Design and evaluation of TIEE, a peer-reviewed electronic teaching resource

Charlene D'Avanzo[1*], Bruce W Grant[2], Deborah Morris[3], Susan Musante[4], Jason Taylor[5], Josh Riney[6], and Daniel Udovic[7]

"Teaching Issues and Experiments in Ecology" (TIEE) is a peer-reviewed electronic publication designed to help ecology faculty improve their teaching. The Ecological Society of America (ESA) electronically hosts TIEE, which is an important part of the Society's contribution to the BioScience Education Network, a pathway of the National Science Digital Library. A central part of each TIEE "Issue" (mainly for use in lectures) and "Experiments" (for inquiry-based labs) are published figures, genuine datasets, and open-ended investigations. Surveys and interviews show that users teach both at liberal arts colleges (61%) and research universities (26%), and that TIEE provides a much-needed outlet for peer-reviewed education scholarship. Over 75% of respondents to our survey (n = 59) adapted TIEE materials for their courses and 30–50% used TIEE as a model for changing their method of teaching. In addition, over 60% said that publishing in TIEE would be valued in reappointment or tenure decisions. Evaluation findings and recent interest in "scientific teaching" has prompted us to establish a team of faculty who are doing research on their own teaching. We are testing the hypothesis that these faculty will become more invested in, and more successful at, changing the way they teach. Our future plans for TIEE include expansion of this research component.

Front Ecol Environ 2006; 4(4): 189–195

What does it take to change an ecology professor's thinking about teaching and learning and, subsequently, their classroom teaching? This question stimulated the creation of "Teaching Issues and Experiments in Ecology" (TIEE), a peer reviewed, electronic publication (TIEE), a peer reviewed, electronic publication hosted by the Ecological Society of America (ESA) and designed to help ecology faculty improve their teaching (www.tiee.ecoed.net). As of May 2006, four volumes of TIEE have been published. Here, we describe TIEE's design and foundation in education and cognitive theory, present the first evaluation results of TIEE's effects on ecology teaching, and explain the next research phase.

We began working on TIEE during the late 1990s, a period characterized by a strong interest in changing higher-education science teaching. Numerous studies published at that time claimed that many students learn more effectively in courses that emphasize active learning and scientific inquiry, are problem-based, and use cooperative groupwork. Specifically, students are more attentive, learn content well, and improve their critical thinking skills (eg George 1996; McNeal and D'Avanzo 1997; Bransford *et al.* 1999). Studies like these prompted a teaching survey by the ESA Education section, the results of which indicated that undergraduate ecology teaching was generally not based on current thinking about how most students learn best. Most classes (90% of 131) depended heavily on passive lectures; open-ended labs were rare in introductory biology courses (10%), and many students never went outside to study ecology (34% in ecology and 17% in introductory biology courses; Brewer and Berkowitz 1998). TIEE grew out of discussions among ESA educators wanting to address these issues.

TIEE addresses three fundamental challenges to the development and dissemination of new ecology resources designed to help faculty use inquiry-based, student-active teaching methods (Table 1). The first challenge was to integrate sound science and good pedagogy into a coherent electronic publication. To ensure rigor and consistency, reviewers are asked to explicitly judge both the scientific and educational aspects of submissions. Second, materials needed to be useful to a range of faculty teaching in different settings and in many ecology and environmental science courses. Effective activities would also be "low risk" and easy to use, and should empower faculty to try new approaches. The third and final challenge was to address the reward system for TIEE authors and faculty willing to take the time to change their teaching. Professors are much more likely to devote efforts to these endeavors if teaching and educational scholarship are valued in retention and promotion decisions. These three challenges led us to

[1]*School of Natural Science, Hampshire College, Amherst, MA *(cdavanzo@hampshire.edu); [2]Department of Biology, Widener University, Chester, PA; [3]Program Development, Florida Community College at Jacksonville, Jacksonville, FL; [4]Education & Outreach Program, American Institute of Biological Science, Washington, DC; [5]Education Program, Ecological Society of America, Silver Spring, MD; [6]Riney Consultants, Boulder CO; [7]Ecology and Evolution Program, University of Oregon, Eugene, OR*

Table 1. Three challenges to the development and use of TIEE (Dissemination, Integration and Scholarship) form the basis for evaluation; listed here are questions used in the evaluation of TIEE, relationship of these questions to the three core challenges, and specific goals for each challenge

Questions that are basis for evaluation	*Core TIEE challenges*	*Specific goals*
Who uses TIEE and how?	Dissemination	• For a wide range of faculty • Widely disseminated • Appropriate for large and small classes
What are users' opinions about scientific and pedagogical quality?	Integration	• Integrates sound science and pedagogy • Includes commonly taught ecological concepts and ideas • Offers excellent ecology and pedagogy
What is the impact of TIEE on their teaching practice?	Integration Integration	• Faculty modify materials • Helps faculty link teaching approaches with content • Encourages faculty to dive deeper into the pedagogy • Encourages use of alternative assessment and formative evaluation
Who are TIEE authors and what is the motivation for their submission?	Scholarship	• Authoring counts as scholarship

identify three specific goals: (1) TIEE will help faculty use active inquiry in the context of current ecological research; (2) ecologists will support TIEE; and (3) TIEE publications will be valued as scholarship. As explained in more detail below, these goals formed the basis of the TIEE evaluation.

TIEE composition and design

The three sections of TIEE – "Experiments", "Issues", and "Teaching" – are designed to meet a broad range of faculty needs. Experiments are for labs, Issues can be used in lectures, labs, and for homework, and the Teaching section is integrated into both (Figure 1). The four volumes include 19 Issues and 14 Experiments, written by 40 authors, on a wide range of topics. Within the Issues section there are "Figure Sets" (based on figures from published papers) and "Data Sets" (data students can download and use in class), including data from Long Term Ecological Research (LTER) sites.

TIEE materials include an "Overview" or "Synopsis" of the ecological focus written for faculty, "Student Instructions" that faculty can hand out if they wish, and "Notes to Faculty" that describe various ways to use suggested approaches and offer core points and questions to consider (Figure 1). In addition, both Experiments and Issues contain ideas for alternative assessment (non-traditional ways to test student learning) and formative evaluation (feedback for faculty about their teaching and student understanding). There are many links from Experiments and Issues to the Teaching section, which includes web-based resources, essays, and tutorials.

We designed TIEE so that: (1) it targets ecological topics that most faculty teach; (2) downloads are convenient; (3) teaching approaches are connected to specific items (eg a figure from a paper; Table 2); (4) links provide background pedagogical and ecological information; and (5) faculty are given enough information to use a particular approach (or "scaffolding"), but are encouraged to modify material to suit their needs. In addition, approaches are linked to critical thinking skills such as "synthesis" or "application" (Table 2). In our experience, faculty often cite critical thinking as a course goal, but rarely give students the opportunity to practice more sophisticated cognitive skills in class. By directly linking a class exercise with particular thinking skills, we intend faculty to make the connection between teaching specific ecological concepts and students' use and development of specific cognitive skills.

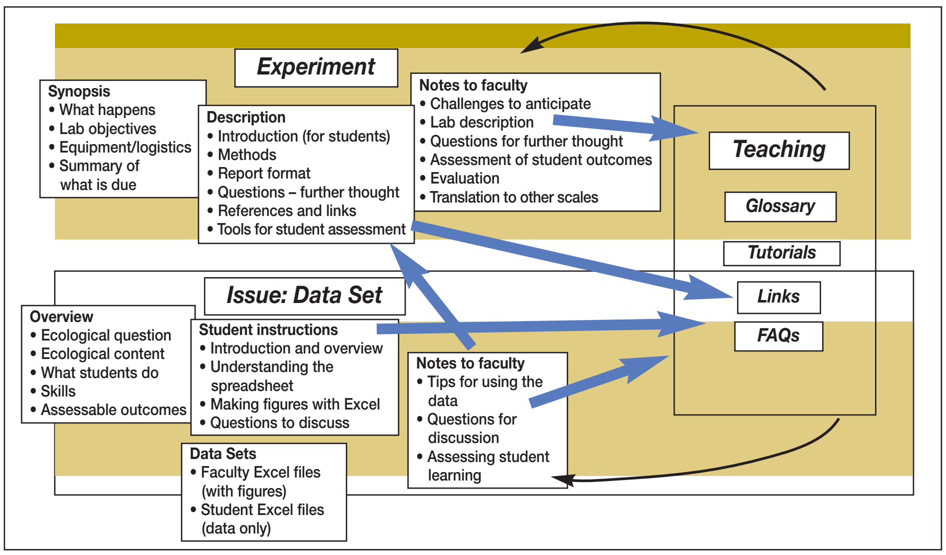

Figure 1. *Faculty can use the three components of TIEE – "Experiments", "Issues", and "Teaching" – to learn about and apply a range of student-active approaches to their labs, lectures, and homework assignments. The arrows indicate interaction between the components; the Issue example is an Issue Data Set.*

Theoretical basis for TIEE

Student focus: inquiry-based instruction

TIEE is based on ideas and theories concerning inquiry teaching, which engages students in the process of science and takes many forms in the classroom. For example, students can work on open-ended problems; study their own data and hypotheses; read primary papers and examine other scientists' data; and, in pairs, address questions posed in large lectures (D'Avanzo and McNeal 1997; Mazur 1997). Examples of these and many other approaches are found throughout the TIEE site.

Although inquiry has for decades been the central defining characteristic of good science teaching and learning (AAAS 1993; Anderson 2002), students in most of today's undergraduate science classes do not really engage in it (Brewer and Berkowitz 1998). The numerous reasons why science faculty are reluctant to do more inquiry-based teaching include reduced coverage of topics, restricted time for development of new activities, limited rewards for innovative teaching, and lack of conviction about its value. TIEE addresses these issues by providing faculty with rigorous, tested, and peer-reviewed activities, together with classroom-ready computer projections and handouts. Many pages have links to on- and off-site literature and references about the efficacy and challenges of suggested approaches. These links are strategically placed so that faculty will use them on a "need to know" basis.

Scientists "do" inquiry in the context of real problems or questions that are meaningful to them. In contrast, when learning is taken out of context, students view knowledge as an end in itself and not as a tool that can be used to solve problems (Resnick 1987). To reinforce genuine inquiry, we used Herrington and Oliver's (2000) critical characteristics of contextualized learning, particularly in an online situation, as underpinnings for the design of TIEE. To provide an example, the dataset titled "Changes to lake ice: ecosystem response to global change" (Bohanan *et al*. 2005) is based on 100 years of ice-cover data for Wisconsin lakes. Small groups of students plot and attempt to find patterns in data over 20-year intervals (*collaborative groupwork*); the long-term trend is only revealed when students combine data to see the 100-year pattern (*authentic activity*). Students attempt to find patterns in "messy data" (*authentic activity*), orally describe their findings (*articulation*), combine and compare their data with that of the other teams (*reflection*), and discover the value of long-term datasets (*real-life application*). One suggested assessment in "Notes to Faculty" (*coaching* and *scaffolding*) is for students to predict the ice cover trend for lakes with very different physical characteristics, such as size and depth, and explain the reasoning behind their predictions (*authentic assessment*).

Table 2. Ecology of Disturbance Issue (Figure Set) table linking cognitive skills based on Bloom's taxonomy (column 3; Bloom 1950) with a suggested student-active approach (column 2) and a figure from a published paper (column 1). Suitability of approach in regard to class size and time is also listed (column 4)

Ecological focus and papers	*Student-active approach*	*Cognitive skill*	*Class size and time*
Intermediate disturbance hypothesis (Lubchencho 1978; Sousa 1979)	Pairs-share	Comprehension Interpretation Application Analysis	Small–medium; intermediate Small–medium; intermediate
Hubbard Brook (Likens *et al.* 1978)	Take home/group take home/	Comprehension Interpretation	Small–medium; long
Ecology of fire (Bormann & Likens 1979; Minnich 1983)	Citizen's argument	Comprehension Interpretation Application	Any; intermediate
Fir waves: regeneration in New England conifer forests (Sprugel 1976)	Turn-to-your-neighbor	Comprehension Interpretation Comprehension	Any; short

http://TIEE.ecoed.net/vol/v1/figure_sets/disturb/disturb_figs.html.

A *Figure Set* is a type of TIEE *Issue* that shows faculty how to use published figures to teach ecological topics with a variety of active approaches

Faculty focus: adult learning theories and misconceptions about teaching and learning

Adult learning theories particularly emphasize adult motivation and impediments to learning (Merriam and Caffaraella 1999). For instance, Knowles (1980) stresses adults' independence and the importance of their participation in the content and delivery of curricula. Therefore, one focus of our evaluation (below) is the degree to which faculty modify activities and ideas to match their own teaching styles and the needs of their students.

There is a large literature about students' misconceptions – deeply held, often predictable ideas based on a student's understanding of the world, which are ingrained and often intractable to traditional teaching (Bransford *et al*. 1999; D'Avanzo 2003). Much less studied are faculty misconceptions about teaching and learning. Faculty who believe in content/teacher-centered approaches have misconceptions about what it takes to promote deep learning in their students (Menges and Rando 1989). Research on teaching behavior shows that: (1) teachers' practice is strongly rooted in their beliefs about teaching and learning; (2) changes in practice require changes in beliefs; and (3) these belief systems are notoriously difficult to change. For example, instructors often attribute students' failure to the students' motivations or abilities, rather than to the instructor's own skill. They therefore tend to view students' difficulties as "errors" rather than as teaching opportunities (Druckman and Bjork 1994).

Given the intractability of teachers' beliefs about their students' learning, how do faculty question these ideas and reflect critically and constructively upon their practice? Interestingly, workshops, so commonly used for faculty development, appear to be relatively ineffective at getting teachers to modify their implicit beliefs about teaching and learning (Yerrick *et al.* 1997). This may be due to the short-term nature of one-time workshops. Faculty need time to explore models of what active, student-oriented teaching looks and feels like. Several aspects of TIEE, including emphasis on ongoing feedback and encouragement of exploration and adaptation, are designed to help faculty safely try out new approaches and get the information and feedback they need to genuinely change their teaching methods.

Evaluation approaches and results

Evaluation of TIEE was designed to address several questions. Who uses TIEE, and how? How do users rate the scientific and pedagogical quality of TIEE materials? How has TIEE influenced teaching practice? Who submits materials to TIEE for publication, and why? Each question relates to the three overarching and associated specific goals we were particularly interested in examining (Table 1).

According to the National Science Foundation's guidelines for project evaluation, "while randomized controlled trials might be best to answer some evaluation questions, most…will require alternative or mixed methods (both quantitative and qualitative data gathering and analysis), including interviews, observations, case studies, surveys…[When] applied appropriately, the scientific rigor of these methods can be established" (Callow-Heusser *et al.* 2005). In addition to relying on mixed approaches, effective evaluation is often iterative, with initial findings affecting later instruments (Callow-Heusser *et al.* 2005).

For the TIEE study, the evaluators (Udovic and Morris) used surveys and interviews. The surveys provided descriptive data about a range of participants, while interviews allowed more in-depth study of some participants' views. An initial survey was conducted in spring 2004, to identify the population of users and gain preliminary information on their usage of TIEE and its impact on their teaching. The first survey also provided volunteers for follow-up telephone interviews, which were conducted in summer 2004. These interviews generated new hypotheses about participants' use of TIEE, which were the basis for a revised, second survey of different faculty, carried out in spring 2005. All surveys and interviews were conducted with the approval of the University of Oregon Office of Research and Sponsored Programs, according to standard protocols for the protection of human subjects.

Both surveys were conducted using web-based software. TIEE users who registered on the site were sent a link to a survey that requested information on their use of the materials (see below), together with demographic information such as institutional type, discipline, and professional status. Twenty-three users completed the first survey and 59 completed the second; data reported below are from the second survey. Five individuals in the first survey group participated in a semi-structured, 30-minute telephone interview. One of the authors (Morris) conducted the interviews using the same sequence of open-ended questions and analyzed the survey results.

Respondent profiles

The majority of survey respondents (61%) taught at liberal arts colleges, 26% were from research universities, and the rest were from community colleges and other institutions. The large number of liberal arts faculty was expected, because teaching is emphasized at these schools; we were pleased that a quarter of respondents taught at universities, given the large populations of students at these institutions. In contrast, few respondents were from community colleges, even though roughly 50% of college students attend these schools (NSF 1999). We intend to actively expand the TIEE user base in the future.

About 50% of survey respondents rated themselves as "very familiar" with non-traditional pedagogy. Despite this, respondents allocated 25% or less of their course time to active learning, indicating that even faculty who are knowledgeable about active teaching primarily rely on traditional approaches in their classrooms.

Increased use of active learning approaches

Ninety-three percent of those surveyed agreed or strongly agreed that TIEE had helped them improve their teaching of ecology. More specifically, respondents indicated that they used more active learning strategies and inquiry-oriented teaching approaches (Figure 2a). However, while cooperative learning or inquiry approaches were used by many, relatively few faculty had employed alternatives to traditional tests or formative (ongoing) evaluation. This suggests that changing testing strategies and gaining ongoing student feedback are especially challenging for many faculty. These data have prompted us to place greater emphasis on these aspects of active teaching (see below). Many studies have shown that ongoing feedback is critical for teachers who are changing their teaching practice (Angelo and Cross 1993). Furthermore, faculty who emphasize active learning in class, but who examine student learning with multiple choice tests, may well undermine student willingness to participate actively in class (Angelo and Cross 1993).

Adaptation and innovation of TIEE

A key finding from both the survey and interviews was that faculty who use TIEE often adapted or modified the materials, rather than using them as published. Only 20% of respondents said that they used the TIEE materials "as is", while the rest used selected elements of TIEE activities or adapted them for a different use (Figure 2b). Faculty adapted TIEE by substituting different research papers, in courses without labs they pulled out parts of an Experiment to use in lectures, and designed their own activity to help students learn to interpret graphs. Even more importantly, 40% indicated that they used TIEE as a model to modify activities they had used in the past, either to be more in line with the "TIEE approach", or to design their own inquiry-oriented activities (Figure 2b).

Most users who modified or adapted TIEE materials did not do so because the materials were incomplete or lacked a necessary element – in fact, the completeness and level of detail of TIEE materials was consistently cited as a strength. Rather, respondents commented that they needed to adapt materials or use the "TIEE approach" to address particular concepts, make connections to local topics or research, or to continue to use activities that had been successful in the past. We consider modifying components of TIEE as an important indicator that faculty are genuinely engaged with active learning ideas and are therefore more likely to choose these approaches in the future.

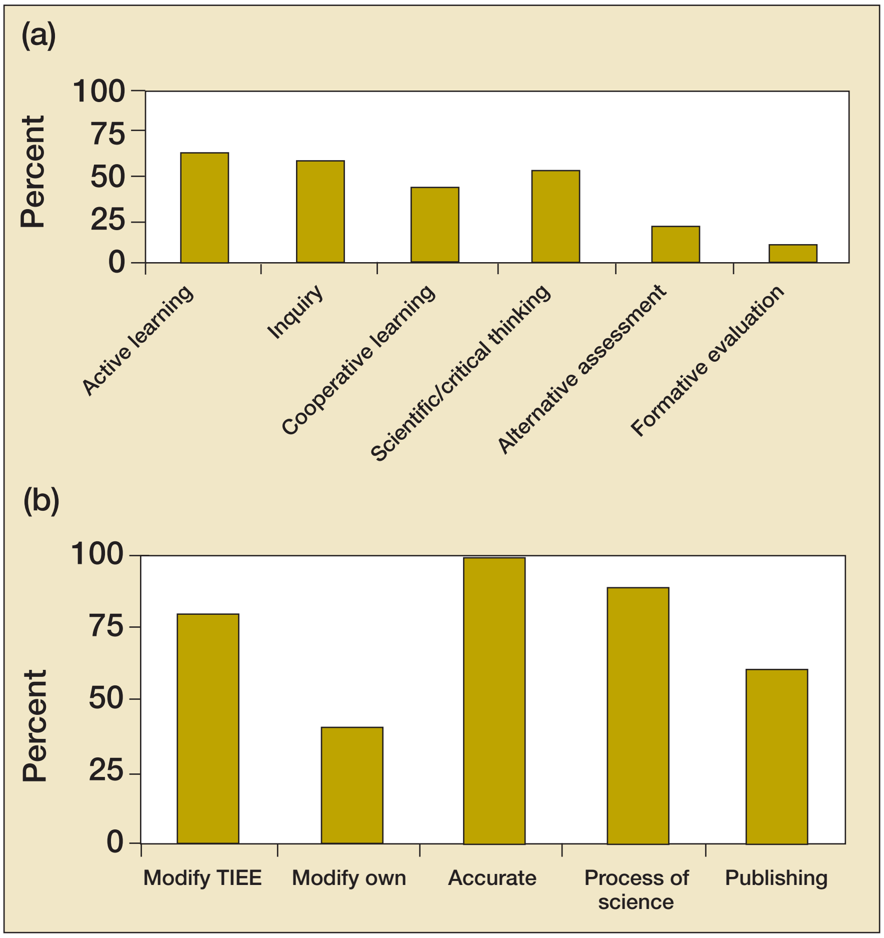

Figure 2. *(a) Percent of survey respondents who used a range of non-traditional teaching approaches as a result of* TIEE *(n = 59); (b) Percent of users surveyed who modified aspects of* TIEE*, modified their own teaching as a result of using* TIEE*, stated that* TIEE *materials were scientifically accurate, stated that* TIEE *helped their students to better understand the process of science, and who believed that publishing in* TIEE *would weigh at least moderately in their promotion and tenure process.*

High quality ecological and pedagogical material

Respondents stated that they valued TIEE because of the high scientific and pedagogical quality of the materials. They also indicated overwhelmingly that TIEE materials were scientifically accurate (100% "agreed," or "strongly agreed") and focused on core ecological principles (98%). Users also report that TIEE had helped their students to better understand science as a process (88%) and the broader context in which science operates (77%). In interviews, users often used the term "rigorous" to refer to both the scientific and pedagogical aspects of TIEE and felt that the quality far exceeded the type of labs generally published on the web or in lab manuals. They frequently noted that TIEE helped students learn ecology through the use of real-world data and investigations.

"Hit" data

A different way to evaluate the use of electronic resources like TIEE is with "hit" data – the number of times a web page is accessed. These data suggested high use by visitors to the site. For example, from January to September 2005, the TIEE site received about 150 000 page hits (about 15 000 per month). Every TIEE Issue and Experiment received hundreds to thousands of hits, indicating broad interest in these materials. However, it was not just the web pages that visitors viewed – there were also more than 10 000 successful downloads of PDF files, the printable full text versions of every publication on the TIEE site. The annual pattern could be shown to correspond to academic year needs, with the highest usage in September.

Clearly, it is difficult to interpret hit analyses in terms of impact on teaching and learning. For instance, once faculty have PDF files, they need not access the TIEE site for these materials again. Furthermore, we cannot tell how faculty members are using these materials in their teaching. All that the hit data can tell us is that large numbers of people are visiting the TIEE site, that materials are being downloaded, and that some visitors are browsing the site extensively.

Creating TIEE: sharing and scholarship

A major goal of TIEE is to provide a peer-reviewed venue where ecology educators can publish their work so that it will be recognized in their institution's promotion and tenure process. Two questions were included on the survey that addressed this issue. To the first, "Do you believe that using TIEE has been or will be beneficial to your own career advancement?", 46% said "yes", 22% said, "no", and 32% were "uncertain". To the second question, "In your judgment, how much would publications in TIEE count in the promotion and tenure process at your institution?", 15% said, "significantly", 44% said, "moderately", 29% said, "little", or, "not at all", and 12% were uncertain. Thus, over 60% of individuals familiar with TIEE believe that publishing there would carry at least moderate weight in their institution's faculty evaluation processes.

All interview participants felt that TIEE's formal peer-review process was the critical aspect of its role as a venue for teaching scholarship, and that it fulfilled the need for a peer-reviewed outlet for teaching-focused ecology faculty. In our experience, institutions differ greatly in attitudes towards teaching as scholarship, and faculty, not administrators, tend to be the most conservative force. Thus, as TIEE and other educational initiatives make headway in helping faculty change their teaching practice, faculty's attitudes towards publishing in educational journals should also change.

Future directions

The results of the evaluation suggested that few faculty were methodically studying the impact of their teaching on student learning (Figure 2). To address this, over the past year, we have begun working closely (eg via workshops and conference calls) with a team of 15 selected faculty from a range of institutions, who are systematically studying possible impacts of TIEE on their teaching. These individuals have identified measurable outcomes – such as students' ability to create figures from raw data – and are using a variety of approaches, including pre/post tests and surveys, in their studies. Replicate measurements within the same course over a semester, and over several years, as well as across institutions, could potentially result in publishable findings.

Our hypothesis is that these "practitioner researchers" will have a deeper understanding of why student-active approaches (such as groupwork) promote increased student learning and will therefore be more committed to their use. This can be tested in a comparative study. During the past few years, Handelsman *et al.* (2004) and others have emphasized the need for "scientific teaching" – the application of scientific research methodology by faculty to their own teaching. Future plans for TIEE include expansion of this research component.

Acknowledgements

We are grateful for the ongoing support of the ESA, the ecology education community, and especially TIEE's reviewers and authors. TIEE is funded by National Science Foundation Division of Undergraduate Education grants DUE 0127388 and DUE 9952347

References

AAAS (American Association for the Advancement of Science). 1993. Benchmarks for science literacy. New York, NY: Oxford University Press.

Anderson RD. 2002. Reforming science teaching: what research says about inquiry. *J Sci Teach Ed* **13**: 1–12.

Angelo TA and Cross KP. 1993. Classroom assessment techniques: a handbook for college teachers. San Francisco, CA: Jossey Bass.

Bloom BS and Broder LJ. 1950. Problem solving processes of college students: an exploratory investigation. Supplemental Educational Monographs No 73. Chicago, IL: University of Chicago Press.

Bohanan RE, Krasny M, and Welman A. 2005. Changes in lake ice: ecosystem response to global change. TIEE 3: 30 April 2005. http://tiee.ecoed.net/vol/v3/issues/data_sets/lake_ice/abstract.html. Viewed 14 April 2006.

Bormann FH and Likens GE. 1979. Pattern and process in a forested ecosystem. New York, NY: Springer-Verlag.

Bransford JD, Brown AL, and Cocking RR. 1999. How people learn: brain, mind, experience, and school. Washington, DC: National Academy Press.

Brewer CA and Berkowitz A. 1998. Preliminary results of the ESA survey on ecology in the undergraduate curriculum. *B Ecol Soc Amer* **79**: 106–107.

Callow-Heusser C, Chapman HJ, and Torrers RT. 2005. Evidence, an essential tool – planning for and gathering evidence using the design–implementation–outcomes (DIO) cycle of evidence. Arlington, VA: National Science Foundation NSF Report 05-3.

D'Avanzo C. 2003a. Research on learning: potential for improving college ecology teaching. *Front Ecol Environ* **1**: 533–40.

D'Avanzo C. 2003b. Application of research on learning to college teaching: ecological examples. *BioScience* **53**: 1121–28.

D'Avanzo C and McNeal A. 1997. Research for all students: structuring investigations into first year courses. In: McNeal A and D'Avanzo C (Eds). Student active science: models of innovation in college science teaching. Philadelphia, PA: Saunders College Publishing.

Druckman D and Bjork RA. (Eds) 1994. Learning, remembering, believing: enhancing human performance. Report of the National Research Council's Committee on Techniques for the Enhancement of Human Performance. Washington, DC: National Academy Press.

George MD. 1996. Shaping the future: new expectations for undergraduate education in science, mathematics, engineering, and technology. Arlington, VA: National Science Foundation. Report No 96-136.

Handelsman J, Ebert-May D, Beichner R, *et al.* 2004. Scientific teaching. *Science* **304**: 521–22.

Herrington J and Oliver R. 2000. An instructional design framework for authentic learning environments. *Ed Tech Res Devel* **48**: 23–48.

Knowles M. 1980. The modern practice of adult education: from pedagogy to andragogy. New York, NY: Cambridge Books.

Likens GE, Bormann FH, Pierce RS, and Reiners WA. 1978. Recovery of a deforested ecosystem. *Science* **199**: 492–96.

Lubchenco J. 1978. Plant species diversity in a marine intertidal community: importance of herbivore food preference and algal competitive ability. *Am Nat* **112**: 23–39.

Mazur E. 1997. Peer instruction: a user's manual. New Jersey: Prentice Hall.

McNeal AP and D'Avanzo C. 1997. Student-active science: models of innovation in college science teaching. New York, NY: Saunders College Publishing.

Menges RJ and Rando WC. 1989. What are your assumptions? Improving instruction by examining theories. *Coll Teach* **37**: 54–60.

Merriam S and Caffarella R. 1999. Learning in adulthood: a comprehensive guide. San Francisco, CA: Jossey Bass.

Minnich RA. 1983. Fire mosaics in southern California and northern Baja California. *Science* **219**: 1287–94.

NSF (National Science Foundation). 1999. Investing in tomorrow's teachers: the integral role of two-year colleges in the science and mathematics preparation of prospective teachers. Arlington, VA: NSF Report No. 99-49.

Resnick L. 1987. Learning in school and out. *Educ Res* **16**: 13–20.

Sousa W. 1979. Disturbance in marine intertidal boulder fields: the non-equilibrium maintenance of species diversity. *Ecology* **60**: 1225–39.

Sprugel DG. 1976. Dynamic structure of wave-regenerated *Abies balsamea* forests in the north-eastern United States. *J Ecol* **64**: 889–911.

Yerrick R, Parke H, and Nugent J. 1997. Struggling to promote deeply rooted change: the "filtering effect" of teachers' beliefs on understanding transformational views of teaching science. *Sci Ed* **81**: 137–59.