The benefits of engaging K–12 students in science learning that is “consistent with the nature of scientific inquiry” (AAAS 1989) are well-recognized (NRC 2005, 2007, 2008). Several authors have argued that inquiry-based learning is also important at the undergraduate level, because students often enter college without this experience (eg O’Sullivan and Weiss 1999; NRC 2005; Campbell and Bohn 2008) and because inquiry-based learning is valuable for college students, regardless of their background (DeHaan 2005; Handelsman et al. 2007; Campbell et al. 2012). In general, inquiry-based learning involves a departure from education focused solely on content and instead promotes engagement in the processes of science – encouraging students to pose questions, generate and analyze data, draw conclusions, and communicate findings. Here, we highlight how two citizen-science projects – the Monarch Larva Monitoring Project (MLMP, www.mlmp.org, affiliated with the University of Minnesota [UM] and directed by K Oberhauser) and the Great Sunflower Project (GSP, www.greatsunflower.org, affiliated with San Francisco State University [SFSU] and directed by G LeBuhn) – involve students in the processes of science in three ways: data collection and analysis, independent or collaborative research projects, and class projects.

Background

MLMP data document the distribution and abundance of eastern migratory monarch butterflies (Danaus plexippus) during the breeding stage of their annual migratory cycle. Participants monitor residential backyards, natural areas, abandoned fields, pastures, and restored prairies; the only requirement is that surveyed areas contain milkweed (Asclepias spp), the host plant for larval monarchs (Figure 1). Most volunteers conduct weekly surveys of monarchs and milkweeds (most commonly Asclepias syriaca, Asclepias incarnata, Asclepias asperula, or Asclepias curassavica), assessing monarch densities per plant on randomly chosen milkweeds. Additional optional activities include comparing the height, phenology, and condition of plants occupied by monarchs to those of randomly chosen plants, and measuring rates of parasitism by parasitoid flies or wasps in collected larvae.

GSP data help researchers understand the ecosystem service provided by pollinators and the relative importance and abundance of both native and introduced (honey bee [Apis spp]) pollinators. Volunteers plant target species (primarily the variety lemon queen sunflower [Helianthus annuus]) in sites of their choice, usually gardens. From once to many times in a year, the volunteers record the number of bees visiting focal plants during 15-minute periods. In both projects, MLMP and GSP volunteers upload data to online databases.

While most volunteers in these projects are not undergraduate students, key features of the MLMP and GSP make them particularly amenable to undergraduate involvement in a variety of educational settings and geographic locations. Each project is focused on common insect–plant interactions that can be easily documented in both pristine and human-dominated environments, is based on basic and applied research questions, and is directed by active researchers who use the collected data to describe ecological patterns and inform experimental research. These features make it relatively easy to engage undergraduates in data collection, data analysis, and additional research. Undergraduates also work with volunteers in several capacities – as trainers, mentors, or experts in an “ask the expert” forum – and are involved with data validation and analysis. Additionally, research-associated connections between project directors and colleagues or former students at other institutions provide ways to expand student involvement beyond the home institution. Here,
we further describe how undergraduate students are involved in these projects.

### Undergraduates and insect citizen science

#### Data collection

The UM “Monarch Lab” monitors several MLMP sites throughout each summer, with undergraduate research assistants forming the core of the monitoring crew (Figure 2). While these students are generally compensated, their work goes beyond that of paid technicians. Early in the project's development, undergraduates helped design and test data collection protocols and provided samples of “standard” data against which to compare volunteer data. During the first 4 to 5 years of the MLMP, project staff made minor changes to the protocols and their descriptions, based on undergraduate research assistants' behavior and suggestions. As the project matured, the students' role changed to focus more on maintaining data collection continuity at the sites monitored by the Monarch Lab. Every undergraduate who worked with Oberhauser since the MLMP started (more than 30) has been involved with data collection.

During the formative stages of the GSP, undergraduate students helped test protocols for data collection, compared how protocols worked in different settings (eg community gardens), and collected sunflower seed heads to study the relationship between pollinator visitation rate and seed set. LeBuhn's lab group, including undergraduate research students, continues to monitor two sites on the SFSU campus throughout the flowering season.

#### Research opportunities

Strong connections between citizen-science data collection and independent inquiry make citizen science an ideal starting point for conducting research. Two features of the MLMP and GSP promote these connections among undergraduate students. First, student engagement is facilitated because both projects are located at universities. Second, large quantities of data – collected by citizen scientists – are available for analysis and to inform hypothesis-driven research. For example, undergraduate researchers conducted MLMP-related projects that resulted in coauthored peer-reviewed publications about heat stress in monarchs (York and Oberhauser 2002; note that, in the references section below, undergraduate coauthors for selected publications are highlighted in bold font), effects of rearing temperatures on larval color patterns (Solensky and Larkin 2003), and impacts of insecticide-based mosquito control treatments on monarchs (Oberhauser et al. 2006, 2009). Undergraduates at Emory University in Atlanta, Georgia, coauthored a study that used MLMP-derived data and involved laboratory experiments driven by findings of the MLMP and another monarch citizen-science project, Project Monarch Health (Lindsey et al. 2009). More than 20 students have conducted summer research projects – on parasitoids and other natural monarch enemies, heat stress, and monarch–milkweed interactions – that resulted in oral, poster, and written presentations in a variety of forums.

#### Class projects

College faculty at UM, SFSU, and elsewhere use MLMP and GSP protocols in classes, in some cases building them into independent summer research projects for students. Here, we provide brief examples to illustrate the variety of ways in which this is done. Bethann Lavoie at Minnesota State University Mankato in Mankato, Minnesota, teaches a one-credit research course for students preparing to be secondary science teachers; most of these students are juniors and seniors. Minnesota state law requires that these prospective teachers take a course that demonstrates their competency in developing and implementing a research project – in other words, in science inquiry. Because none of the students’ other required science courses met this objective, Lavoie developed the research course. Most of her students collected data based on MLMP protocols and then used data from other monitoring sites to supplement their own findings. Says Lavoie, “The MLMP was a nicely set up program, with a sampling procedure [that the students] could follow and a huge database to analyze. This allowed them to focus on developing a question, place the question within the context of the literature, collect and analyze data, and draw conclusions – all in one summer” (B Lavoie pers comm).

In an ecology class at the University of Georgia in Athens, Georgia, students made a film that promoted participation in the GSP. In connection with a project to “green” the campus landscape, ecology students also designed, constructed, and monitored on-campus “bee yards” (adding bee-pollinated flowers to gardens).

In other examples, Oberhauser engaged students in a freshman seminar on monarch biology, having them compare monarch growth and survival rates in the labo-
We have identified three areas in which citizen science might enhance undergraduate education: data collection, research opportunities, and class projects. In all cases, students are engaged in inquiry-based learning. While our roles as MLMP and GSP project directors have made it easy for us to use undergraduates in these citizen-science projects, our examples demonstrate that other educators and researchers have applied MLMP and GSP data and protocols in similar ways. The very nature of citizen science promotes broad engagement and data use; we encourage faculty members to take advantage of existing citizen-science projects to provide learning and research opportunities for undergraduates, and citizen-science coordinators to connect with undergraduate educators. Citizen Science Central (www.citizenscience.org) provides a useful database of projects for educators who would like to find citizen-science opportunities relevant to their locations and subjects.

We recommend research that both quantifies the educational benefits of using citizen-science projects in colleges and universities and provides guidance on how best to promote undergraduate understanding of science through programs like those described above. Although we have focused on science learning outcomes, citizen science also provides opportunities for integrating community service with instruction. This instructional strategy, often called service learning, has positive effects on students’ sense of personal identity (Osborne et al. 1998), leadership skills (Peterson 1998), ability to apply concepts outside of the classroom (Miller 1994; Kendrick 1996), future involvement in community service (Astin et al. 1999), and even course grades (Markus et al. 1993).

References