ARTICLE

Using Biological-Control Research in the Classroom to Promote Scientific Inquiry & Literacy

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Abstract

Scientists researching biological control should engage in education because translating research programs into classroom activities is a pathway to increase scientific literacy among students. Classroom activities focused on biological control target all levels of biological organization and can be cross-disciplinary by drawing from subject areas such as ecology, molecular biology, physiology, and chemistry. We evaluate published "how-to" biological-control activities to determine whether they meet National Science Education Standards *and use a constructivist pedagogical approach. We also provide an example classroom activity developed from our research that scientists can use as a template to develop their science-education activities.*

Key Words: *Student-centered inquiry; applied ecology;* National Science Education Standards; *constructivist pedagogy; Bloom's taxonomy;* Diaphorina citri.

Biological control is a well-established field of applied ecology in which pest species are managed through the use of predators, parasites, pathogens, herbivores, or other natural mechanisms. Scientists who research biological control should be involved in science education because translating research programs into classroom activities is a pathway to increase scientific literacy among students. For example, activities for the classroom that focus on biological control help students learn the process of scientific inquiry, target all levels of biological organization, and are cross-disciplinary by drawing from subject areas such as ecology, molecular biology, physiology, chemistry, and integrated pest management.

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Educators at all grade levels are interested in activities for life sciences that target multiple levels of biological organization and are cross-disciplinary, and science-education journals disseminate activities for the classroom. Research scientists are minimally involved in these journals, in part because of their unfamiliarity with publishing in the field of science education (Richardson, 2010), but scientists should disseminate their knowledge of science education as broadly as their research programs because of the potentially positive impact on society and the field of science.

Having a citizenship that is well educated in science is a lofty, but necessary, goal because citizens sponsor science and offer input into public policies that influence science. However, 25% of students who graduated from high school in the United States in 2009 completed a science curriculum that was below standard (Nord et al., 2011). Educators and policymakers have called for increasing emphasis on science, technology, engineering, and mathematics in schools to create a workforce that can compete globally and keep pace with expanding scientific and technical expertise (President's Council of Advisors on Science and Technology, 2010). Scientists can help create a culture of science by dispelling negative stereotypical images of scientists (Richardson & Mitchell, 2010), being involved in the teaching process, and contributing activities that require students to engage in cognitive tasks performed by scientists.

Biological control is a subject area that is amenable for a constructivist pedagogical approach that facilitates student-centered inquiry for all grades, meets *National Science Education Standards* (NSES; National Research Council, 1996), and, as previously mentioned, promotes scientific literacy. We review biological-control activities for the classroom that were published in refereed journals to determine (1) the level of involvement of biological-control researchers in education and whether involvement is influenced by gender or employer, (2) which topics of biological control are taught and which are neglected, (3) whether the activities meet NSES standards to promote scientific inquiry and literacy, and (4) whether the activities use an effective teaching style (i.e., constructivist pedagogy) to improve students' skills in scientific inquiry and literacy. We also provide an example of how our research in biological control can be adapted for the classroom with the hope that scientists will use it as a reference when converting their research programs into classroom activities.

○ Methods

We reviewed all "how-to" articles for the classroom published from 2000 through August 2011 in three refereed journals: *The American Biology Teacher* (targets primary, secondary, and college education), *Journal of*

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Table 1. Questions used to evaluate biological-control activities for the classroom published in refereed journals, with a focus on constructivist learning.

Questions
Which content standards from NSES are addressed with this activity?
Does the activity highlight the relevance of biological control?
What principles of biological control are addressed?
What species of organisms are the biological-control agents and which are the targeted pests?
Is the activity student centered? Is the teacher involvement secondary to students? (Teacher acts as a facilitator, resource, student, coach, observer, etc.)
Is the activity relevant? Does it use authentic questions generated from student experiences?
Are students engaged by scientifically oriented questions?
Are students learning about scientific inquiry as well as subject matter?
Does the activity allow for open investigation (including design and implementation) by students?
Is it an active learning process that the students do (i.e., make observations, organize and interpret data), not something that is done to them?
Are there opportunities/applications for students to conduct the investigation in the field?
Does the activity facilitate constructivist learning? Specifically, do students • develop and evaluate explanations that address scientifically oriented questions? • formulate explanations from evidence to address scientifically oriented questions? • evaluate their explanations in light of alternative explanations, particularly those that reflect scientific understanding? • communicate and justify their proposed explanations based on evidence? • apply concepts or abilities to new scenarios?

Biological Education (mainly targets primary and secondary education), and *Scientific Activities* (targets primary and secondary education). We also reviewed "how-to" articles published from 2004 through August 2011 in *Teaching Issues and Experiments in Ecology* (targets college education). We noted the total number of how-to articles and those that directly or indirectly discussed concepts from the field of biological control. We noted the gender, title, and affiliation of all authors of biological-control activities. We used a spreadsheet (Table 1) to determine which NSES content standards (Table 2) were met by the activity, what principles of biological control were discussed, the scientific validity and importance of the activity, and whether a constructivist pedagogical approach was used. Articles were evaluated against the NSES guidelines for the appropriate grade levels (i.e., K–4, 5–8, 9–12), and articles for college students were evaluated using the standards for grades 9–12.

We focused on constructivist pedagogy because it provides a progressive and supportive approach to help students engage in inquiry and build literacy in ways similar to those of scientists. Inquiry-based teaching and learning has dominated science discourse and practice since the NSES were adopted in 1996, which are explicitly inquiry based (National Research Council, 1996). However, we believe that most teachers who say they are engaging in inquiry-based teaching and learning are not, because their teaching has become teacher-directed and objectivist. The objectivist approach transfers knowledge from an outside source, such as teachers and textbooks, to the learners because knowledge is thought to exist independently of learners (Chan, 2010). In many self-identified inquiry-based classrooms, the teacher transfers knowledge through traditional pedagogies like direct instruction (S. L. Richardson, pers. obs.). Alternatively, teachers in constructivist classrooms believe that knowledge is constructed by the individual learner through their experiences, perceptions, imaginations, and mental and social constructions (Jonassen et al., 2007). Therefore, learners need to solve problems and take actions in order to construct knowledge (Dijkstra, 1997; Chan, 2010). Learning is more open, meaningful, practical, and relevant in the constructivist classroom because knowledge is constructed instead of merely discovered (Pinar et al., 2006). We considered five guiding principles of constructivist pedagogy during our evaluation of articles: (1) posing problems of emerging relevance to students, (2) structuring learning around primary concepts, (3) seeking and valuing students' points of view, (4) adapting curriculum to address students' suppositions, and (5) assessing student learning in the context of teaching (Brooks & Brooks, 1999); all these support the NSES's five essential features of classroom inquiry (Table 1, last box; National Research Council, 2000).

For each education article, we randomly selected one article published during the same year from the research journal *Biological Control* (hereafter, "research article" refers to articles from the journal *Biological Control* and "education article" refers to how-to activities for the classroom from science-education journals). We noted the gender, title, and affiliation of each author in these research articles. We used a chi-square contingency test to determine whether the percentage of male and female authors and their affiliations differed among research and education articles. Affiliations were divided into four categories for comparison: public university, private university, government (state and federal), and non-governmental organizations (NGOs). Some K–12 educators and students were authors of science-education articles but were not included in the analysis because they would rarely, or never, be represented in the research literature and therefore would bias our analysis if included.

○ Results

Level of Involvement of Biological-Control Researchers in Education

We surveyed 882 education articles, and ~1.5% (n = 13) directly or indirectly discussed concepts from the field of biological control. Over 73% of the authors of education articles were women, whereas women represented ~17% of authors of research articles (contingency test; $\chi^2 = 61$, df = 1, $P < 0.001$). The affiliations of authors differed between research and education articles (contingency test; $\chi^2 = 43$, df = 3, $P < 0.001$).

Table 2. Content standards, summarized from the National Research Council (1996), used to evaluate biological-control activities for the classroom published in refereed journals and the number of activities that addressed the standards.

Standard	Concepts or Processes	
Unifying concepts and processes	Students should develop understanding and abilities about	No. of activities out of 12
	• Systems, order, and organization	12
	• Evidence, models, and explanation	12
	• Constancy, change, and measurement	9
	• Evolution and equilibrium	1
	• Form and function	5
Content standard A	Students should develop	No. of activities out of 12
	• Abilities necessary to do scientific inquiry	12
	• Understandings about scientific inquiry	12
Life science content standard C: grades 5–8	Students should develop an understanding of	No. of activities out of 3
	• Structure and function in living systems	2
	• Reproduction and heredity	1
	• Regulation and behavior	2
	• Populations and ecosystems	2
	• Diversity and adaptations of organisms	2
Life science content standard C: grades 9–12	Students should develop an understanding of	No. of activities out of 10
	• The cell	1
	• Molecular basis of evolution	0
	• Biological evolution	2
	• Interdependence of organisms	10
	• Matter, energy, and organization in living systems	1
	• Behavior of organisms	1

Table 3. Percentage of authors of research and science education articles affiliated with four types of employers. NGO = non-governmental organization.

	Author Affiliation (%)			
Type of Article	Public University	Private University	Government	NGO
Research	66.7	0.0	24.4	8.9
Education	54.2	25	4.2	16.6

Authors of research articles were predominantly affiliated with public universities and government (Table 3). The authors of education articles had more diverse affiliations, and private universities and NGOs were more heavily represented, whereas government was not (Table 3). The heavier involvement by employees at private universities in education articles, in part, indicates more participation by employees at liberal arts colleges, whereas no authors of research articles were employed by a liberal arts college. Six authors of education articles were not included in the analysis because they were secondary educators (n = 2) or high school students (n = 4).

Topics of Biological Control Taught or Neglected in the Classroom

Only 4 of the 13 articles presented an activity explicitly focused on biological control (Palevitz et al., 2002; D'Avanzo & Musante, 2004; Chanchaichaovivat et al., 2008; Schutzenhofer & Knight, 2009), whereas the other 9 discussed topics from biological control without mentioning this subject area. Given the paucity of biological-control activities for the classroom, the list of biological-control topics neglected in the literature is too long to discuss here, so we will focus on topics they do cover. The biological-control agents and pest species used in the activities are diverse despite the low number of published activities. The articles used insect predators and parasitoids to control insects (Geoghegan, 2000; D'Avanzo & Musante, 2004; Richardson & Hari, 2009), herbivorous insects to control plants (Schutzenhofer & Knight, 2009), wolves to control elk (Dott, 2009), host-plant resistance against insects (Palevitz et al., 2002; Zycherman & Taylor, 2004), host-plant resistance against pathogens (Goetsch et al., 2002), repellency of neighboring plants to insects (Eason & LaManna, 2000), biopesticides (Stalter et al., 2000) or pathogenic fungi to control insects (Chanchaichaovivat et al., 2008), and two focused on the biological control of plants and insects without mentioning the control agent (Haefner et al., 2006; Buczynski, 2007).

Most education articles focused on interactions between two species, but some discussed complex community-level interactions. For example, in Dott's (2009) activity, students examined population data of elk (*Cervus canadensis*) and survival of woody vegetation after reintroduction of wolves (*Canis lupus*) in Yellowstone National Park. Eason and LaManna (2000) developed an activity in which students tested whether common household plants repel insects. Their activity tested "folklore" passed between generations of gardeners and introduced students to development of pesticides from natural plant products.

Targeting NSES Content Standards

One activity (Haefner et al., 2006) contained insufficient detail to determine whether it met NSES content standards, but the other 12 met some standards. The articles incorporated a mean of 3.3 out of 5 Unifying Concepts and Processes in their activities, and one activity (Richardson & Hari, 2009) incorporated all 5. The three most commonly addressed Unifying Concepts and Processes are (1) systems, order, and organization; (2) evidence, models, and explanation; and (3) constancy, change, and measurement (Table 2). Fewer activities incorporated the Unifying Concepts and Processes of form and function and evolution and equilibrium (Table 2). All activities helped students develop abilities necessary to do scientific inquiry and understandings about scientific inquiry, which are the two elements in Content Standard A (Table 2).

Too few activities targeted students in grades K–8 to adequately evaluate which elements of Content Standard C were addressed. Ten activities (5 for college, 5 for high school) were assessed using Content Standard C for grades 9–12. Interdependence of organisms was the only element addressed by all 10 articles, whereas the others were rarely or never addressed (Table 2).

Effectiveness of Pedagogy

All the education activities engaged students to some degree and taught scientific inquiry as well as subject matter. Most activities asked students to evaluate scientific explanations and data. Teachers, as epistemological authorities, should have facilitated an open investigation in which students proposed questions and hypotheses, designed and implemented their experiments, and evaluated their hypotheses against the data they collected. However, only one activity (Richardson & Hari, 2009) used this constructivist approach, whereas the other activities, especially those aimed at college students, used the objectivist approach because teachers provided questions and published data sets for students to evaluate (e.g., Palevitz et al., 2002; D'Avanzo & Musante, 2004; Zycherman & Taylor, 2004; Dott, 2009; Schutzenhofer & Knight, 2009). In the cases where students evaluated published data, a constructivist approach would have had students find and analyze data sets that they believed would be helpful, with facilitation by teachers. Evaluation of published data is an important scientific skill, but other skills should not be overlooked. These scientific skills can be naturally developed when teachers support their students' investigations by encouraging them to engage in complex cognitive activities. The revised version of Bloom's taxonomy suggests the following cognitive levels (from least complex to most complex): remembering, understanding, applying, analyzing, evaluating, and creating (Anderson & Krathwohl, 2000).

The activities we reviewed lacked opportunities for students to conduct research in the field (except for Geoghegan, 2000) or to apply concepts and abilities to new scenarios (except for Eason & LaManna, 2000; Richardson & Hari, 2009), which are critical and relevant experiences for the development of students and scientists. Experiential learning, which is largely constructivist, in natural settings is powerful for constructing new and relevant knowledge. The teacher should facilitate the recognition and use of possible field sites so that the environment lends itself to student growth (Dewey, 1938).

An Example Biological-Control Activity for the Classroom

The following activity is an example of how our research program can be adapted for the classroom. It is not a complete how-to activity. We include it so that other scientists can see how we use an important research topic to engage students, how research converted to classroom activities can meet NSES content standards, and how constructivist, student-centered, inquiry-based teaching and learning are possible. Therefore, we hope that scientists will refer to our example when converting their research programs into effective activities for the classroom.

Biological Control of the Asian Citrus Psyllid

One way to engage students is to investigate a topic of local concern that has received attention from the scientific community and the general public, such as invasive species. The Asian citrus psyllid (ACP; *Diaphorina citri*; Figures 1 and 2) is an important invasive pest of citrus in the Americas because it transmits phloem-limited bacteria that are putatively responsible for citrus greening disease (Bové, 2006). Citrus greening disease is the most serious disease of citrus worldwide because it causes trees to decline in productivity and die within months to several years (Bové, 2006). ACP has spread to Florida, Texas, California, Alabama, Arizona, Georgia, Louisiana, Mississippi, and South Carolina since the late 1990s. Oranges are the fourth-highest-valued fruit or nut crop in the United States, and the value of citrus production is ~$3 billion. ACP and citrus greening have had a significant negative impact on citrus production in the United States.

We research the ecology of ACP, including chemical control and nontarget effects on natural enemies, host-plant resistance, repellency by plants, and biological control with predators, parasitoids, and entomopathogenic fungus (e.g., Qureshi et al., 2009; Hall & Richardson, 2012). Predaceous arthropods, such as ladybeetles, syrphid flies, lacewings, and spiders, feed on ACP, as does a parasitoid (*Tamarixia radiata*) from Asia. Our research can be adapted to a classroom activity for any grade level to explore all levels of biological organization and to teach

Figure 1. Adult Asian citrus psyllid and orange psyllid eggs attached to flush of citrus.

Figure 2. The five nymphal instars of the Asian citrus psyllid.

many topics within biological control. Our research can also provide authentic learning experiences in the field and laboratory and promote skills of advanced students and scientists. ACP and natural enemies can be collected from active or abandoned citrus groves or from orange jasmine (*Murraya paniculata*), a common ornamental tree or hedge in urban areas, in regions where ACP has become established. ACP is easy to maintain indoors on seedling citrus plants, especially if they are clipped regularly to induce leaf flush, because eggs and nymphs are dependent on flush for development.

Constructivist pedagogy encourages students to postulate questions, design and implement experiments, analyze and interpret results, communicate and justify data, consider alternative explanations, and apply concepts and abilities to new scenarios, while the teacher acts as a facilitator, resource, or coach to help guide the students. Therefore, we present possible questions the students may ask during our lesson rather than a step-by-step activity. After such questions emerge, it is the responsibility of teachers to help students fully explore their inquiries by providing access to scientific materials and data, the field, and the expertise of the teachers.

Example Questions That May Emerge during the Lesson

- What species of predators consume ACP?
- What are the life stages of ACP, predators, and the parasitoid (*T. radiata*)?
- Which life stage of ACP is most often consumed by predators? By the parasitoid (Figure 3)?
- Are predators and the parasitoid generalist or specialist feeders?
- Will predators consume parasitized ACP?
- Do predators or the parasitoid control the population of ACP?
- Are predators less effective at controlling populations of ACP when alternative prey are available?
- Do predators and the parasitoid jointly control ACP or do they interfere with each other?
- Do predators and the parasitoid randomly search plants or can they detect ACP from a longer distance?
- How many color morphs does ACP have, and do predators or the parasitoid influence which color morph predominates over several generations?
- How many ACP are necessary to sustain a predator during its development from egg to adult?
- Has the phylogeny of the parasitoid radiated in response to speciation of psyllid species?
- Does the structure of the host plant influence how many ACP are consumed or parasitized?
- What range of temperatures can predators and the parasitoid withstand, and does this differ from ACP or influence the ability to control populations of ACP?
- What behavioral and morphological adaptations do ACP have to escape becoming prey?
- What behavioral and morphological adaptations do predators and the parasitoid have to consume or parasitize ACP?
- Can common household plants repel ACP?
- Are insecticidal soaps toxic to ACP and their natural enemies?
- Do insecticidal soaps and natural enemies jointly control ACP or do soaps interfere with biological control?

The NSES content standards (Table 2) targeted by these questions include all five Unifying Concepts and Processes, both elements of Content Standard A, all five elements of Content Standard C for grades 5–8, and biological evolution, interdependence of organisms, and behavior of organisms, which are elements of Content Standard C for grades 9–12.

○ Discussion & Implications for Teaching

Biological control is a well-established field of applied ecology that has been around for centuries, but despite this, our review uncovered few

Figure 3. Exit holes in nymphs of the Asian citrus psyllid caused by a parasitic wasp (*Tamarixia radiata*).

published how-to activities for the classroom that highlight this field. Although science has become a largely collaborative endeavor, scientists probably are less likely to discuss their ideas in education. This is supported by the fact that the mean number of authors on papers in *Biological Control* was higher than the mean number of authors on science-education papers (3.5 vs. 2.3 authors, respectively). Another trend in the literature is that women are more heavily represented as authors of education papers than men. Our review of published literature may not reflect which gender is more involved in science education *per se*, but rather the gender that is more likely to publish. Some barriers to scientists wishing to publish in science education have previously been identified (Richardson, 2010), and perhaps women are more willing to overcome these barriers. Scientists employed at liberal arts colleges also are more likely to publish biological-control activities for the classroom than those employed by research universities or government agencies. Scientists at research universities and government agencies may be heavily involved in science education, but we speculate that the rewards for publishing articles about science education are lower than at liberal arts universities. Government agencies also have a mission, and some preclude education as part of that mission

Despite the low number of published activities, the biological-control agents and pest species used in the activities are diverse, focusing on fungi, invertebrates, and vertebrates. The diverse taxa amenable to classroom activities highlight one benefit of using topics from biological control to teach scientific literacy. Another benefit is that these activities focus on multiple units of biological organization, especially populations and simple community-level interactions (i.e., interactions between two species). Biological control, by definition, should focus primarily on community-level interactions and provide an opportunity for students to study complex interactions between multiple species as well as interactions at the cellular, individual, and ecosystem levels. By targeting additional levels of biological organization, more of the NSES content standard would be addressed, such as the cellular and molecular standards for grades 9–12. The reviewed activities largely ignore the Unifying Concepts and Processes of form and function and evolution and equilibrium, but these concepts and processes are frequently studied by researchers of biological control and can be added to education curricula. Few activities target grades K–8, when students are first being exposed to life science, so we suggest that scientists need to contribute more activities targeting all grades, all levels of biological organization, and the NSES standards.

Scientists should share education activities to ensure that they are vetted as rigorously as their research programs, to assist educators at all grade levels, to improve science education for students, and ultimately to create a stronger culture of science. Scientists can ensure that their activities are appropriate for the classroom, in part, by using a constructivist pedagogical approach that facilitates student-centered inquiry and science literacy. How-to activities are usually inquiry based, but we found that teachers provide students with the questions in many of the activities and often have specific non-alternative answers to those questions before the student does the activity. These types of activities are essential and beneficial for students learning the process of science, but higher levels of learning need to be encouraged by helping students engage in complex cognitive activities that develop a complete skill set, which will allow them to succeed in school and compete for jobs that require expanding scientific and technical expertise.

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