The American Biology Teacher
Inquiry and Investigation

Helena Puche
Biologist
USA, IL, Chicago

Using Scientific Inquiry to Teach Students about Water Quality

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Abstract

This is an exploratory activity of the macroinvertebrate fauna from water sources affected by different levels of pollution in which students practiced scientific inquiry. Following a semi-guided inquiry, students developed their ability to identify macroinvertebrates, compared the aquatic fauna from different sources of water samples, evaluated water quality using an index, documented and analyzed data, raised questions and hypotheses, and discussed other possible issues that could be investigated at a later time. These sets of activities were designed for freshman high school students but also are applicable to middle school science students.

Keywords*:* *macroinvertebrates, aquatic, insects, inquiry, quality*

Introduction

Inquiry is a process of interaction between teacher and students where the teacher engages students on generating questions and pursuing answers through careful observation and reflection (Llewellyn 2004). The inquiry cycle begins with a question that has to be comparative, time-wise, simple and exciting. In this cycle: question→ action→ reflection → question, students help decide what to compare, what to measure (compare at least two, measure one), and how to measure and collect the data (action). In the reflection process, students explain their results, and deliberate about what to do differently next time, which generates new questions. These simple steps are the stepping stones to reach a global understanding of the inquiry process, and to involve students in doing science, both of which are conducive to more sophisticated comparisons later on.

One way to help students understand the scientific inquiry in sience is by encouraging them to investigate the quality of different types of water samples. This is important because the water quality in streams and rivers had been declining since the 1960s, becoming a serious concern (Feminella and Flynn 1999). Due to the release of harmful pollutants in the water such as heavy metals, sewage and other chemical wastes, the Clean Water Act (CWA) was enacted in 1977. The goal of CWA was to "restore and maintain the chemical, physical and biological integrity of the nation's waters (CWA 1977)."

In order to identify which water sources were becoming polluted, a water quality monitoring approach was needed. The traditional water quality monitoring approach became a collection of water samples and laboratory analysis for suspended physical and chemical pollutants. However, a biological approach to water quality monitoring was less costly and incorporated water organisms as a basis for pollution detection. The basis of biomonitoring is that certain types of water animals, such as macroinvertebrates, occur or thrive only under certain water quality conditions (Lenat 1988). When conditions change, such as when a stream receives a significant chemical runoff, the abundance and distribution of invertebrates in the affected site changes as well (Feminella and Flynn 1999).

To introduce students to the cycle of inquiry and how to conduct real world science, the ideal situation would be to bring students outdoors to stimulate their curiosity. However, when this is not possible, an alternative is to bring the outside world into the classroom. This is the case of water samples taken from rivers and ponds which are filled with macroinvertebrates and microscopic organisms. They are easily identified and categorized using magnifying glasses, portable scopes, ID books, and pictures. The instructor could introduce the water unit a few weeks before this activity, to start getting students engaged in the macroinvertebrate-inquiry activity and to help students understand the impact of pollution on the health of the ecosystem, and. The game "macromania" (see methods) could be played in-class to prepare the students to the macroinvertebrate activity before it occurs.

Macroinvertebrates are small animals, usually greater than 1 mm long, that do not have backbones and live on the bottom of a pond, lake stream or river for at least part of their lives (Feminella and Flynn 1999). They can be found in crevices between submerged stones, in organic debris, on aquatic vegetation or within sediments. Most of the species are aquatic insects, represented by immature stages of mayflies, dragonflies, damselflies, stoneflies, caddishflies, flies and beetles. However, other types of organism can be commonly found in the water such as crustaceans (side swimmers, crayfish, scuds), oligochaetes (earthworms, leeches), mollusks (snails, mussels, clams) and arachnids (aquatic mites).

We presented a semi-guided inquiry-based activity in the classroom to compare abundances of macroinvertebrate faunas from water samples that were assumed to have different pollution levels. Students related these macroinvertebrate abundances to pollution levels using macroinvertebrate tolerance levels and a key. The students processed the samples, analyzed and interpreted the data, and discussed the effects of pollution on macroinvertebrate populations. The students' discussion of their findings generated more questions that could be used for new inquiry investigations.

Materials and Methods
Materials

3 gallon plastic buckets for water samples
3x magnifying lenses (http://www.amazon.com)
Dual plastic magnifiers (3x and 6x) (http://www.carolina.com/product)
Battat two way microscopes (http://www.amazon.com)
Illuminated zoom microscopes (60x -100x) (http://www.dealextreme.com)
ID books (National Audubon Society 1980, Eddy and Hodson 1982, Needham and Needham 1988, UWEX 1998, The Stream Study 1999, FDEP 2007, NABS 2009, Friends of the Chicago River 2009)
ID cards (Voshell 2001)
ID-water-quality sorting sheet (Fig. 1)
Petri dishes, one for each student (www.enasco.com)
Dropper (http://www.amazon.com)
Forceps (http://www.emsdiasum.com)
Plastic spoons, 1-3 for each group
Plastic containers for vegetation and water

The teachers used 3-gallon plastic buckets to scoop and bring water samples from each of three locations (see Appendix A): the Des Plaines River, the Salt Creek and a Pond (Bison Pond). Some floating vegetation was added to increase the chances of capturing macroinvertebrates. Because the purpose of the inquiry method is to encourage students to think and make their own conjectures through questions, observations, classification, communication, measures, predictions, inference, experimentation, as opposed to merely learning facts, concepts, and theories someone else has concluded (Yoon and Ariri 2006), the teachers did not explain to the students how the samples were collected. This was important for later reflections about the results. Even though the three water sources corresponded to two running waters and one stagnant pond, the goal was to assure that the water samples had different pollution levels. Bison pond is located in an isolated area in the middle of the Brookfield Zoo, IL, has no tributaries and neither animals nor humans have access to it. Therefore, it had no source of pollution (turbidity: 2.61 NTU, pH: 8.1, nitrogen: 0.03 mg/l and phosphorus: 0.09 mg/l, collected by students several weeks prior to this activity). The Des Plaines River is near factories and has many tributaries (turbidity: 59 ppm, pH: 6.7-8.4, nitrogen: 0.65 mg/l and phosphorus: 0.169 mg/l; EPA 1993, Nairn and Mitsch 2000, ILEPA 2009). Therefore, there was a higher risk of pollution. Salt creek is a tributary of the Des Plaines River (turbidity 4-39 NTU, pH: 7.8, nitrogen: 0.44-0.84 mg/l and phosphorus: 0.09-0.122 mg/l; Figueroa-Nieves *et al.* 2006, Heatherly and Whiles 2007). Therefore, there was a lower risk of pollution than the Des Plaines River but higher risk of pollution than Bison pond. All water samples with their respective organisms were returned after the activity to the exact locations where they were collected.

A total of 59 freshman students (20 students per class) participated in the study. Using 3x plastic box magnifying lenses, dual plastic magnifiers (3x and 6x), Battat two way microscopes and illuminated zoom microscopes (60x -100x. Lumagny illuminated pocket microscope) students, in groups of 4-6, placed aliquots of water samples on Petri dishes, observed for 12 minutes for each location (two evaluations (2) per location (3) per group (4) per class (3), N = 72 observations), and identified the organisms that were present in each water sample. ID books, ID cards, and a new ID-water-quality sorting sheet (Fig. 1) based on tolerance levels for each type of organism were used for identification of macroinvertebrates (see timeline for additional provisions). Certain macroinvertebrates are less tolerant to pollution (Lenat 1988). Therefore, they will be found more in pristine waters (like Bison Pond). Other macroinvertebrates are more tolerant to pollution (Heatherly and Whiles 2007), and those will be found mostly in polluted waters (such as the Des Plaines River or Salt creek). In this inquiry-based activity, the simplest premise of "measure one," "compare at least two" was used and the students measured water quality through an index ("measure one") and compared three locations.

We designed a sorting sheet (Fig. 1) based on Macro Mania (LaMotte 2004), a classroom game that introduces the use of stream macroinvertebrates to determine water quality. Our sorting sheet presented three groups of organisms: Group 1 represented macroinvertebrates that were very sensitive to pollution. Therefore, they could only survive in water of high quality. Group 2 represented a group of macroinvertebrates that were somewhat sensitive to water quality but could survive in waters that weren't quite clean. Group 3 represented macroinvertebrates that were tolerant to poor water quality. Therefore, they survive in more polluted waters where invertebrates from Group 1 and Group 2 sometimes could not live (Lenat 1988).

To determine the overall quality of the water samples using macroinvertebrates, the students counted the number of organisms of each type within each of the three groups on the sorting sheet (Fig. 1). The total number of types-of- macroinvertebrate in each group was multiplied by a number: Group 1 was multiplied by 3, Group 2 was multiplied by 2 and Group 3 was multiplied by 1 (LaMotte 2004). These values corresponded to ranges of tolerance levels (Fore *et al.* 1996). The sum of the three types of macroinvertebrate on each group that was previously multiplied by each respective number, was assigned to a water quality that could be excellent, good, fair or poor (see Fig. 1). The hypothesis was that the Des Plaines River water corresponded to the poorest water quality with macroinvertebrates characteristic of polluted waters, compared to Salt Creek. Bison Pond was expected to have the highest water quality.

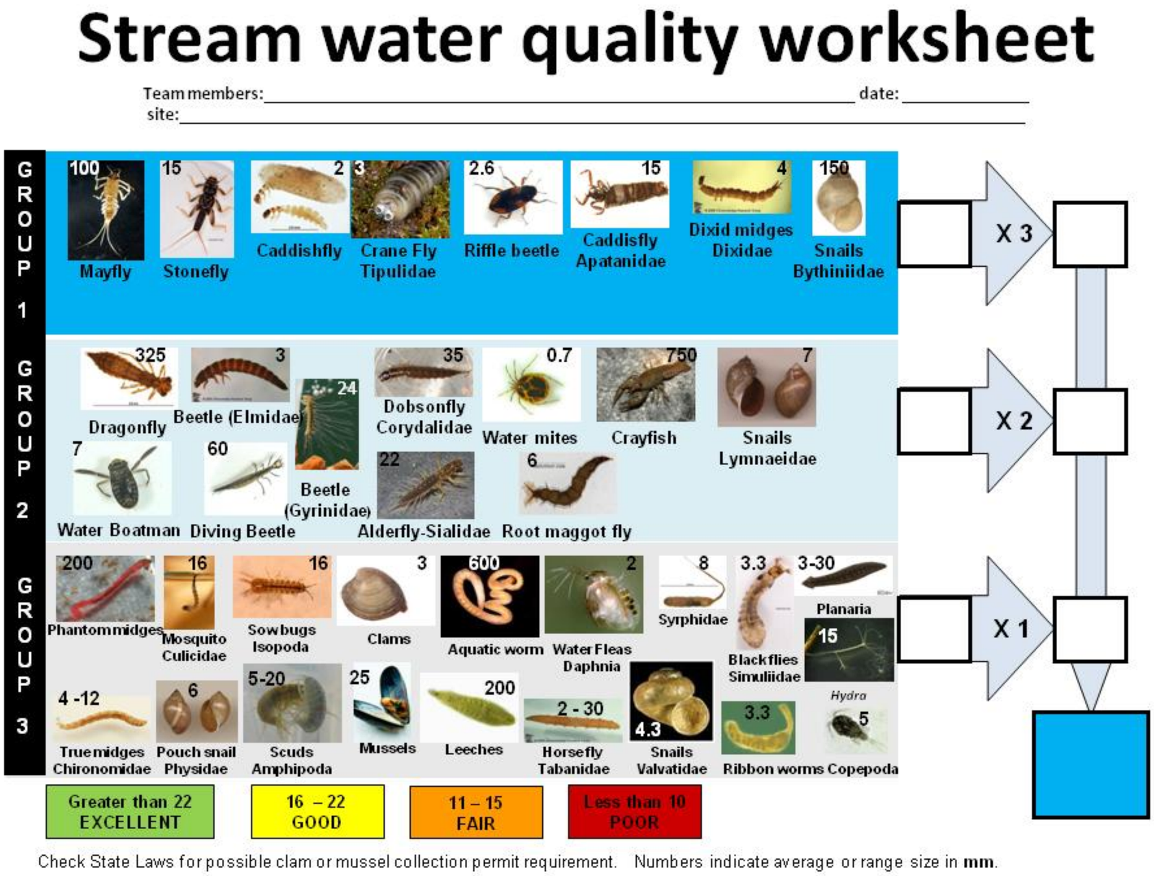

Figure 1: Sorting sheet to evaluate water quality using macroinvertebrates. Each group represents organisms that are 1) very sensitive to pollution (high water quality, Group 1); 2) somewhat sensitive to water quality but that could survive in waters that weren't quite clean (mid-level pollution, Group 2); and 3) tolerant to high pollution (poor water quality, Group 3).

<u>Statistical Analysis</u>: Even though students detected differences among sites (high, medium, low), the teachers tested the data for normality and homocedasticity prior to performing analysis of variance to corroborate the students' findings. Because normality was not reached after any transformation, a Kruskal-Wallis ANOVA (Statview, SAS institute, 2002) was used to determine if group results were different among sites. Statistical differences were detected by a non-parametric multiple comparison between treatments (NP_MCBT, $P < 0.05$; Sieguel and Castellan 1988). These results were later presented to the students for discussion.

Timeline

This type of activity is best conducted from spring through fall when aquatic organisms are available and active. Water samples were collected two days prior to the activity. Several Petri dishes with macroinvertebrates from each site were prepared two hours before the activity, anticipating that students might not be able to find macroinvertebrates in their water samples. That way, students have an alternative resource to see and identify these organisms.

RESULTS

Students found that Bison pond had a water quality that ranged from 5 to 24 (Fig. 2). The maximum value of 24 corresponds to excellent water quality (Fig. 1). Discrepancies in evaluations were due to students' inexperience at identifying macroinvertebrates, and due to the short time available for identification. However, since a group of students was able to obtain a water quality of 24 (excellent water quality, see Fig 1), this was an indication that the sample had low levels of pollution, if at all. The water samples from Bison pond were statistically different from the Des Plaines River and Salt creek (Kruskal-Wallis ANOVA, N = 72, df = 2, P = 0.0030). The water quality of the Des Plaines River ranged from 1 to 12 (Fig. 2). These values correspond to waters that are of poor to fair quality (Fig. 1). Even though it was assumed that this dark brown river had more pollution than its tributary, the Salt creek, more organisms were found by the students in the Des Plaines River samples, although these values were not statistically different between sites (NP_MCBT, P > 0.05). The Salt creek water samples ranged from 1 to 8 (Fig. 2), which are indicative of a poor water quality.

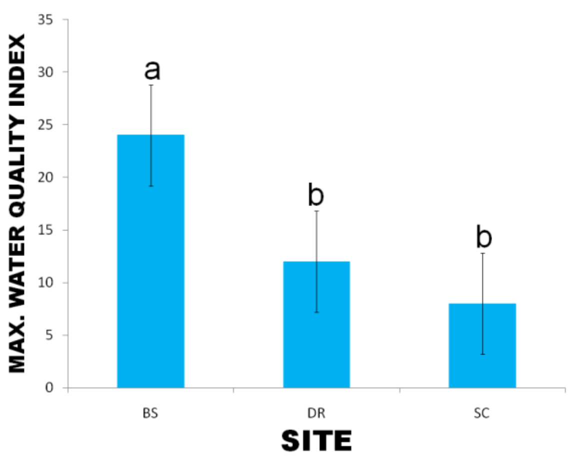

Figure 2: Maximum water quality (± SE) results after student evaluations of macroinvertebrate faunas from water samples with assumed different pollution levels. BP: Bison Pond; DR: Des Plaines River; SC: Salt Creek. Bars with different top letters are significantly different (Kruskal-Wallis ANOVA, N = 72, df = 2, P < 0.05).

Discussion and Implications for Teaching

The objective of this investigation was to promote a semi-guided inquiry activity in the classroom and encourage students to critically think, make their own conjectures, and to go through the inquiry cycle using macroinvertebrates to assess water quality. The original question was: “Is the quality of a water sample with no source of pollution different from samples that have been exposed to chemical run offs and human activity?” Our goal also was to meet the National Science Education Standards that require students to understand the processes of scientific inquiry to “investigate questions, conduct experiments and solve problems” (ILSS 2007). Furthermore, this experience was essential to increase the student's awareness of threats to the community and broadened their perspective on how to identify and deal with environmental problems.

The students found that a water source that is protected from contamination had increased populations of mayflies, caddishflies and stoneflies, corroborating that Bison pond had the highest water quality. In contrast, water samples that were assumed to have pollutants from human activity such as fertilizers from lawns, pet excrements, motor oil and littering were going to be affecting these organisms. Accordingly, other organisms less vulnerable to pollution were going to thrive, such as midges, water fleas, leeches and mosquitoes, which were the macroinvertebrates that the students found in samples from Salt Creek and Des Plaines River.

We are uncertain why the abundance of macroinvertebrates was lower in Salt Creek than in the Des Plaines River because we predicted the opposite pattern. Salt Creek is a tributary of the Des Plains River and its watershed is protected for recreation and land use (NIPC 2004). Therefore, we assumed that pollution should be lower and macroinvertebrates of group 1 and 2 (Fig. 1) would be more abundant here than in the River. The Des Plaines River transforms from a prairie creek to a suburban stream and a large urbanized river, flowing 150 miles through Wisconsin before crossing into Illinois, at which point, it flows northwest of Chicago to become a major industrial waterway (EPA 2004). This information made us assume that the Des Plaines River had higher pollution levels than Salt Creek. Therefore, we hypothesized that organisms from group 3 (Fig 1) were going to be more abundant in these samples than in Salt Creek water samples. Therefore, this experiment would need to be repeated in order to identify if our conclusion always applies.

When the students reflected about the macroinvertebrate abundances in the creek and the river, they wondered if water samples from these two sites were taken at different depths. Scooping water from the top of the river might have affected the efficiency of macroinvertebrate collection because many macroinvertebrates are found in the bottom of the river within sediments or between submerged stones (Feminella and Flynn 1999). This collection procedure might explain discrepancies in our results and expectations. In spite of these discrepancies, our goal was to promote students' reflection and new questioning about the results, continuing the inquiry cycle. Furthermore, students recorded and represented data in charts and graphs, discussed the importance of averages and analyzed data using the calculated indexes to identify the quality of the waters, all of which are actions used in scientific research.

This inquiry-based activity also promoted students' reflections about pollution. After the students were provided with a map of water samples' collections (Appendix A), they realized that it would have been interesting to carry out several trials with different samples along the river. They hypothesized that samples near a golf course (where pollutants from fertilizers and pesticides might be higher) would have lower quality than samples taken at the forest preserve, where pollution might be lower. Reflecting about these possible outcomes increased the student's awareness of threats to the community. They also discussed connections to the real world by considering how to deal with environmental problems. If chemical runoffs were affecting water quality near golf courses, this could be used to promote new legislation for pollution control to fine the culprit (Bajaj 2010, Elks 2010).

The students also postulated other new questions to modify the investigation, such as "What is the water quality on the north part of the river, compared to samples on the south which are near a dam?;" "Will the macroinvertebrates in one place differ if we compare collections in the spring to those in the summer?"

Suggestions and further applications

- Let the students investigate on the web about macroinvertebrates: The types of macroinvertebrates expected in waters with different pollution levels, the role of macroinvertebrates in their ecosystems, their habitat needs, their tolerance to pollution levels, what do they eat? Are they carnivores, or herbivores? By investigating about these organisms on the web, students will realize the type of pre-research activities that scientists need to do for their investigations. In addition, students will get familiar with the animals that they might encounter, get excited when they find them, and make a connection between macroinvertebrates and aquatic food webs.

- As an alternative, use a monitor connected to a microscope to let students view the discoveries of other students or your pre-prepared Petri dishes with macroinvertebrates. Students will have visualization of what was to be found in their samples if they are unable to find macroinvertebrates in their water aliquot sample.

Conclusions

Studying and discussing the quality of waters using macroinvertebrates is a quick and fun way to encourage students' interest in scientific discovery. It is also a way to fill in the gap between the formal education system and the students' real life, bringing perspective into how to identify environmental problems and insight into how to deal with them and take action. Incorporation of inquiry-based classes in the curriculum is the key to promote students' critical thinking and habits of mind, to empower them to become independent and life-long learners, to teach them to confront problems, to generate and test ideas for themselves, and to question everyday values and their understanding of the world. We hope that you and your students will find exploring the aquatic macoinvertebrate fauna as exciting as we do.

Acknowledgements

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Appendix A

Detailed map of the Des Plaines River, Bison Pond and Salt Creek sampling locations. Students' reflections included sampling the Des Plaines River near the Riverside Golf Club (where chemical runoffs from fertilizer and pesticides might be higher than at other sites, ★) and the Cook County Forest Preserve (where pollutants are assumed to be lower, ★).