Recent research has changed our understanding of how people learn. These findings are based on well-established learning theories that can potentially help faculty teach more effectively. Unfortunately, most science faculty, including ecologists, have little or no exposure to research on learning or its application to teaching. In this paper, four areas of research on knowledge and learning are given as the basis for an approach designed to help students overcome the common misconception that plants do not consume oxygen. To help improve college ecology instruction, ecology faculty and researchers who study learning should collaborate to design research about ecology teaching and ecological thinking.

How can ecology teaching benefit from this kind of research? How do ecology faculty members find out about education studies and theories, how students learn best, and which teaching practices work well and why? Unfortunately, most college ecologists (and biologists in general) have little exposure to research on teaching and learning. This is regrettable, because there are many valuable ways to apply learning theory to biology teaching (eg Lawson and Thompson 1988; Anderson et al. 1990; Lawson et al. 2000); some that are specifically relevant to ecology (eg Bishop and Anderson 1990; Hogan and Fisherkerker 1996) are presented in publications such as the Journal of Research in Science Teaching. However, few science faculty members, including ecologists, read education journals.

An ecology professor’s ignorance of research on learning is akin to a tropical bird ecologists’ ignorance about research on tree canopies. We would be appalled if a researcher never read journals in his or her field, or was unaware of fundamental hypotheses. Why aren’t we similarly disturbed by professors who know nothing about research on learning or its application to teaching?

We should not single out ecologists; most science professors know little about research on science learning. My intention is to stimulate interest among ESA members about this issue. I will begin with an overview of cognitive/education theories, explore how research on learning could improve ecology teaching, and conclude with several suggestions for improving college ecology teaching.

In a nutshell:

- Recent research has deepened our understanding of how people learn.
- Although most science faculty members know little or nothing about this research or its theoretical basis, it can be used to improve classroom teaching.
- Ecology teachers and scientists who study learning need to work together to conduct research on ecology instruction.

A brief history of learning theories

Today, it seems natural that psychologists, neuroscientists, linguists, and anthropologists all study learning. Until the late 1800s, however, the study of the mind was left to theologians and philosophers. This changed at the turn of the 20th century, when the new school of behaviorism brought considerations of the mind into the domain of scientists (Figure 1).
Behaviorists view the mind as a “black box”; for them, “knowing” means observably connecting a response with a stimulus, and “learning” means making and strengthening those connections through reinforcement (or the reverse). Thus, a behaviorist might teach a caged animal to press a lever for food by initially rewarding the animal for simply turning towards the lever. Similarly, students will learn complex processes that are broken into component pieces and strung together, and then demonstrate their learning with a defined, desired behavior (Mestre 1994).

The behavioral approach does not take into account the cognitive aspects of learning (e.g., memory, reasoning, and thinking). The Swiss psychologist Jean Piaget championed the importance of cognition in the US in the 1960s, when he developed the concept of cognitive structures—patterns that change with age—by observing that similarly aged children make the same “mistakes” about the natural world. For instance, young children believe that things disappear when they are out of sight, and that big things sink and small ones float. Einstein, a contemporary of Piaget, was especially intrigued by children’s claims that going faster takes more time.

As they formed very different ideas about learning and knowledge from behaviorists, cognitive constructionists asked whether what was learned made sense to people. Constructivism relies on the belief that people actively construct their knowledge; constructivist teachers therefore reject the notion that students can assimilate exactly what they are taught. Moreover, because knowledge already in place is thought to affect our ability to learn new things, these teachers try to assess whether previously constructed ideas conflict with the information they want students to learn. Social constructivists further propose that learning is both cognitive and behavioral, that learning happens when people discuss and debate, and therefore that people create knowledge in a social setting (Steffe and Gale 1995). Their ideas are the basis for peer collaboration, a widely used method for involving students in their own learning (Figure 2).

### Four related areas of research

Constructivism is the basis for four aspects of interrelated research on learning that have been particularly fruitful for educators.

#### Organizing knowledge

How experts organize and use knowledge, as compared to novices, has been an important research focus for physics educators (Dufresne et al. 1992; Mestre et al. 1992). For instance, Chi et al. (1981) gave experts and novices physics problems on index cards, which they were asked to sort according to principles or features they would use to solve the problems. More advanced
learners organized their cards by major concepts in physics (eg conservation of energy in a mechanics problem), while novices sorted by surface features (eg mechanics problems with inclined planes). Thus, novice learners did not recognize the concepts they could use to tackle the problems.

This expert/novice work is based on the existence of cognitive structures called “schema”, and is therefore influenced by Piaget’s ideas about cognition. Schema are thought to be “chunks” of recurring patterns of information (in physics, ideas and principles such as “conservation of energy”) mentally arranged by the learner and readily accessible when needed.

Can research like that of Chi et al. influence classroom practice? Although studies are limited (Eylon and Linn 1988), there is some classroom research showing that it can. For instance, Dufresne et al. (1992) designed physics questions specifically designed to highlight common misconceptions, energy, food webs, evolution, and living versus nonliving things (Table 1). There are many ways teachers can reveal and then allow students to confront misconceptions. For instance, concept mapping – a method developed by Novak (1990) as a tool for organizing and presenting knowledge – exposes college students’ misunderstandings of ecological phenomena (Okebukola 1990). Another avenue, which is more useful in large classes, is students’ response to multiple choice questions specifically designed to highlight common misperceptions (Mestre 1994; Wenk et al. 1997).

The findings from misconception research on college biology and ecology students is quite discouraging. In one study, Anderson et al. (1990) used interviews and questionnaires to examine 100 college students, nearly all of whom had taken high school and college biology, on their understanding of photosynthesis and respiration. Most showed fundamental misunderstandings, believing for instance that plant roots were vaguely equivalent to animals’ mouths. The authors found no relationship between the amount of biology a student had taken and his or her knowledge or understanding. The authors’ conclusion that typical biology instruction leaves classic misconceptions unchanged has been confirmed in other studies of college biology and physics classes (eg Clement 1982; Nazario et al. 2002). However, other research, documenting the success of classroom approaches specifically designed to target misconceptions, is more encouraging (Eylon and Linn 1988).

**Student misconceptions**

Addressing students’ misconceptions (also called alternative or naive conceptions) is a related and important area of research in science education. Hundreds of studies show that students tenaciously hold onto erroneous, often predictable ideas that interfere with their ability to learn new concepts correctly. Constructivism forms the basis for research on misconceptions. Because constructivists believe that knowledge acquisition requires students to mentally restructure their own learning, they expect that students’ understanding is often different from what teachers are attempting to teach.

Common misconceptions in ecology include students’ understanding of photosynthesis, energy, food webs, evolution, and living versus nonliving things (Table 1). There are many ways teachers can reveal and then allow students to confront misconceptions. For instance, concept mapping – a method developed by Novak (1990) as a tool for organizing and presenting knowledge – exposes college students’ misunderstandings of ecological phenomena (Okebukola 1990). Another avenue, which is more useful in large classes, is students’ response to multiple choice questions specifically designed to highlight common misperceptions (Mestre 1994; Wenk et al. 1997).

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**Metacognition**

Metacognition is a mental skill that students use to monitor their understanding, and could also be called “knowing what we know and what we don’t know”. It relies on self-teaching and other student-centered learning skills (Flavell 1979). For example, Schoenfeld teaches metacognitive skills using a group method that helps math students to be more aware of their thinking.

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>Misconception</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photosynthesis</td>
<td>Plant roots are like animal mouths (plants take in all nutrients through their roots)</td>
<td>Anderson et al. 1990</td>
</tr>
<tr>
<td></td>
<td>Plants get energy from soil and fertilizers in addition to the sun</td>
<td>Anderson et al. 1990</td>
</tr>
<tr>
<td>Respiration</td>
<td>Defined as people exhaling CO$_2$ and plants releasing O$_2$</td>
<td>Anderson et al. 1990</td>
</tr>
<tr>
<td>Food Webs</td>
<td>Only predator and prey populations affect each other</td>
<td>Griffiths and Grant 1985</td>
</tr>
<tr>
<td></td>
<td>A population higher on a food web preys on all below</td>
<td>Griffiths and Grant 1985</td>
</tr>
<tr>
<td></td>
<td>Organisms on lower trophic levels are there to serve ones higher up</td>
<td>Hogan and Weathers 2003</td>
</tr>
<tr>
<td>Evolution</td>
<td>Changes in traits are need-driven, so variations within a population or reproductive success are not important</td>
<td>Bishop and Anderson 1990</td>
</tr>
<tr>
<td>Ecosystems</td>
<td>Each component has properties identical to the whole</td>
<td>Hogan and Weathers 2003</td>
</tr>
<tr>
<td></td>
<td>Both matter and energy are physical substances</td>
<td>Hogan and Weathers 2003</td>
</tr>
</tbody>
</table>

Misconceptions are erroneous, often predictable ideas that interfere with students’ ability to learn new concepts correctly. Constructivist learning theories hold that we develop conceptions about the world based on our own observations, and that these “logical” ideas are therefore very hard to change.
Research on learning

C D’Avanzo

Research on learning C D’Avanzo

processes (Schoenfeld and Herrmann 1982). As students
work on problems in small groups, they are required to
verbally address three questions: What exactly are you
doing? (can you describe it precisely?); Why are you
doing it? (how does it fit into the solution?), and How
does it help you? (what will you do with the answer once
you find it?). Schoenfeld also returns to these questions
frequently during lectures.

There is evidence that this type of instruction can
improve learning. Compared to control groups,
Schoenfeld’s students give more expert-like solutions to
math problems. King (1992) also found that college stu-
dents who had been taught self-questioning strategies
were better learners, and retained information on exams
longer than control groups.

Adult developmental stage theories

Various adult developmental stage theories describe how
people’s ideas about knowledge and the degree to which
they turn to external authorities for “right answers” to
complex questions advances with maturity (Kitchener
and King 1981). A student with advanced epistemology
(the nature of knowledge) in science knows, for example,
how to evaluate controversies and about the existence of
uncertainty.

William Perry is well known for his work on young adult
development, based on his studies of Harvard students
(1970). He was particularly interested in the interaction
between personal agency (the degree of reliance on outside
authority) and epistemology. According to Perry, students
pass through stages of dualism (thinking there are “right
and “wrong” answers) and multiplicity (thinking one
answer is as good as another) to relativism (thinking differ-
ent opinions or outcomes may result from factors such as
different assumptions or judgments). While students in the
dualistic stage believe that external authorities can tell
them the right answers to questions, more mature students
trust their own ability to make decisions. The students
Perry studied tended to be dualistic thinkers when they
entered college and only reached the more mature stages
after graduation. Piaget’s influence on Perry’s work includes
the recognition that learning and development follow a
linear sequence, and that learning is stage-driven.

Adult developmental theories form the basis for teaching
practices that are designed to encourage students to ques-
tion assumptions and not to take information at face value.
These include inquiry-based teaching (D’Avanzo and
McNeal 1997; Figure 3) and problem-based learning (PBL)
(Wilkerson and Gijseelaers 1996). Even though PBL is used
in many medical schools and undergraduate courses,
including ones with very large enrollments (Allen et al.
1996), research documenting its success is limited (Stage et
al. 1998). As with PBL, few researchers have studied the
effects of inquiry teaching on student learning. For this rea-
son, Wenk’s (2000) pre–post research, which shows sub-
gstantial gains in epistemology and justification for students
in inquiry-based science courses (as opposed to comparison
students), is particularly intriguing.

Applying theories about learning to ecology
teaching

Theories about learning can be the foundation for prac-
tices designed to improve student learning in ecology
courses. Many beginning ecology and biology students
believe that plants do not use oxygen (Anderson et al.
1990). This misconception points to a fundamental lack
of understanding about respiration and energetics. If stu-
dents don’t recognize that plants produce and use oxygen,
they cannot truly understand core eco-
logical topics such as the role of oxygen
in cell metabolism.

How can a professor help students to
recognize and change this misconcep-
tion? As an example, I will describe a
five-step scenario that can be incorpo-
rated into any course, even with hun-
dreds of students in a lecture hall. This
example has been studied in numerous
college biology courses (Ebert-May et al.
1997). Here it illustrates how a process
deeded successful by classroom assess-
ment (Mestre et al. 1992; Lumpre and
Staver 1995; Ebert-May et al. 1997) is
based solidly on constructionist theo-
ries. It is also an example of a learning
cycle-type approach (Lawson et al.
1989), because students first engage in
an investigation before they are for-
mally introduced to a scientific concept
(Panel 1).

Figure 3. It makes sense that students learn scientific inquiry when they do their own
field or laboratory research. However, adult development and expert/novice learning
theories can also inform teaching practices that help students improve their scientific
inquiry and critical thinking skills in courses, even those with large enrollments.
This exercise is designed to help students "think more like an ecologist" when they identify, talk about, and apply core ecological concepts and information—in this case, respiration. Thus, students behave as ecologists when they examine the oxygen data and match their reasoning with that of their peers. Working with and analyzing ecological data is also central to the final assessment step, because students must create their own graphs and explain the reasoning behind them (D’Avanzo 2000).

It is important for teachers to acknowledge that interpreting and applying data in this way are sophisticated skills that require practice and a good deal of time. The plant-respiration exercise might well take a full hour of a class session. Its use is based on the “less is more” idea—less material is covered, but more is retained (Sutman 1992).

**Misconceptions**

The exercise is designed to highlight and change the idea that plants in the dark do not consume oxygen, and is based on the assumption that students will come face to face with their misconceptions as they try to explain their thinking, answer questions, and listen to the reasoning of their peers. The predicted outcome is that students who recognize and discuss their “error” will retain the information that plants respire, as students working collaboratively have successfully done with misconceptions about photosynthesis (Lumpe and Staver 1995).

**Metacognition**

Like students in Schoenfeld’s math class, students discussing the plant–jar question may become more aware of their own thinking when they share their reasoning with peers. Faculty members can encourage metacognitive thinking by coaching students to ask each other ques-
Panel 2. An authentic assessment of students’ understanding of photosynthesis and respiration. According to current theories about learning, assessment is not something that happens at the end of a lesson; it is a tool for learning the lesson.

Early naturalists debated whether corals were plants or animals. We now know that photosynthetic organisms called zooxanthellae live in the outer cells of corals, an example of symbiosis (“living together”) in which both the coral animal and the zooxanthellae benefit. Coral bleaching, a phenomenon that is occurring in reefs worldwide, may be a result of global warming. During bleaching events, corals eject their zooxanthellae into the ocean (it is unclear why). Since the zooxanthellae’s dominant photosynthetic pigments are brown, the corals look white when they are gone.

Imagine an experiment in which pieces of unbleached coral were put into three aquariums and bleached coral into three other aquariums. The number of coral pieces and species are the same. Sketch a simple X-axis/Y-axis graph (the type we have been discussing in class), showing change of oxygen with time in the two sets of aquariums. You will not be graded on your drawing ability. However, the figure must be clear and easy to interpret, so you should label all important aspects. In addition, in two paragraphs briefly write a description and interpretation of the figure, in no more than 150 words.

Collaboration between learning researchers and ecology faculty

Introductory ecology is taught in thousands of ecology and biology courses, so the impact of improving ecology teaching could be far reaching. There is some evidence that a reform of college ecology is needed – that ecology faculty members, like their colleagues in other scientific disciplines (eg Walczyk and Ramsey 2003), still rely on traditional teaching tactics. A recent survey of Ecological Society of American faculty showed that most introductory-level biology and ecology teaching is not based on current thinking about how students learn best. Most classes (90%; n = 131) depend heavily on passive lecture; open-ended labs are rare in majors’ introductory biology courses (10%), and many students never go outside to study ecology in introductory courses (34% ecology, 17% biology) (Brewer 1998).

How can we fundamentally change ecology faculty member’s thinking about teaching and learning? Clearly this will require a variety of tactics. One facet that is essential and potentially far-reaching is research on ecology teaching, which could result from a collaboration between ecology faculty members and scientists who study learning. Ecology educators, ecology researchers, and cognitive scientists should therefore work together to design research about ecology instruction and ecological thinking.

Such collaborations have happened in other sciences. For instance, computerized visualizations of molecules are potentially powerful teaching tools, but chemistry teaching staff were unsure how to use them. By observing chemistry students, education researchers were able to suggest better ways to help students make the link between these symbolic images and the abstract concepts they are designed to illustrate (Kozma and Russell 1997). In contrast to chemists, few ecology teachers have worked with learning researchers. Perhaps this is because ecology educators have not clearly defined ecological “ways of thinking and knowing” that are unique or especially important in our discipline (Picket et al. 1994). Possibilities include space for time thinking (as in assuming that different patterns across a landscape represent different time periods) and systems thinking (Hogan and Weathers 2003). Cognitive scientists, like all researchers, must be personally drawn to an area of inquiry before they become
willing to devote time to it.

Of course, research on ecology teaching will not influence classroom practice unless faculty members can easily learn about the research and its foundations and are motivated to do so (Table 2). Reading journals is a traditional way to learn about research, but science teachers rarely read education journals. One way to address this conundrum in ecology is for the flagship journals to publish ecology education research. While this has not been the case in the past, the situation is changing. For example, Ecological Applications has expanded its focus to include ecology education research (“[Since] there is increasing interest in education within the science of ecology . . . papers on educational topics . . . may be considered for publication”) (Schimel 2002). Frontiers is another ESA journal that publishes education articles.

Still, easy access to research on learning will probably not matter to ecology educators unless they see teaching reform as important. Both motivation and time are issues. There is no getting around the fact that improving a course takes time, which means not doing something else. Regarding motivation, Walczyk and Ramsey’s (2003) research shows that even faculty members who willingly participate in teaching workshops must be very determined to fundamentally change their teaching. They must educate themselves about learning theories (Table 2), be open-minded about what constitutes good teaching, and update their knowledge through workshops and journals. However, as numerous articles and reports have pointed out, they will not make this considerable effort unless they are rewarded financially, and in tenure and promotion decisions (Boyer 1990; George 1996).

Despite these difficulties, ecology teaching can still benefit from research on learning. For this to happen, ecology educators must seriously consider what it means to teach and learn ecology, and then seek out colleagues who will stretch their thinking and collaborate on research. We ecology professors really should do this. Our students deserve it.

### Table 2. Learning theories and their application to teaching: some helpful introductory references

<table>
<thead>
<tr>
<th>Source</th>
<th>Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kurfiss 1988</td>
<td>Learning theories related to teaching critical thinking</td>
</tr>
<tr>
<td>Gabel 1994</td>
<td>Introduction to research on science teaching and learning</td>
</tr>
<tr>
<td>Stage et al. 1998</td>
<td>Application of learning theories to “learning-centered” teaching</td>
</tr>
<tr>
<td>Bransford et al. 1999</td>
<td>New developments in the science of learning</td>
</tr>
<tr>
<td>Uno 2002</td>
<td>Includes section on how students learn</td>
</tr>
<tr>
<td>Colburn 2003</td>
<td>Concise discussion of education terms and ideas</td>
</tr>
<tr>
<td>D’Avanzo in press</td>
<td>Application of theories about metacognition to ecology teaching</td>
</tr>
</tbody>
</table>

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### References


