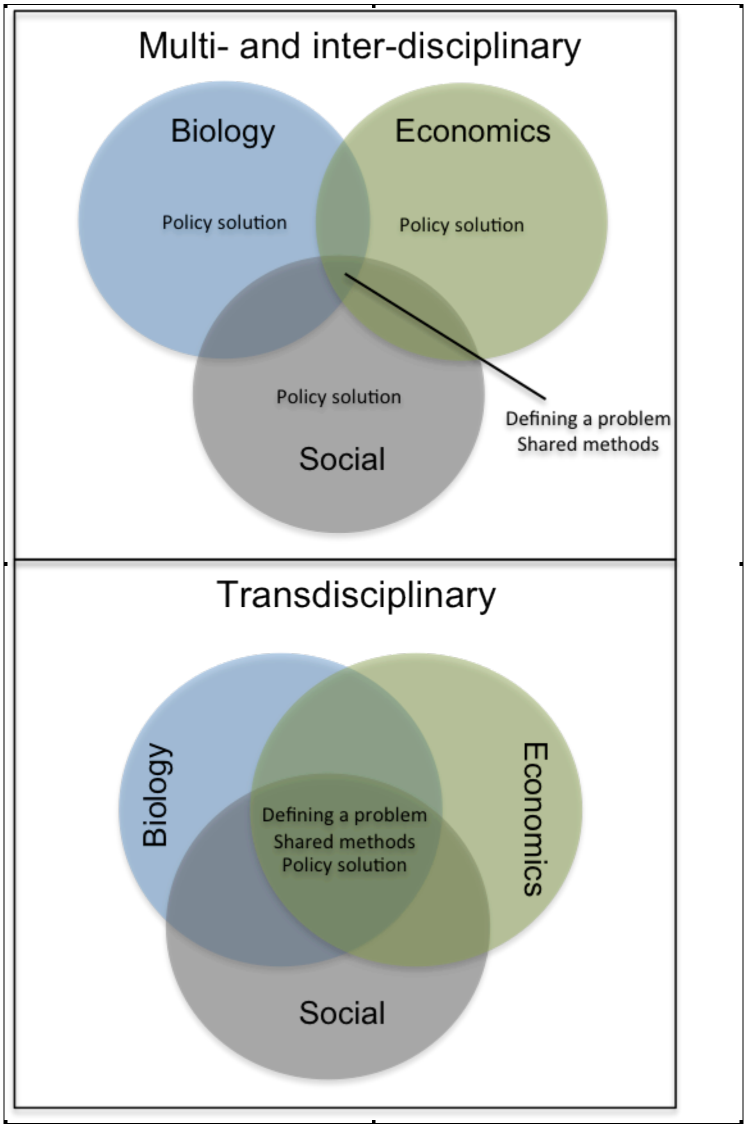

Fig. 1. Levels of knowledge integration in three cross-disciplinary research programs: multidisciplinary, interdisciplinary (top panel) and transdisciplinary (bottom panel). Circles of different colors represent different disciplinary perspectives. For example, blue could be biology, green could be economics, and gray could be social aspects (e.g., equitable allocation of fishery resources). Three aspects of knowledge integration are recognized: defining a problem, developing a methodology, and proposing a course of action (solution). In multi- and inter-disciplinary programs, team members work on a common problem but have limited integration

when defining the problem and sharing a methodology to address it. As a consequence, three separate policy solutions are developed, based on each discipline. In transdisciplinary research programs there is greater integration during all three phases of collaboration, leading to a single integrated policy outcome (after Rosenfield, 1992).

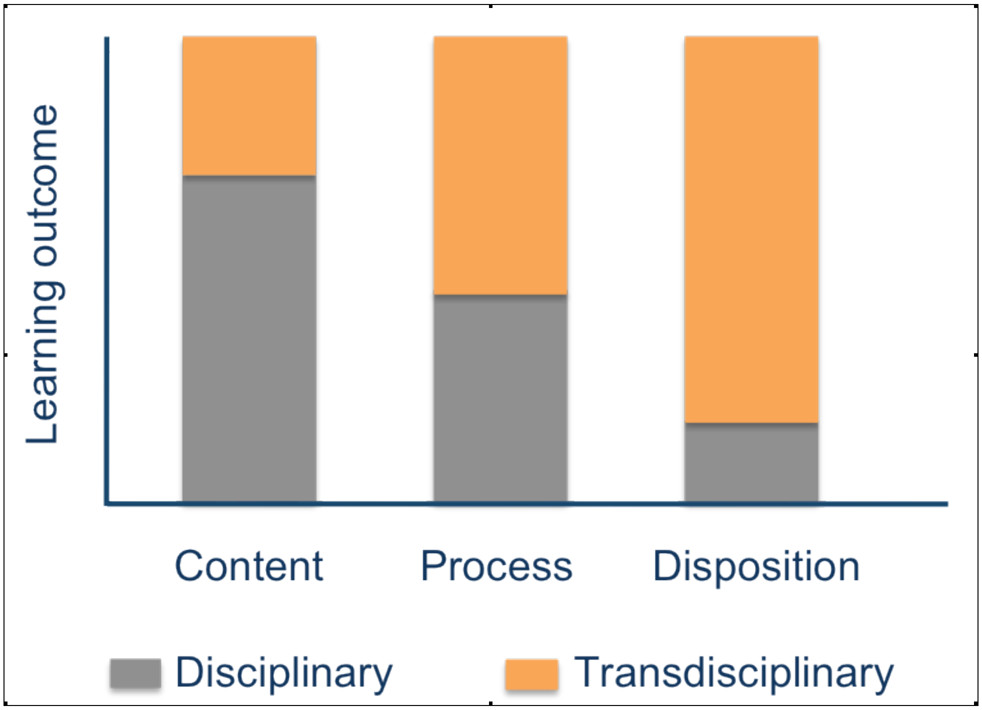

Fig. 2: Content (information), process (e.g., problem-solving skills, methodological approaches) and disposition (ability to work effectively in a cross-disciplinary research team) learning outcomes of traditional disciplinary versus transdisciplinary curricula in graduate education. In the former, there is a greater emphasis on content and processes, and less on individual disposition. We propose reversing this distribution in a transdisciplinary curriculum.