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PERSPECTIVE

Ecological literacy and beyond: Problem-based learning for future professionals

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Abstract Ecological science contributes to solving a broad range of environmental problems. However, lack of ecological literacy in practice often limits application of this knowledge. In this paper, we highlight a critical but often overlooked demand on ecological literacy: to enable professionals of various careers to apply scientific knowledge when faced with environmental problems. Current university courses on ecology often fail to persuade students that ecological science provides important tools for environmental problem solving. We propose problem-based learning to improve the understanding of ecological science and its usefulness for real-world environmental issues that professionals in careers as diverse as engineering, public health, architecture, social sciences, or management will address. Courses should set clear learning objectives for cognitive skills they expect students to acquire. Thus, professionals in different fields will be enabled to improve environmental decision-making processes and to participate effectively in multidisciplinary work groups charged with tackling environmental issues.

Keywords Problem-based learning · Teaching ecology · Conceptual underpinnings · Interdisciplinary work

INTRODUCTION

In a complex and fast-changing world, ecological science is uniquely equipped to address intricate environmental questions, and it is nowadays expected to contribute substantially to understanding and addressing environmental problems in local, regional, and global instances. Ecologists have been rising to this challenge by producing research that is readily applicable to environmental problems. Several initiatives that tackle such problems have been established, or strongly supported, by ecologists, such as the Sustainable Biosphere Initiative (Lubchenco et al. 1991) or the Millennium Ecosystem Assessment (MEA 2005). Nonetheless, most ecologists nowadays would agree that ecological science is not being deployed as much as it should in the wider decision-making spheres (e.g., Kiker et al. 2005; Roux et al. 2006; Cardelús and Middendorf 2013). This may be due in part to impediments which beset the ability of various professionals to integrate relevant scientific knowledge in making decisions and developing policy regarding environmental issues.

There has been increasing concern with enhancing "ecological literacy" in society. The current literature on ecological literacy emphasizes the role of scientific knowledge and ecological thinking in identifying cause-effect relationships in socioenvironmental systems, in order to allow more enlightened decision-making; therefore, its primary pedagogical goals are cognitive and experimental. In this, it differs from the broader concept of environmental literacy, which incorporates civic literacy that pertains to changes in values and behaviors, and thus also contains affective and moral pedagogical goals (McBride et al. 2013).

Ecological literacy is meant to enable conscious and participant citizens to make informed decisions or take action on environmental issues (Jordan et al. 2009; Cid and Pouyat 2013). Efforts in this direction include books by experienced ecologists for the general public, of which two outstanding examples are Levin (2000) and Slobodkin (2003); see also the ongoing series of opinion and case papers inaugurated by Cardelús and Middendorf (2013). Other contributions discuss ways of enhancing ecological literacy in formal education in early schooling (Magntorn and Helldén 2007; Ju and Kim 2011) or in general biology courses (Pool et al. 2013; Long et al. 2014).

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Fig. 1 Examples of environmental issues that professionals of different fields have to address in their work (clockwise from top left). **a** Afforestation of extensive areas in south Brazil, often with exotic trees, has been advocated by the cellulose industry and unsoundly justified as "restoration of deforested areas" that in fact are natural grassland—an indication of lacking ecological knowledge by the professionals involved. The sign reads "Entrance forbidden—environmental preservation." **b** Forest dieback caused by bark beetle outbreaks in the Bavarian Forest National Park (SE Germany). Contrary to general understanding, research demonstrated that such outbreaks do favor regeneration of spruce, the species mainly affected by bark beetle, showing that decisions of practitioners need to be informed by current ecological research. **c** Exclusion of human interference may be an ineffective strategy for biodiversity conservation if ecological processes are not understood. The depicted species-rich subtropical grasslands in the South Brazilian highlands need periodic fire or grazing to maintain their biodiversity; otherwise, succession to shrubland and forest takes place. **d** Clamshell diggers, as well as traditional fishers, are losing ground to beach houses, tourism, and industrial fishing in the coast of NE Brazil. Combined conservation of natural resources, traditional livelihoods, economic, and demographic growth is hard to achieve in fragile coastal ecosystems and requires interdisciplinary work (photo credits **a** V. Pillar **b** J. Kollmann **c** G. Overbeck **d** T. Lewinsohn)

One aspect of ecological literacy has been largely overlooked despite its evident strategic importance. In our view, it is especially important to enhance literacy of a wide spectrum of professionals whose day-to-day work touches on environmental issues (Fig. 1). The inadequate ecological literacy among those who should apply ecological science to environmental problems as part of their professional activities points to a specific impediment that needs to be addressed by academic ecologists at universities: the gap between current ecological research as practiced, and the way ecology is presented in university courses for various careers. Here we discuss how this gap arises, and propose ways to promote effective acquisition of the knowledge needed across this broad range of future professional activities.

In this paper, we therefore propose to consider how ecological science is taught and learnt, especially in general or introductory courses at the undergraduate (i.e., B.Sc.) level. In many careers, this is the only opportunity to further the understanding of ecology as a science and to foster the capacity of applying principles and procedures to environmental questions in their own professional field. Moreover, many biologists also are required to take only a single ecology course in their basic undergraduate curriculum. Hence, introductory courses are critically important to develop a minimum literacy in ecological concepts and their connection to real-world problems. To reflect on these issues, we draw on our experience in teaching ecology in different countries to students in a wide variety of university degrees such as agricultural science, architecture, biology, environmental management, landscape planning, geology, among others. Although there are substantial differences in the syllabi and curricula between courses and countries, there are pervading common concerns and approaches, which we develop here.

CHALLENGES OF TEACHING ECOLOGY IN UNDERGRADUATE COURSES

The first challenge faced by ecology instructors at the undergraduate level is to persuade students that ecology is actually a scientific discipline, since most students take it to be a philosophy, an activist movement, or an ideology. In many cases, students will still hold this "tree-hugger" view even after having attended introductory ecology courses. We believe this failure to reach the students and to show the relevance and scientific soundness of ecological concepts is at least partly caused by an insufficient connection to real-world problems. In particular, these courses often focus on theoretical concepts and on classical examples, but do not link them to applications in other fields of professional activity.

To address this gap, the current major ecology textbooks do include applied issues, which often comprise most drivers of change in biodiversity and ecosystems listed by the Millennium Ecosystem Assessment (MEA 2005). Unfortunately, these are presented as simplified examples and usually restricted to a final unit or chapter, apart from the main ecological content, and included language and metaphors detaching humanity and nature (Cachelin et al. 2010). In our view, this disconnection reinforces the perceived gap between ecological concepts and the real world. Emphasizing simpler classical examples can facilitate comprehension, but if students are not faced with concrete cases linked to their professional interests, they will not envisage the application of ecological concepts to the complex problems faced in real life. This difficulty to apply ecological knowledge is probably reinforced by the fact that most introductory ecology courses are largely lecture based, so that students have insufficient opportunity to deploy ecological concepts in a practical way.

ENDOWING STUDENTS WITH ECOLOGICAL CONCEPTS FOR THEIR PROFESSIONAL ACTIVITIES

We propose problem-based learning (PBL) as a way of overcoming the gap between the perception of ecology as a science and the real-world problems that the students will be exposed to as professionals. PBL is a student-centered teaching method in which the role of the instructor is to facilitate the learning process. It begins with the statement of a specific problem and directs groups of students to an active, self-directed process of gathering and synthesizing information that would lead to its solution (Hmelo-Silver 2004; Savery 2006). Therefore, in ecology teaching it can help to link ecological concepts, methods, and models with concrete situations related to the student professional profile (Tapio and Willamo 2008). PBL is being increasingly used in higher education and there is evidence that it has a robust positive effect on the students' motivation, on long-term retention of learned contents and on students' higher cognitive skills (Dochy et al. 2003; Hmelo-Silver 2004; Jones et al. 2013). The most complex cognitive levels, as discussed in the next section, are achieved when students or professionals are able to engage ecological understanding in creating solutions for problems they have to address (Table 1). When these levels are attained, future conservation managers, landscape planners, environmental engineers, or public health managers, among others, should be able to modify current practices or to conceive novel solutions for environmental issues within their fields of activity.

In consonance with PBL, ecological understanding can be envisioned as the combination of two components: conceptual constructs and observable phenomena (Pickett et al. 2007). The conceptual constructs can be relatively simple such as the concepts of organisms, populations, and communities as distinct levels of biological organization; these are useful to define the level(s) at which the relevant observable phenomena should be investigated. Other concepts can be highly abstract and derived from simpler ones. For example, a model of population growth is a more abstract and derived conceptual construct than the concept of population. Conceptual constructs of varying degrees of complexity are essential for building ecological theories (Peters 1991). Basic ecology teaching customarily does include several ecological concepts of different levels of complexity. However, in the PBL approach to ecology

Table 1 Desired learning outcomes for an effective education in ecology, in increasing order of cognitive complexity (Krathwohl 2002). Outcomes at lower complexity levels (top) are necessary to achieve those of higher complexity (bottom). See text for explanation

Cognitive level	General learning outcomes
To remember …	Key ecological concepts
To understand …	How ecological concepts are essentially related to environmental problems relevant to their professional activities
To apply …	A standard ecological approach to a particular environmental problem
To analyze …	Ecological issues associated with a problem encountered in a given professional area
To evaluate …	Whether professional practices incorporate sufficient and appropriate ecological reasoning
To create …	Solutions based on ecological science in their professional activities

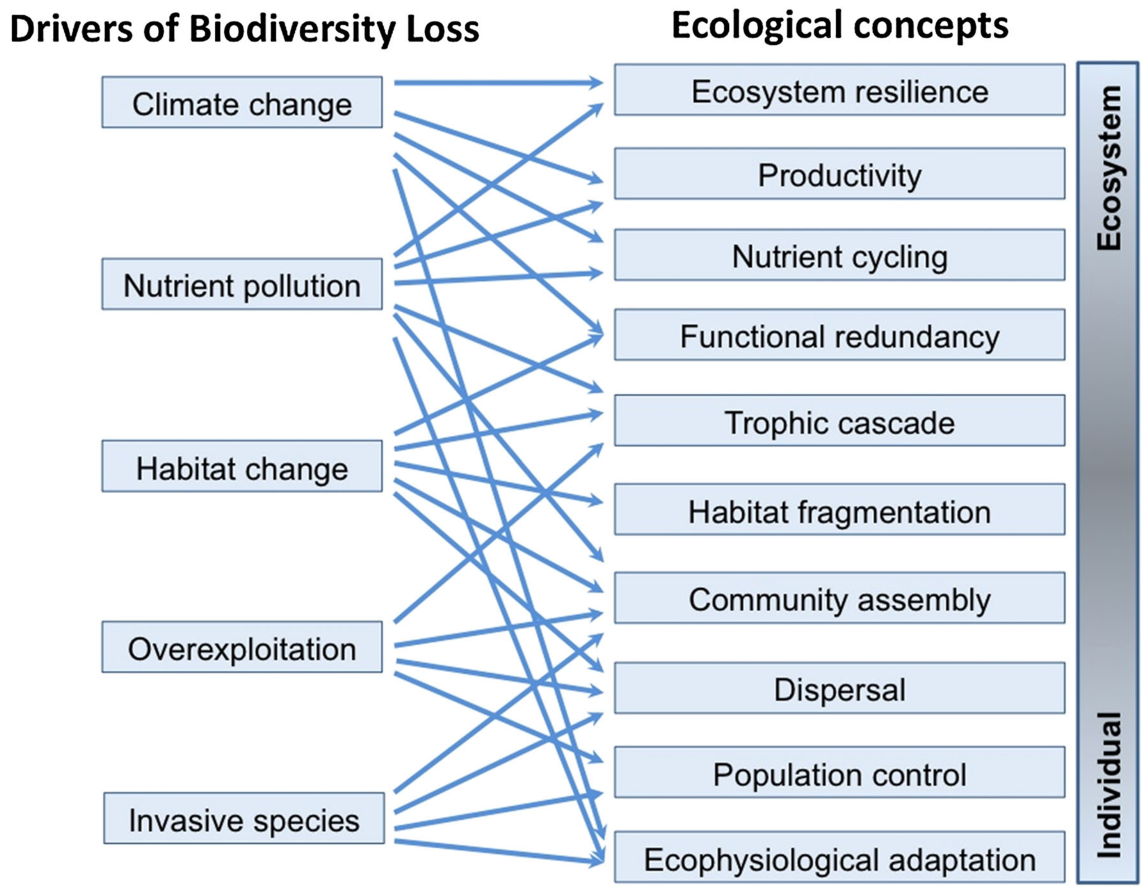

Fig. 2 Linking drivers of biodiversity loss (Millennium Ecosystem Assessment 2005) to key ecological concepts. The concepts refer to different levels of biological organization and are only illustrative. The learning outcomes in basic ecology courses may involve different cognitive levels for science-based mitigation or adaptation solutions to the environmental problem of biodiversity loss (see Table 1)

teaching, the selection and inclusion of these concepts should be guided by their relevance to the problem at hand. Rather than adding problems as examples at the end of the presentation of a given concept, in PBL, each concept and method is incorporated as needed in the process of developing a solution to a given problem. Figures 2 and 3 show examples that have been used in classroom work.

LEARNING OUTCOMES IN ECOLOGY

A second, equally important, feature of our proposed framework for undergraduate courses entails the shift from content-centered teaching to outcome-based learning as a paramount reference. This shift signifies that, rather than assessing teaching success through evaluation of the formal content retained by students, one should focus on the actual skills that students acquire and develop in response to stimuli and elements provided by the course (Biggs and Tang 2011). Following the taxonomy of cognitive learning objectives formulated by Bloom (1956), the desired learning outcomes encompass a progression of cognitive skills from the retention of concepts or information, up to the capacity of addressing and solving environmental problems (Krathwohl 2002). In order to reach more comprehensive cognitive levels, the flow of the learning process starts with the retrieval of key ecological concepts which are needed to understand information provided by scientists, governmental agencies, NGOs, and media. With this conceptual framework at hand, students should be able to execute appropriate procedures, e.g., choose and measure relevant data and then fit them to simple models. Analyzing complex ecological problems (parameters, structures, and relationships) and evaluating alternative solutions based on justifiable criteria are two very advanced learning outcomes heading toward the creation of ecologically sound solutions in their own professional fields.

Take, for instance, biodiversity loss and its five major drivers according to the Millennium Ecosystem Assessment (MEA 2005). A distinct set of ecological concepts would be needed for students to understand how each problem needs to be related to certain causes more than to others (Fig. 2). Furthermore, the problem will require different cognitive levels (Table 1) for learning outcomes that

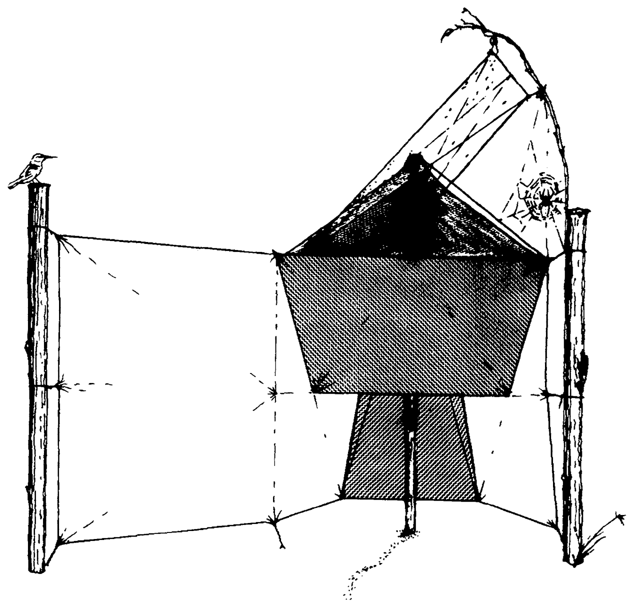

Fig. 3 A trap for tsetse flies developed to reduce human sleeping sickness and cattle nagana disease (Dransfield et al. 1991). The trap was built with simple and inexpensive materials, but its design and deployment in the field could only be achieved by a combination of ecological concepts and methods. Humans are beset by sleeping sickness in several regions of Africa, and their cattle by nagana disease. Both are caused by trypanosomes and transmitted by tsetse flies, *Glossina* spp. Several methods have been employed to control the vector, some very expensive and none entirely successful. Dransfield et al. (1991) described a deceptively simple trap whose development entailed a number of skills and ecological concepts. Tsetse attraction is based on understanding of its behavior and response to color, texture, and odors. Trap spacing and placement was based on fly population dynamics and dispersal rates, and optimized through a mathematical model which also incorporated human and cattle demography and economic data. A field trial in Kenya placed 200 traps built and operated by local Maasai communities over 120 km^2, at a cost of US$ 15 per trap per year. Tsetse densities fell by 99 % after eight months. Insufficient financing, the need to monitor and adjust parameters continuously (Baylis and Stevenson 1998), and the lobby from chemical industries prevented this effective solution from being adopted more widely (reproduced with permission from Elsevier)

capacitate students to attempt designing solutions for mitigation or adaptation to the drivers of biodiversity loss. For example, if the problem at hand is biodiversity loss due to overfishing, ecological concepts such as population control and trophic cascades are relevant for the development of a population model to predict maximum sustainable yield, whereas the concepts of nutrient cycling and ecosystem resilience are less pertinent. Conversely, if the proposed problem involves biodiversity loss due to eutrophication, the concepts of nutrient cycling and ecosystem resilience are directly applicable. Therefore, in a problem-based learning approach, the problem and the learning outcomes establish the relevant concepts to be learned (Table 2; Fig. 3). This is different from our customary way of teaching in which concepts are presented in a hierarchical sequence that may start with physiological ecology, proceed to population ecology, and conclude with concepts of community and ecosystem ecology.

Different student groups have distinct needs from ecological learning for their professional practice. Although general ecological concepts form a common ground, instructors should select methods and practical examples appropriate to the learning necessities of each class. Table 2 shows examples of ecological problems particularly related to three professional groups and how ecological concepts, together with the appropriate skills, can lead to the targeted learning outcomes of students in these professions. We should not expect everyone to attain the same level of cognitive achievement, however, all students will benefit from such an evidence-based ecological learning process.

PUTTING IT INTO PRACTICE

For the reasons given, courses should be designed based not only on lists of content, but also on learning outcomes. We need to ask "What should future professionals be able to do?" instead of "What do they need to know?". In training those professionals, one should prioritize two general learning outcomes: (1) students need to learn what ecology is as a science, by understanding how ecological questions are posed and answered and (2) they should learn how to apprehend environmental causes and implications of problems within their sphere of activity, and how to devise solutions that utilize ecological concepts and methods. Once the learning outcomes are clear, we proceed to evaluate and choose teaching and learning activities, in class or outside, that will enable the students to reach the intended outcomes.

Very different teaching approaches are currently being used in university education, and many of them include practical learning and problem-based approaches, which enables students to attain higher cognitive levels beyond those achieved by traditional content-based teaching. Additionally, practical learning is especially motivating when dealing with heterogeneous audiences in ecology courses offered for students from more than one field of study. The choice of method will depend on the specific learning outcome, which will vary between professional areas and environmental settings. With no attempt at comprehensiveness, we note some approaches that in our experience have proved fruitful.

Simulated practical professional activities

Students can conduct studies linking human land use to vegetation change, produce management plans for

Table 2 Examples of learning outcomes for selected professionals and environmental issues relevant to their respective fields

Profession Issues	Public health Parasitic diseases	Agriculture Pollution	Landscape planning Habitat loss
Learning outcomes			
Remember:	Concepts of population structure and dynamics, vector niche, host–parasite interactions, metapopulation	Concepts of eutrophication, primary production, decomposition, nutrient cycling, top-down versus bottom-up control	Concepts of habitat fragmentation, metacommunity, island biogeography
Understand:	How these concepts relate to parasitic diseases	How land use in a watershed is related to water pollution	How these concepts relate to landscape planning
Apply:	Models of population dynamics to predict fluctuations of parasitic diseases	Models of eutrophication to predict critical loading of nutrients	Remote sensing analysis and GIS to solve planning issues
Analyze:	Link between vector habitat abundance versus vector population spread	Risk of eutrophication for different external loadings of nutrients	Relative importance of connectivity versus source and sink dynamics to solve landscape problems
Evaluate:	Effectiveness of host parasite models to predict disease spread	Effectiveness of current techniques to control algae and plant growth	Effectiveness of landscape ecology models
Create:	Epidemiological models for disease control	Innovative solutions to control eutrophication	Alternative solutions to solve spatial ecological problems

conservation units, or carry out environmental impact studies for real-world situations, possibly with a reduced spatial or thematic scope, to practice professional tasks rather than only considering their theoretical basis. Here, the instructor takes the role of "guide on the side," instead of the "sage on a stage" who would simply expound methods and approaches in lectures (King 1993). Other learning outcomes may be included, such as familiarization with a local flora and fauna, field instrumentation, and analytical methods.

Modern technologies: the inverted classroom

New technologies have radically changed research and communication practices in ecology and they can also improve our teaching capabilities. Today's students, which have grown up in a digital environment, can benefit from and enjoy high quality ecological web pages with interactive modes that support PBL, both in independent study assignments and classroom exercises. For example, in simulated virtual experiments, students can easily manipulate parameters and initial conditions to understand ecological situations that are not suitable for practical experiments in a true inquiry-based exploration (Meir 2001; Alstad 2007; Smetanaa and Bell 2012). Computer simulations also help to grasp the essential logic of mathematical models and ecological concepts in a more concrete way (Wilensky and Reisman 2006; Alstad 2007; Long et al. 2014). Furthermore, the internet helps to bring real problems to the classroom. Videos on emerging infectious diseases, pollution, land use changes, high impact engineering enterprises in different continents or biomes can be used to stimulate reflection and discussion. Hence, multimedia and computational resources allow shifting the initial cognitive tasks to activities outside the classroom. If explanatory teaching is kept to a minimum, more classroom time can be used for group activities based on concepts that students learn on their own with the help of such new technologies (the "inverted classroom": Lage et al. 2000; Strayer 2012).

Field courses

A field course may comprise a series of small research projects that students develop fully in the field (from choice of problem, experimental design up to presentation of results), or it may be used for training in particular methods for a given specialty. In either case, the focus is on applying ecological science to real-world problems or specific disciplines, but enabling students to reach high cognitive levels, creating their own projects or experiments. Field courses may be located not only in "pristine" environments but also in areas related to the students' future occupations, e.g., an agricultural setting. Whenever possible, both kinds of environmental settings should be exploited. The importance of this kind of experience has been highlighted for high school teachers (Dresner 2008; Ju and Kim 2011), and we believe the same benefits should be expected for any professional working with environmental problems.

Excursions

These allow students to get acquainted with communities or ecosystems and have a long tradition in basic ecology courses. Problem-based learning can be easily included into excursions by planning student activities. Excursions that span various habitats, landscape forms, or gradients of disturbance give students first-hand experience with ecological phenomena that express themselves over larger spatio-temporal scales and various modes of human impact. Additionally, excursions can provide students direct contact with systems and landscapes that are degraded or under human impact, enhancing their understanding of the link between ecological processes and environmental problems.

All outdoor activities, excursions as well as field courses, are constrained by a series of conditions: class sizes, number of professors and teaching assistants, cost and logistics of transportation and lodging, insurance and legal requirements, etc. Given the particularities that each course will cope with, generic advice would be largely pointless. Nonetheless, we would recommend a wide and enterprising survey of possibilities, starting with those on or near campus, to consider opportunities of associating these projects with excursions offered by other courses, or using facilities in public parks or private areas (e.g., reserves, restoration projects). To sum up, the general suggestion we would offer is to be imaginative and opportunistic in designing such activities.

CONCLUDING REMARKS

Ecological literacy of people of all walks of life is certainly important and deserves attention. In more immediate terms, we assign a high priority to the enablement of future professionals in a wide range of careers, whose activities are affected by, and have consequences for, actual environmental issues.

Professionals should have a sound understanding of key concepts of ecology and their deployment to better apprehend the environmental causes and effects related to problems they face in their practice. For a start, they need to realize the scientific nature of ecological knowledge; then, the relevance and ways of applying this knowledge to their concerns and interests must be fully clear. We suggest that the combination of problem-based learning and clearly defined learning objectives can uplift ecology teaching, and hence the ecological literacy of professionals, in ways that will enhance the effective involvement of Ecology in the solution of environmental problems.

If we succeed in enabling a broad gamut of professionals in various careers in this way, consequences should be felt not only in their own occupations but also in wider communication, opinion-forming, and decision-making spheres. Thus, we expect that over time there should be palpable improvement in the debate of environmental issues in many social, political, and public assessment arenas, and indeed enhance the attending of decision-making processes.

Environmental problems are intrinsically complex. Dealing with them, either conceptually or practically, is demanding in several ways. Inevitably, one has to draw on heterogeneous information and a diversity of specialized fields and bridge the gap between academic and applied knowledge. This leads necessarily to multi-, inter-, and transdisciplinary work. In practice, almost all environmental demands are dealt with by multidisciplinary groups. The problem-centered, rather than discipline- or content-centered, framework that we advocate should also enable professionals to function better in a multidisciplinary work environment.

Though in this paper we direct our concerns mainly to the education of professionals in other disciplines, biologists often also have little contact with ecology in their basic curriculum, and the same ideas are largely applicable to their introductory ecology courses. Moreover, even students enrolled in undergraduate ecology programs, with more time to acquire knowledge of ecological science, will benefit from problem-based activities that link conceptual knowledge with environmental problems in the real world.

To achieve this has a cost. Ecologists sometimes consider introductory courses, especially for other careers, a minor activity that gets short shrift as a cut-down or diluted version of a conventional "complete" content course. To produce a course that captivates and engages students of various areas through problem-centered activities, ecologists have to devote time to familiarize themselves and consult with colleagues in other fields. This is needed not only to find and prepare suitable examples, but also to understand approaches and essential concepts from other areas of knowledge. Improving ecological literacy of future professionals will almost always require a collaborative effort with lecturers and researchers of different specialties.

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REFERENCES

Alstad, D. 2007. Populus: Simulations of population biology. Version 5.5. Retrieved 1 March, 2014, from http://www.cbs.umn.edu/populus.

Baylis, M., and P. Stevenson. 1998. Trypanosomiasis and tsetse control with insecticidal pour-ons—Fact and fiction? *Parasitology Today* 14: 77–82.

Biggs, J., and P. Tang. 2011. *Teaching for quality learning at university: What the student does*. Maidenhead: McGraw-Hill.

Bloom, B.S. 1956. *Taxonomy of educational objectives: Handbook I, The cognitive domain*. New York: David McKay.

Cachelin, A., R. Norvell, and A. Darling. 2010. Language fouls in teaching ecology: Why traditional metaphors undermine conservation literacy. *Conservation Biology* 24: 669–674.

Cardelús, C., and G. Middendorf. 2013. Ecological literacy: The educational foundation necessary for informed public decision making. *Frontiers in Ecology and the Environment* 11: 330–331.

Cid, C.R., and R.V. Pouyat. 2013. Making ecology relevant to decision making: The human-cnetered, place-based approach. *Frontiers in Ecology and the Environment* 11: 447–448.

Dochy, F., M. Segers, P. Van der Bossche, and D. Gijbels. 2003. Effects of problem-based learning: A metaanalysis. *Learning and Instruction* 13: 533–568.

Dransfield, R.D., B.G. Williams, and R. Brightwell. 1991. Control of tsetse flies and trypanosomiasis: Myth or reality? *Parasitology Today* 7: 287–291.

Dresner, M. 2008. Using research projects and qualitative conceptual modeling to increase novice scientists' understanding of ecological complexity. *Ecological Complexity* 5: 216–221.

Hmelo-Silver, C.E. 2004. Problem-based learning: What and how do students learn? *Educational Psychology Review* 16: 235–266.

Jones, B.D., C.M. Epler, P. Mokri, et al. 2013. The effects of a collaborative problem-based learning experience on students' motivation in engineering capstone courses. *Interdisciplinary Journal of Problem-based Learning*. doi:10.7771/1541-5015.1344.

Jordan, R., F. Singer, J. Vaughan, and A. Berkowitz. 2009. What should every citizen know about ecology? *Frontiers in Ecology and the Environment* 7: 495–500.

Ju, E.J., and J.G. Kim. 2011. Using soil seed banks for ecological education in primary school. *Journal of Biological Education* 45: 93–101.

Kiker, G.A., T.S. Bridges, A. Varghese, P.T. Seager, and I. Linkov. 2005. Application of multicriteria decision analysis in environmental decision making. *Integrated Environmental Assessment and Management* 1: 95–108.

King, A. 1993. From sage on the stage to guide on the side. *College Teaching* 41: 30–35.

Krathwohl, D.R. 2002. A revision of Bloom's taxonomy: An overview. *Theory into Practice* 41: 212–218.

Lage, M.T., G.J. Platt, and M. Treglia. 2000. Inverting the classroom: A gateway to creating an inclusive learning environment. *The Journal of Economic Education* 31: 30–43.

Levin, S.A. 2000. *Fragile dominion: Complexity and the commons*. Cambridge, MA: Perseus.

Long, T.M., J.T. Dauer, K.M. Kostelnik, J.L. Momsen, S.A. Wyse, E.B. Speth, and D. Ebert-May. 2014. Fostering ecoliteracy through model-based instruction. *Frontiers in Ecology and the Environment* 12: 138–139.

Lubchenco, J., A.M. Olson, L.B. Brubaker, S.R. Carpenter, M.M. Holland, S.P. Hubbell, S.A. Levin, J.A. MacMahon, et al. 1991. The Sustainable Biosphere Initiative: An ecological research agenda. *Ecology* 72: 371–412.

Magntorn, O., and G. Helldén. 2007. Reading nature from a 'bottom-up' perspective. *Journal of Biological Education* 41: 68–75.

McBride, B.B., C.A. Brewer, A.R. Berkowitz, and W.T. Borrie. 2013. Environmental literacy, ecological literacy, ecoliteracy: What do we mean and how did we get there. *Ecosphere* 4: 1–20.

Meir, E. 2001. *Ecobeaker.0: Laboratory guide and user manual*. Ithaca: BeakerWare.

Millennium Ecosystem Assessment (MEA). 2005. *Millennium Ecosystem Assessment—Synthesis report*. Washington, DC: Island Press.

Peters, R.H. 1991. *A critique for ecology*. Cambridge, UK: Cambridge University Press.

Pickett, S.T.A., J. Kolasa, and C.G. Jones. 2007. *Ecological understanding: The nature of theory and the theory of nature*. New York: Academic Press.

Pool, R.F., G.D. Turner, and S.A. Bottger. 2013. Ecology content in introductory biology courses: a comparative analysis. *The American Biology Teacher* 75: 544–549.

Roux, D.J., K.H. Rogers, H.C. Biggs, P.J. Ashton and A. Sergeant. 2006. Bridging the science—management divide: moving from unidirectional knowledge transfer to knowledge interfacing and sharing. *Ecology and Society* 11(1): 4. http://www.ecologyandsociety.org/vol11/iss1/art4/.

Savery, J.R. 2006. Overview of problem-based learning: definitions and distinctions. *Interdisciplinary Journal of Problem-based Learning*. doi:10.7771/1541-5015.1002.

Slobodkin, L.B. 2003. *A citizen's guide to ecology*. New York: Oxford University Press.

Smetanaa, L.K., and R. Bell. 2012. Computer simulations to support science instruction and learning: a critical review of the literature. *International Journal of Science Education* 34: 1337–1370.

Strayer, J.F. 2012. How learning in an inverted classroom influences cooperation, innovation and task orientation. *Learning Environments Research* 15: 171–193.

Tapio, P., and R. Willamo. 2008. Developing interdisciplinary environmental frameworks. *AMBIO* 37: 125–133.

Wilensky, U., and K. Reisman. 2006. Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—An embodied modeling approach. *Cognition and Instruction* 24: 171–209.

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