Investigating Ecological Disturbance in Streams

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ABSTRACT

Teaching students about ecological disturbance provides them with an understanding of a critical factor that shapes the structure and function of biological communities in environmental systems. This article describes four simple experiments and related curriculum that students can use to conduct inquiry around the theme of disturbance in stream ecosystems: insect drift, colonization, life history, and the intermediate disturbance hypothesis. Over five years, our students conducted these experiments 57 times; 79% of the experiments resulted in data that supported students’ hypotheses. Our findings show that the experiments can be used as a framework for inquiry-based learning about important ecological processes such as disturbance, dispersal, colonization, and succession. These experiments meet several of the Next Generation Science Standards, are easily and ethically conducted, and require very little equipment.

Key Words: inquiry-based learning; stream insects; stream disturbance; insect drift; intermediate disturbance hypotheses; life history.

Introduction: Ecological Disturbance in Streams

From forest fires to floods, disturbance plays a major role in shaping the diversity of biotic communities. Disturbance is an event that temporarily disrupts and changes an ecosystem or biotic community (White & Pickett, 1985). For the purposes of this article, we differentiate ecological disturbance, which occurs through natural events, from environmental disturbance, which is related to human activities. Ecological disturbance drives biotic community succession, maintains species diversity, and supports ecological function (Hobbs & Huenneke, 1992). Despite its relevance to the study of ecology and environmental science, few of our students understand the importance of ecological disturbance, and many students view disturbance as having only a negative effect on ecosystems.

Disturbance is an important aspect of natural science education and an interesting topic for inquiry. However, in most natural systems, disturbance experiments can be difficult to conduct in the short timeframe required by most educational settings. Moreover, causing a large disturbance may harm organisms and be counterproductive to student learning (Orlans, 1988). Because streams and stream insects rapidly recover from disturbance (Resh et al., 1988), they represent an opportunity for conducting disturbance experiments that can be completed over a couple of days. Furthermore, the main form of disturbance in streams is substrate mobilization (Resh et al., 1988); thus, stream disturbance can be nonlethally simulated by simply moving substrate or removing insects from substrate. The relative ease of simulating disturbance in streams and the fast colonization rates of stream insects make streams ideal ecosystems for education-based experiments focused on ecological disturbance. Here, we describe four stream experiments and the curriculum that we developed around the theme of ecological disturbance. These experiments are simple to conduct, nonlethal, and aligned with several of the Next Generation Science Standards for high school (Table 1). For each experiment, we provide the relevant background information, experimental methods, and examples of typical student results. We also describe the related curriculum and provide recommendations for how to implement the curriculum and experiments.

Methodology

Pedagogical Overview & Fieldwork

We developed these experiments so that our students could conduct authentic ecological inquiry on short field trips during which multiple experiments could be conducted simultaneously. All the disturbance experiments described here can be conducted in two field trips but, if necessary, the life history, disturbance, and energy experiments can be completed during a single field trip. Using a guided-inquiry approach, we have implemented the ecological disturbance curriculum and experiments in a range of educational settings from freshman high school to upper-division college courses. For all educational settings, we used the same
basic approach, but with different requirements for analyzing data and communicating the results. For example, some students analyzed data with a box plot and gave a short presentation about their results, while others conducted a statistical test and communicated their findings through a scientific paper. To facilitate online learning or to shorten the classroom time requirements, we developed online content videos and created virtual disturbance experiments (SWRP, 2020).

Table 2 outlines the timing of the major curricular activities and the related student and teacher roles. Scaffolding for the experiments begins with an introductory unit on stream ecology and stream insects. We then discuss the overarching design of ecological experiments and introduce the overarching topics of stream disturbance, life history and succession, dispersal, and stream energetics. The next major phase of the curriculum is the experimental design, and make a graphical prediction of their expected results. Students are not permitted to conduct the experiment without prior approval. During short (1- to 1.5-hour) field trips, students work in groups to install the experiments and then return two to seven days later to remove the experiments. Experimental data sheets, proposal forms, and example data sets are available online (SWRP, 2020).

**Field Methods**

The basic methodology for the disturbance experiments is based on a similar set of experiments focused on sediment pollution (Edwards & Shroufe, 2016). Our students have conducted the disturbance experiments in five different streams with consistent results; however, it is important to carefully consider the type of streams selected for these experiments. Streams should be shallow enough to wade across, have a moderate flow (0.5–3.0 feet/second), have rocky substrate, and not be severely polluted.

The specifics of each experimental methodology are described below, but some general procedures are followed for all the experiments. To avoid disturbing insects into downstream experiments, the experiments should be installed from upstream to downstream and harvested in the opposite direction. When collecting rocks for use in the experiments, make sure to use rocks from the stream that have sufficient algae growth (rocks with sufficient algae will feel “slimy”). When rocks are removed from the streams, quickly pick up the rock and directly transfer it to a white tub, and then gently rub the rock to dislodge insects. Some of the insects may be very small and hard to see; thus, “poking” debris with a pencil will force the insects to move and make them easier to count. For two of the experiments, both the total number of insects and insect density (e.g., insects/cm²) on the rock surface area will need to be calculated. The surface area of rocks can be estimated by measuring the two longest axes with a string and applying the following formula (Berger & Getty, 2006): rock surface area = length × width (π/4).

Table 1. Summary of the Next Generation Science Standards addressed by the disturbance experiments.

| Disciplinary Core Idea | Science & Engineering Practices (SEP), Crosscutting Concepts (CCC) | Experimental Activity or Result |
|------------------------|---------------------------------------------------------------------|--------------------------------|
| LS2.C: Ecosystem Dynamics, Functioning, and Resilience. | SEP: Mathematical and computational thinking. | Standardizing rock size, calculating stream flow and drift rates. |
|                        | CCC: Scale, proportion, and quantity.     | Identification of sample unit. |
|                        |                                      | Scaling up drift energy to kilocalories per day. |
| LS2.B: Cycles of Matter and Energy Transfer in Ecosystems. | SEP: Mathematical and computational thinking. | Estimating drift, biomass, and energy in the stream. |
|                        | CCC: Energy, matter, system models, structure, and function.      | Calculating percent ν- and K-selected organisms. |
| LS2.C: Ecosystem Dynamics, Functioning, and Resilience. | SEP: Engaging argument from evidence. | Using data to test hypothesis. |
|                        | CCC: Stability and change.                                    | Analyzing potential error. |
|                        |                                                                | Understanding disturbance and diversity. |
| LS2.C: Ecosystem Dynamics, Functioning, and Resilience. | SEP: Constructing explanations. | Interpreting results. |
|                        | CCC: Stability and change.                                    | Proposing cause and effect. |
|                        |                                                                | Documenting the intermediate disturbance Hypothesis. |
| LS4.C: Adaptation     | SEP: Using mathematics and computational thinking. | Estimating drift and energy in the stream. |
| ETS1.B: Developing Possible Solutions. | CCC: Cause and effect.                                    | Explaining cause and effect related to disturbance. |
| ESS3.C: Human Impacts on Earth Systems. | SEP: Constructing explanations and designing solutions. | Documenting the effect of flood disturbance on stream insects and algal communities. |
| ETS1.B: Developing Possible Solutions. | CCC: Stability and change.                                    | Documenting the intermediate disturbance hypothesis. |
The stream insects featured in three of the disturbance experiments are mayflies in the family Baetidae (Figure 1). Baetids are common and present in nearly all streams in the United States, with the exception of the lowlands in the southeastern part of the country (U.S. Environmental Protection Agency, 2006). Baetids represent the classic r-selected organism with a fast life cycle, high reproductive rate, and wide dispersal ability. These mayflies' life history characteristics and their ubiquity in streams make them an ideal model organism for studying stream disturbance. Baetids are also easy to identify; they are small, fast swimmers with an unsegmented thorax and two or three cerci (tails). Baetids are often confused with stoneflies, but they can be distinguished from stoneflies by their ability to swim. In contrast to the other experiments, the life history experiment is focused on the response of mayflies, caddisflies, stoneflies, and true flies to disturbance.

To evaluate the reliability of the experiments, we reviewed student work samples since 2015 and were able to document 57 disturbance experiments conducted by our students. We reviewed each poster and used p-value <0.05 or evaluated general trends to determine if the experimental hypothesis was supported by the results.

### Table 2. Summary of the main pedagogical activities associated with the disturbance experiments. Videos for all content and experiments are available online (SWRP, 2020).

| Day (Duration) | Major Class or Online Activity | Participant Roles |
|----------------|--------------------------------|-------------------|
| Day 1 (1.25 hours) | Content lecture or video on stream macroinvertebrates, stream ecology. Practice identifying live or preserved insects. | Student role – Learn relevant content material. Teacher role – Give lecture or show content videos, help with insect identification. |
| Day 2 (1.25 hours) | Content lecture or video on experimental design for natural science experimentation. Introduction to experiments. Experiment proposal. | Student role – understand experimental design, become familiar with experiments, and work in groups to propose the experiment. Teacher role – Give lecture or show video. Guide experiment proposals. |
| Day 3 (1–1.5 hours) | Field trip to install experiments. | Student role – Prepare experimental substrate, measure rocks, install experiments. Teacher role – Help with substrate selection, select sites for experiments, demonstrate how to install experiments. |
| Day 4 (1–1.5 hours) | Field trip to remove experiment. | Student role – Remove experiments and count insects. Teacher role – Help remove experiments if necessary. |
| Day 5 (1.25 hours) | Content lecture or video on data analysis using the CRAN R statistics program. Data organization and analysis. | Student role – Organize results and analyze data. Teacher role – Give lecture or video on data analysis. Support data analysis. |
| Days 6–7 (2.5 hours) | Communicating science through a paper or poster. Peer review. | Student role – Work in groups to write and revise a scientific paper or poster describing their experiment. Students peer review each other papers or posters. Teacher role – Facilitate peer review activity and grade at least two drafts of the paper or poster. |

**Insect Drift & Colonization**

Downstream dispersal of some insects occurs through a process known as drift. There are two main types of drift. Catastrophic drift

![Figure 1. Small minnow mayfly (Baetidae) and scale view in an ice cube tray. Baetids are easy to identify by their fast swimming and resemblance to minnows.](image)
occurs through substrate disturbance or from high-flow events that scour insects off substrate. Behavioral drift is an intentional behavior that insects exhibit when they are feeding, avoiding predation, or colonizing open habitat (Brittain & Eikeland, 1988). Baetids are well known as prolific behavioral drifters, intentionally releasing from the substrate in the evening and morning to drift downstream and colonize habitat that may provide better feeding opportunities and predator avoidance (Allan, 1987). Once drift is initiated, baetids and other drifting insects colonize open habitat through a process primarily related to stream velocity (Townsend & Hildrew, 1976). In areas of a stream with higher velocity, there are more insects drifting and thus they are more likely to colonize open habitat. In this experiment, students take 6–10 similar-sized rocks from the streams, remove all organisms from them, and measure their size (Figure 2E). The rocks are then placed back in the stream across a range of velocities (Figure 2A). The rocks are marked with flags so that they can be found at the end of the experiment. Students then measure stream velocity at the different locations where the rocks were placed. These measurements can be accomplished with a cork and stopwatch or, more accurately, with a flow meter. After three to five days, each rock is removed from the stream and placed in a tub where insects are removed from the rocks and counted. In this experiment, the number of insects on the rocks is the dependent variable and the stream velocity is the independent variable. The hypothesis for this experiment is that stream insect abundance on rocks will be positively correlated with stream velocity. Data can be displayed with a scatter plot and statistically analyzed using linear or polynomial regression models.

**Energy in the Drift**

Drifting insects are a major food source for fish (Brittain & Eikeland, 1988) and other organisms, yet few students realize the amount of food energy in the drift. Baetids are the primary insects in the drift, and their abundance can be estimated using a small drift net (less than one square foot) or some other secured small net to collect drifting insects (Figure 2B). The drift net is placed in the stream (Figure 2B) for an hour, and then students count the number of baetids captured in the net. In some cases, there may be too many baetids in a sample to count, in which case a subsampling procedure is used to quickly estimate the total number of baetids in the net (Edwards, 2016). After counting, insects should be immediately returned to the stream. In general, more insects will be captured in the morning and evening than in the middle of the day.

To estimate the number of baetids in the total stream drift, students will need to measure the stream profile, calculate flow, and make assumptions about the distribution of insect drift through the stream channel. With this information, students can estimate the total number of baetids in the drift per hour for that cross section of the stream and then convert that value to calories. This requires that students know the mass of a baetid, which can be estimated by measuring the mean length of the specimens. Students estimate the mean length of 10–20 baetids and use an empirical model to calculate the mean mass as follows (Benke et al., 1999): 

\[ \text{baetid dry mass (mg)} = \text{length (mm)}^{2.875} \times 0.0053. \]

Using published caloric values of baetids (Cummmins & Wuycheck, 1971), students estimate the total calories of insects in the stream cross section. We ask our students to convert this value to their favorite food and estimate the daily and annual number of servings in the drift. The sample unit in this experiment is kilocalories per day.

Caution should be taken when conducting this experiment, because drift nets can harm or kill insects if they are not checked frequently enough. It is not necessary to leave the drift net in the stream more than an hour, and low numbers of insects captured can still be used to estimate energy.

**Life History & Disturbance**

Disturbance in streams is primarily associated with high-flow flood events that mobilize and turn over rocks on the stream bottom. When streambed mobilization occurs, insects detach from the
substrate and drift downstream (Gibbins et al., 2007). When the flood subsides, insects begin recolonizing the open habitat by drifting in from upstream. Life history traits can be generally categorized as either r- or K-selected: r-selected insects are highly mobile drifters and early colonizers of open substrate, while K-selected insects are late colonizers and typically associated with stable environments.

In this experiment, students disturb the substrate and then observe the initial stages of succession by documenting the quick colonization of r-selected insects. Students disturb one square foot of the stream bottom and use a D-net to capture insects leaving the area (Figure 2C). Students place the insects in a tub and then categorize them as either r- or K-selected. This sample is considered the post-disturbance community. Four to 24 hours later, students resample the same locations and count the number of mayflies, stoneflies, caddisflies, and true flies. This sample is considered the post-disturbance sample. The most common r-selected insects in a stream are baetids, but other common r-selected insects include black flies (Simuliidae) and midges (Chironomidae). Stoneflies, caddisflies, and mayflies (other than Baetidae) are generally K-selected (Poff et al., 2006). Using percentages of r- and K-selected, students compare the pre- and post-disturbance communities. The dependent variables in this experiment are the percentages of r-selected and K-selected insects, while the independent variable is pre- and post-disturbance. The sample unit is each one square foot of substrate. The hypothesis of this experiment is that the percentage of r-selected insects will increase in the post-disturbance samples. Data from this experiment can be displayed using box plots and statistically analyzed with a t-test comparing the pre/post percentages of r-adapted.

Intermediate Disturbance Hypothesis

The intermediate disturbance hypothesis (IDH) describes the relationship between disturbance regimes and biodiversity. Initially documented in coral reefs with hurricane disturbance (Connell, 1978), the IDH predicts that the highest levels of biodiversity are maintained at moderate levels of disturbance. The relationship between biodiversity and moderate levels of disturbance is a critically important aspect of ecology and environmental science that few students fully understand. In streams, the major form of disturbance is substrate movement due to high-flow events. This process is one of the primary controls of algal succession and diversity in streams (McCormick, 1996). Diatoms are single-celled algae with silica cell walls that grow on the surface of rocks and other submerged substrate in streams (Stevenson et al., 2010). Early-successional stages of diatoms dominate small rocks that frequently roll over, while late-successional stages of diatoms dominate large rocks that rarely move. Thus, according to the IDH, the highest diversity of diatoms should be found on the medium-sized rocks that experience moderate levels of disturbance (McCormick, 1996).

In this experiment, insect abundance serves as a proxy for diatom diversity because diatoms cannot be identified and counted in the field. This approach requires the assumption that more diatom diversity presents more feeding opportunities and thus more insect abundance. This may not be the case in streams that are polluted or experiencing algae blooms. To explore this assumption, we sampled diatoms from 11 rocks and correlated diatom richness with a small range of rock sizes.

To conduct this experiment, students collect 20–40 rocks from the stream (Figure 2D), place each rock in a white tub, remove and count the insects, and then measure the rock to estimate surface area (Figure 2E). In this experiment, the independent variable is rock size, while the dependent variables are insect counts. The sample unit is each rock. The hypothesis is that the medium-sized rocks will have the highest insect abundance, which can be statistically evaluated using $R^2$ and p-value.

**Results**

**Insect Drift & Colonization**

We have conducted the drift and colonization experiment 15 times with our students, and nine of those experiments resulted in data that supported the hypothesis that insect colonization of rocks would be positively correlated with velocity. Here, we include two student-collected data sets to illustrate representative results (Figure 3A, B). The first data set was collected by high school students and illustrates a positive linear relationship ($R^2 = 0.80$) between insect counts and stream velocity. The second data set was collected by college students and shows a nonlinear (second-order polynomial) relationship.

Figure 3. Example student results from the drift and colonization experiment. (A) Linear and (B) polynomial models for two different colonization experiments from different streams. Insect abundance was expressed as counts per rock (A) or as a density per square centimeter of rock (B).
relationship between insect density (abundance/cm²) and stream velocity ($R^2 = 0.80$).

### Energy in the Drift

Our students have conducted this experiment four times, resulting in estimates of 65,000–500,000 baetids in the drift each day. This estimate is based on a relatively small number (25–200) of baetids captured in the drift net. Using a mean baetid length of 5.5 mm, our students estimated 300–2000 kilocalories of energy in the drift per day, which represents about four slices to nearly 1.5 loaves of bread. The total energy in a stream system can be estimated by multiplying this value with the total length of the stream in feet.

### Life History & Disturbance

We have conducted the life history experiment 21 times with our students, and 17 of those experiments resulted in data that supported the hypothesis that $r$-selected insects will increase after disturbance. Here, we include a student-collected data set to illustrate the range of typical results (Figure 4A, B). Figure 4A shows an increase in the percentage of $r$-selected insects from 57% in the pre-disturbance insect community to 81% in the post-disturbance community ($p < 0.05$). $K$-selected insects showed the opposite pattern, decreasing from 43% to 19% in the post-disturbance community ($p > 0.05$). Figure 4B shows weaker results, but a similar pattern is evident.

### Intermediate Disturbance Hypothesis

Our students have conducted the IDH experiment 16 times, with 14 of those experiments resulting in data that supported the hypothesis. Typical results show that insect abundance (Figure 5A) and insect density (Figure 5B) are highest on the medium-sized rocks. A second-order polynomial regression model best fit the data and showed that insect abundance and density were correlated with rock size ($R^2 = 0.60$ and 0.28, respectively). A second-order polynomial also described the relationship between diatom richness and rock size ($R^2 = 0.27$), with the highest richness observed on the medium-sized rocks (Figure 5C).

### Discussion

#### Drift Experiment

The drift experiment demonstrates one of the primary mechanisms for insect dispersal in streams and the colonization of open stream habitat. The polynomial curve observed (Figure 3B) in some of the students’ data is common in natural settings and illustrates a leveling-off of the relationship between colonization and stream. To ensure the success of the drift experiments, make sure that students place rocks in a wide range of velocities.

#### Energy Experiment

The energy experiment illustrates the large amounts of insect biomass and calories that are in the stream drift and fluxing through stream ecosystems. This experiment always generates useful data; however, the main concern is with the accuracy of the biomass estimates. In the four experiments our students conducted, the estimated number of baetids in the drift ranged from 65,000 to 500,000 per day, which is within the range observed by Allan (1987) for a small stream in Colorado. We ask our students to consider whether they overestimated or underestimated the number of baetids in the drift and to give possible explanations for the error in their estimate.

To ensure the success of this experiment, students should place the drift net in a moderate current, empty the net at least every hour, and ensure that the experiment is not conducted in the fall, when leaves in the stream will clog the net.

#### Life History Traits & Disturbance

The life history experiment documents the early stages of succession after a disturbance, when insects with $r$-selected traits...
rapidly colonize open habitat. Eighty-one percent of the experiments our students conducted showed a moderate to a strong increase in r-selected insects and a decrease in K-selected insects after disturbance. To ensure the success of this experiment, minimize the amount of time between pre- and post-disturbance sampling. In our experience, after more than 24 hours, the r- and K-selected insects are already reaching equilibrium. This experiment could be conducted with as little as an hour between pre- and post-disturbance samples.

Intermediate Disturbance Hypothesis

The IDH experiments show that the medium-sized rocks have the highest insect abundance and that diatom diversity is associated with rock size. These findings illustrate the importance of a diverse algal food source and the role of substrate disturbance regimes in maintaining biotic communities. Eighty-eight percent of the experiments conducted by students resulted in data that supported the hypothesis that medium-sized rocks will have the highest abundance of insects. While the diatom richness data were obtained from a smaller range of rock sizes, these findings suggest that diatom richness is also higher on medium-sized rocks. This provides a possible explanation for the patterns observed in the insect data; high diatom richness on the medium-sized rocks provides more insect feeding opportunities and thus results in a higher abundance of insects. However, it is important to recognize that this experiment only provides correlational evidence of this relationship and there could be other explanations for the observed results, including stream pollution, substrate type, or overall habitat stability. We encourage our students to explore alternative explanations for their results and have found that this generates in-depth conversations about experimental design and causation. To ensure the success of this experiment, make sure that a wide range of rocks sizes are collected, from small pebbles to the largest rocks that students can reasonably handle.

Conclusions & Recommendations

Our findings show that the disturbance experiments can be used as a framework for inquiry-based learning about important ecological principles related to disturbance, dispersal, colonization, and succession. Of the 57 times we conducted these experiments, 45 resulted in data that supported the hypothesis. The value of these experiments is that they are reliable, ethical, require very little equipment, and are quick to set up and harvest (<1.5 hours). There are several sources of error related to the disturbance experiments that are important to recognize. Type 1 errors (false positives) in these experiments are likely associated with mistakes in data collection or the influence of other variables such as flow, substrate texture, or upstream disturbance that could not be controlled in the field or was not measured by students. Type 2 errors (false negatives) are likely due to low statistical power, mistakes in harvesting of substrates, or mistakes in data collection. Table 3 summarizes the potential error for each experiment. All of the experiments are vulnerable to being confounded by a disturbance upstream of the experimental reach that causes insects to drift down into the experiments. As already noted, to ensure that confounding disturbances do not occur, students should install experiments moving downstream and harvest experiments moving upstream. Harvesting rocks slowly or haphazardly can result in a major loss of insects from the rock surface.

As with all inquiry-based learning that takes place in the field, it can be challenging to implement curriculum, conduct the experiments, and account for the uncertainty in experimental outcomes. We encourage teachers who conduct these experiments to communicate the challenge and uncertainty of field experiments, letting students know that there are no failed experiments and that the results that do not support the hypothesis are still a valuable outcome. The research approval process is a critical point in
Table 3. Summary of the potential scientific error associated with each experiment. This information will help students think about their experimental error. A type 1 error occurs when the hypothesis is supported by the data. A type 2 error occurs when the hypothesis is not supported by the data.

| Experiment                                      | Potential Causes for a Type 1 Error (False Positive)                                                                 | Potential Causes of a Type 2 Error (False Negative)                                                                 |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| Insect drift and colonization                   | Recent disturbance upstream. Confirmation bias when counting insects. Confounded by some other stream variable such as food availability or rock texture. | Velocity gradient too short. Mistakes harvesting rocks. Placement of experimental rocks behind large logs or boulders that block drift. |
| Energy in the drift                             | Inaccurate measurements of flow. Assuming baetid drift is the same across the stream cross section or the same throughout the day. | Net clogged or placed in high-velocity/turbulent section of the stream. Not counting very small specimens.           |
| Life history and disturbance                    | Misidentification or misclassification of insects. Confirmation bias when counting insects.                          | Misidentification or misclassification of insects. Collecting outside of the pre-disturbed area. Too much time between pre- and post-disturbance. |
| Intermediate disturbance hypothesis (IDH)       | Confounded by another stream variable such as flow, food availability, or rock texture.                             | Gradient of rock sizes too short. Too few samples. Mistakes harvesting rocks.                                       |

*This experiment is not based on a hypothesis, so we evaluate causes of underestimating or overestimating energy in the drift.*

the curriculum and should be a collaborative and guided learning experience so that students fully understand the design of the experiment and are prepared to conduct a successful experiment. When experiments cannot be successfully completed, for example because of high-flow events or when experiment substrate is lost, we let students use data from a previous class. And finally, most experiments will have a sample that is an outlier or whose accuracy is questionable. We ask that students make field notes about anomalous data and encourage discussions about how to deal with confounding data. In our experience, anomalous data generate valuable in-depth discussions about experimental design, hypothesis testing, and sources of error or bias when collecting data.

We were unable to formally assess the student outcomes of these experiments, but we did evaluate student learning as part of the regular classroom activities. We gave students an exam about their experiment, asking them to describe the independent and dependent variables, draw a graph showing the results, and explain the potential type 1 and type 2 errors associated with the experiment. We also graded posters using a rubric that assessed students’ content knowledge and their understanding of experimental design, data analysis, and communication of science. In general, the exams and posters showed that students understood the material associated with the experiments and had an in-depth understanding of experiment design. These anecdotal results suggest that our curriculum and student outcomes are addressing and meeting the NGSS standards.

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**References**

Allan, J.D. (1987). Macroinvertebrate drift in a Rocky Mountain stream. *Hydrobiologia*, 194, 261–268.

Benke, A.C., Huryn, A.D., Smock, L.A. & Wallace, J.B. (1999). Length-mass relationships for freshwater macroinvertebrates in North America with particular reference to the southeastern United States. *Journal of the North American Benthological Society*, 18, 308–343.

Berger, E.A. & Getty, G.M. (2006). A review of methods for measuring the surface area of stream substrates. *Hydrobiologia*, 556, 7–16.

Brittain, J.E. & Eikeland, T.J. (1988). Invertebrate drift – a review. *Hydrobiologia*, 166, 77–93.

Connell, J.H. (1978). Diversity in tropical rain forests and coral reefs. *Science*, 199, 1302–1310

Cummins, K.W. & Wuycheck, J.C. (1971). Caloric equivalents for investigations in ecological energetics: with 2 figures and 3 tables in the text. *Internationale Vereinigung für Theoretische und Angewandte Limnologie: Mitteilungen*, 18(11), 1–158.

Edwards, P.M. (2016). The value of long-term stream invertebrate data collected by citizen scientists. *PLoS ONE*, 11(4).

Edwards, P.M. & Shroufe, R. (2016). Three simple experiments to examine the effect of sediment pollution on algae-based food webs in streams.* American Biology Teacher*, 78, 57–61.

Gibbins, C., Vericat, D., Batalla, R.J. & Gomez, C.M. (2007). Shaking and moving: low rates of sediment transport trigger mass drift of stream invertebrates. *Canadian Journal of Fisheries and Aquatic Sciences*, 64, 1–5.

Hobbs, R.J. & Huenneke, L.F. (1992). Disturbance, diversity, and invasion: implications for conservation. *Conservation Biology*, 6, 324–337.
McCormick, P.V. (1996). Resource competition and species coexistence in freshwater benthic algal assemblages. In *Algal Ecology* (pp. 229–252). San Francisco, CA: Academic Press.

Orlans, F.B. (1988). Should students harm or destroy animal life? *American Biology Teacher, 50*, 6–12.

Poff, N.L., Olden, J.D., Vieira, N.K., Finn, D.S., Simmons, M.P. & Kondratieff, B.C. (2006). Functional trait niches of North American lotic insects: traits-based ecological applications in light of phylogenetic relationships. *Journal of the North American Benthological Society, 25*, 730–755.

Resh, V.H., Brown, A.V., Covich, A.P., Gurtz, M.E., Li, H.W., Minshall, G.W., et al. (1988). The role of disturbance in stream ecology. *Journal of the North American Benthological Society, 7*, 433–455.

Stevenson, R.J., Pan, Y. & van Dam, H.E. (2010). Assessing environmental conditions in rivers and streams with diatoms. In E. Stoermer (Ed.), *The Diatoms: Applications for the Environmental and Earth Sciences, vol. 2* (pp. 57–85). Cambridge, UK: Cambridge University Press.

SWRP (2020). Online curriculum, Portland State University. https://www.pdx.edu/environmental-science/student-watershed-research-project-swrp

Townsend, C.R. & Hildrew, A.G. (1976). Field experiments on the drifting, colonization and continuous redistribution of stream benthos. *Journal of Animal Ecology, 45*, 759–772.

U.S. Environmental Protection Agency (2006). National Aquatic Resource Surveys. Wadeable Streams Assessment 2004–2005 (Macroinvertebrate data). Available from U.S. EPA web page: https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys (accessed June 15, 2020).

White, P.S. & Pickett, S.T.A. (1985). Natural disturbance and patch dynamics: an introduction. In S.T.A. Pickett & P.S. White (Eds.), *The Ecology of Natural Disturbance and Patch Dynamics* (pp. 3–13). San Diego, CA: Academic Press.

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A note about article word count: Please recognize that tables, figures, and photographs add to the overall length of the article. One page of text has approximately 1,000 words, therefore a 1/4-page graphic will count for 250 words. More extensive graphics should be budgeted accordingly. References are also included in the final article word count.

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- Research on teaching alternatives, including evaluation of a new method, cooperative learning, concept maps, learning contracts, investigative experiences, educational technology, simulations and games, and biology and life science education standards
- Social and ethical implications of biology and how to teach such issues as genetic modification, energy production, agriculture, climate change, health care, nutrition, and cultural responsiveness
- Reviews and updates of recent advances in the life sciences in the form of an “Instant Update” that brings readers up-to-date in a specific area
- Imaginative views of the future of biology education and suggestions for adjusting to changes in schools, classrooms, and student populations
- Other timely, relevant, and interesting content such as discussions of the role of the Next Generation Science Standards in biology teaching, considerations of the nature of science with implications for the classroom, considerations of the continuum of biology instruction from K–12 to post-secondary teaching environments, or contributions that consider the likely/ideal future of science and biology instruction

**Research on Learning** (up to 4,500 words) includes reports of original research on innovative teaching strategies, learning methods, or curriculum comparisons. Studies should be based on sound research questions, hypotheses, discussion of appropriate design and procedures, data and analysis, discussion on study limitations, and recommendations for improved learning outcomes.

**Inquiry and Investigations** (up to 3,500 words) is the section of ABT that features discussion of innovative laboratory and field-based strategies. Strategies in this section should be original, engaging, practical, and related to either a particular program such as AP and/or linked to standards such as NGSS. Submissions should also be focused at a particular grade/age level of student and must include all necessary instructions, materials list, worksheets, and assessment tools. Other appropriate contributions in this category are laboratory experiences that engage students in inquiry.

**Tips, Tricks and Techniques** (up to 1,500 words but may be much shorter) features a range of suggestions useful for teachers including laboratory, field, and classroom activities; motivational strategies to assist students in learning specific concepts; modifications of traditional activities; new ways to prepare some aspect of laboratory instruction; etc.

Writing & Style Guidelines

The Chicago Manual of Style, 17th Edition is the guide for questions of punctuation, abbreviation, and style. List all references in alphabetical order on a separate page at the end of the manuscript. Please review a past issue for examples. Use first person and a friendly tone whenever appropriate. Use concise words to emphasize your point rather than capitalization, underlining, italics, or boldface. Use the SI (metric) system for all weights and measures.

While calls for specific themed issues of ABT are infrequent, February and April are traditionally themed editions on Evolution and the Environment, respectively.

Preparing Tables, Figures, and Photographs

**General Requirements**

- When your article is accepted, we will require that figures be submitted as individual figure files in higher resolution format. See below for file format and resolution requirements.
- Authors should be aware that color is limited within the journal. All artwork, figures, tables, etc. must be legible in black and white. If color is important to understanding your figures, please consider alternative ways of conveying the information.

**Article Photographs**

Digital files must meet the following guidelines:

- Minimum resolution of 300 DPI, 600 DPI is preferred
- Acceptable file formats are TIFF and JPEG
- Set to one-column (3.5” wide) or two-column size (7” wide)
- If figure originates from a website, please include the URL in the figure caption. Please note that screen captures of figures from a website are normally too low in resolution for use.

**Tables and Figures**

- Minimum resolution of 600 DPI, 1200 DPI is preferred
- Acceptable file formats are TIFF, BMP, and EPS
- Set to one-column (3.5” wide) or two-column size (7” wide)

If you have any questions, contact Valerie Haff at managningeditor@nabt.org.
Submission Guidelines

NOTE: All authors must be current members of NABT or a charge of $100 per page is due before publication.

All manuscripts must be submitted online at http://mc.manuscriptcentral.com/ucpress-abt

- Authors will be asked to register the first time they enter the site. Upon receiving a password, authors can proceed to upload their manuscripts through a step-by-step process. Assistance is available in the “Author Help” link found in the menu on the left side of the page. Additional assistance is available from the Managing Editor (managingeditor@nabt.org).
- Manuscripts must be submitted as Word or WordPerfect files.
- Format manuscripts for 8.5 × 11-inch paper, 12-point font, double-spaced throughout, including tables, figure legends, and references.
- Please place figures (including photos) and tables where they are first cited in the text along with appropriate labels. Make sure to include figure and table citations in the text, as it is not always obvious where they should be placed. At the time of initial submission, figures, tables and images should be low resolution so that the final file size remains manageable.
- If your article is accepted, the editors will require that figures be submitted as figure files in higher resolution form. See section on Preparing Tables, Figures, and Photographs.

Supplemental Materials

In order to maintain the word count for individual articles, we are pleased to facilitate publication of supplemental materials accompanying the online issue. If authors have materials (figures, examples, worksheets, appendices, multimedia files, etc.) that support but are not essential to the printed text of the article, authors can include those as separate files with their article submission.

Editorial Procedures

- Communications will be directed only to the first author of multiple-authored articles.
- Typically, three individuals who have expertise in the respective content area will review each article.
- The editors attempt to make decisions on articles as soon as possible after receipt, but the process can take six to eight months, with the actual date of publication to follow. Authors will be emailed editorial decisions as soon as they are available.
- Accepted manuscripts will be forwarded to the Copy Editor for editing. This process may involve making changes in style and content. However, the author is ultimately responsible for scientific and technical accuracy. Page proofs will be sent to authors for final review before publication at which time only minor changes can be made.

Submitting Images

Cover Images

Submissions of cover photographs from NABT members are strongly encouraged. Covers are selected based on the quality of the image, originality, composition, and overall interest to life science educators. ABT has high standards for cover image requirements and it is important for potential photographers to understand that the required size of the cover image generally precludes images taken with cell phones, point-and-shoot cameras, and even some older model digital SLR cameras.

Please follow the requirements listed below.

- Email possible cover images to Kathleen Westrich at kmwestrich@yahoo.com.
- ABT covers feature an almost-square image with a slight vertical orientation.
- Choose an image with a good story to tell. Do not crop the subject too tightly. It is best to provide an area of background around the subject.
- Include a brief description of the image, details of the shot (i.e., circumstances, time of day, location, type of camera, camera settings, etc.), and your biographical information in an email message.
- Include your name, home and email addresses, and phone numbers.
- Please ensure that the image meets the minimum standards for publication listed below and has not been edited or enhanced in any way. The digital file must meet the minimum resolution of 300 pixels per inch (PPI)—preferred is 400 PPI— and a size of 8.5 x 11.25”. We accept TIFF or JPEG images only.

BioMystery Images

Authors who have a photo that does not meet the high resolution required for a cover photo can consider submission as the “BioMystery” image. These submissions can be sent to ABTEditor@nabt.org with a description of the subject of the image.

Thank you for your interest in The American Biology Teacher. We look forward to receiving your manuscripts.

William McComas, Editor-in-Chief
ABTEditor@nabt.org

Valerie Haff, Managing Editor
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