EDITORIAL & GOVERNANCE INFORMATION..........................2

ARTICLES ................................................................................3

A Field Investigation into the Effects of Anthropogenic Disturbances on Biodiversity and Alien Invasions of Plant Communities........................................................................................................3
   Michael J. Wise

INNOVATIONS .........................................................................15

Engaging Non-Science Majors by Integrating Biology and The Liberal Arts .................................................................15
   Donna M. Bozzone and Mary Beth Doyle

Using a Thyroid Case Study and Error Plausibility to Introduce Basic Lab Skills .............................................................29
   Samantha Browning, Margaret Urschler, Katherine Meidl, Brenda Peculis, and Mark Milanick

A New Approach in Examining the Influence of Drugs on Pulsation Rates in Blackworms (Lumbriculus variegatus)........38
   Amy B. Ryan and Nancy L Elwess

SUBMISSION GUIDELINES ...........................................................52
Bioscene Editors

Debbie Meuler, Editor-In-Chief,
Department of Natural Sciences
Cardinal Stritch University
6801 N. Yates Rd, Milwaukee, WI 53217
Telephone: 414-410-4136
Email: dameuler@stritch.edu

Robert Yost, Associate Editor, Indiana
University – Purdue University, Indianapolis, IN

Editorial Board
Janice Bonner, Notre Dame of Maryland University
Rebecca Burton, Alverno College
Elijah Carter, Syracuse University
Melissa Daggett, Missouri Western State Univ.
Jamie Dyer, Rockhurst University
Melissa Elsenpeter, Rockhurst University
Greg Fitch, Avila University
Marvin Furches, Lincoln Memorial University
Anjali Gray, Lourdes University
Neil Haave, University of Alberta
Barbara Hass Jacobus, Indiana University – Purdue University
Wendy Heck Grillo, North Carolina Central University
Luke Jacobus, Indiana University – Purdue University
Carol Maillet, Brescia University
Irina Makarevitch, Hamline University
Judy Maloney, Marquette University
Marlee Marsh, Columbia College
Dave Matthews, University of Minnesota
Andy Petzold, University of Minnesota
Paul Pickhardt, Lakeland College
Denise Piechnik, Pittsburg
Carol Sanders, Park University
Denise Slayback-Barry, Indiana University-Purdue University
Chad Scholes, Rockhurst University
Scott Shreve, Brescia University
Natalia Taft, University of Wisconsin Parkside
Conrad Toepfer, Brescia University
Aggy Vanderpool, Lincoln Memorial University
Kristen Walton, Missouri Western State University
Jason Wiles, Syracuse University

ACUBE Mission Statement

Members of ACUBE share ideas and address the unique challenges of balancing teaching, research, advising, administration, and service.

We are a supporting and mentoring community that provides professional development opportunities to:

- Develop and recognize excellence in teaching;
- Incubate new and innovative teaching ideas;
- Involve student research in the biology curriculum;
- Advise and mentor students in and out of the classroom;
- Enhance scholarship through our nationally, peer-reviewed journal, Bioscene.

ACUBE Governance
Rebecca Burton, Alverno College, President
Christina Wills, Rockhurst University, Past-President, Website Editor, Executive Secretary of Membership
Greg Smith, Lakeland College, Executive Secretary of Finance.
Paul Pickhardt, Lakeland College, Executive Secretary
Jason Wiles, Syracuse University, Member
Laurieann Klockow, Marquette University, Member
Holly Nance, College of Coastal Georgia, Member
Khadijah Makky, Marquette University, Member
Jessica Allen, Rockhurst University, Member
Scott Shreve, Lindenwood Univ. Member
Conrad Toepfer, Brescia Univ., Historian
Debbie Meuler, Cardinal Stritch University, ex officio
A Field Investigation into the Effects of Anthropogenic Disturbances on Biodiversity and Alien Invasions of Plant Communities

Michael J. Wise

1Department of Biology, Roanoke College, Salem, VA 24153

Corresponding Author: wise@roanoke.edu

Abstract: The importance of biodiversity to the health of our planet is increasingly being discussed, not only by scientists, but by the public at large. Therefore, an understanding of how human activities are affecting biodiversity is vital for informed participation in society, and thus it is an important topic for liberal arts education. Here, I present the protocol and results for a field activity that I have used in a non-majors’ biology course to investigate the influence of anthropogenic disturbances on plant communities. Students surveyed plant-species abundances in five sites that had experienced a range of disturbance regimes, including protected nature trails, mowed fields, and a ruderal (waste) site. Disturbances had a negative impact on measures of species richness, evenness, and diversity; moreover, disturbances made the plant communities much more susceptible to invasion by alien species. While the approach taken in this study worked very well in my non-majors’ course, it could easily be adapted and refined for use in ecology, conservation, and botany courses for biology majors.

Keywords: biodiversity, conservation, disturbance, evenness, invasive plants, Simpson’s index, species richness

INTRODUCTION

The scientific focus of conservation biology is on principles related to the protection of biological diversity, or “biodiversity.” Biodiversity can be studied on a wide range of scales, from genetic variation among individuals of a species to the diversity of biomes across the globe. A particularly important scale is the community level, or the mixture of individuals of different species that occur together in the same location. The identities and relative abundances of the species within a community define the community’s “structure,” and the co-occurring species plus the abiotic aspects of the location constitute an “ecosystem.” This paper reports on a field study conducted by a non-majors’ biology course in which students measured plant-community structures and investigated how biodiversity was related to anthropogenic activities.

Biodiversity is a central focus of conservation largely because of its influence on the processes needed to maintain ecosystems so that they can provide services necessary for human well-being (Sekercioglu, 2010; Cardinale et al., 2011; Hooper et al., 2012; Liu, 2016; Thom & Seidl, 2016). These ecosystem services include water purification, flood control, pest control, carbon sequestration, decomposition, and pollination. Ecosystems also provide goods to humans, such as food, timber, biofuels, and medicine. More abstractly, biodiversity in ecosystems provides aesthetic, recreational, cultural, and even spiritual value to humans. Because biodiversity affects so many different aspects of our lives, even students with minimal interest in biology can find some reason to care about biodiversity.

Foremost among the factors believed to drive changes in biodiversity are what
ecologists call “disturbances,” which are defined as events that cause abrupt changes in the physical and biotic characteristics of an ecosystem, displacing or killing some or all of the individuals of some species and creating new opportunities for others (Sousa, 1984; Pickett & White, 1985; van der Maarel, 1993). Disturbances can be natural in origin (e.g., winds, floods, fires, waves, ungulate browsing, and pest outbreaks) or anthropogenic (e.g., logging, mining, agriculture, fires, dredging, and pollution). In addition, anthropogenic changes to the environment are increasing the frequency and severity of some natural disturbances, such as hurricanes, floods, and extreme-temperature events (Turner, 2010; Banks et al., 2013; Altman et al., 2016).

The ecological literature abounds with studies investigating the effect of disturbances on the diversity of a wide variety of taxa, including bacteria (Galand et al., 2016), insects (Yujie & Jindong, 2015), mollusks (Armenteros et al., 2016), fish (Partasasmita et al., 2015), plankton (De Backer et al., 2014), and plants in all sorts of environments (Radford, 2013; Clarke et al., 2015; Nylén & Luoto, 2015; Ripplinger et al., 2015; Baker et al., 2016; Tenzin & Hasenauer, 2016). Interestingly, disturbance seems to be as likely to increase the biodiversity of a community as it is to decrease it. Some of this variation in effects is predicted by the intermediate disturbance hypothesis, which posits that a moderate level of disturbance is necessary to maintain the greatest diversity in a community (Grime, 1973; Connell, 1978). While this hypothesis is still highly cited, many empirical results do not fit its predictions (Fox, 2013). Nevertheless, there is broad consensus that disturbances can have severe negative effects on the biodiversity of communities, and that anthropogenic disturbances can be particularly harmful (Kumar & Ram, 2005; Ripplinger et al., 2015; Tenzin & Hasenauer, 2016). Even so, there is still much to learn about why some disturbance regimes can be beneficial and others detrimental to the biodiversity of a community (Mackey & Currie, 2001; Kershaw & Mallik, 2013).

Disturbances are also believed to be major factors leading communities to be susceptible to colonization by alien (i.e., non-native, non-indigenous, or exotic) species (Larson et al., 2001; Rodgers & Parker, 2003; Paiaro et al., 2007; Eschtruth & Battles, 2009; Torbick et al., 2010). The introduction of alien species, in turn, is one of the most significant factors reducing the biodiversity of communities (Lodge, 1993; Vitousek et al., 1996; Lonsdale, 1999; Cameron et al., 2016). If alien species become so abundant in a community that they force out native species or disrupt the normal functioning of the ecosystem, then they are considered “invasive” species. Invasive species have been found to be responsible for negative impacts on a variety of ecosystems (Ehrenfeld, 2010; Simberloff, 2011), as well as for tremendous economic losses (Pimentel et al., 2005; Marbuah et al., 2014). As is the case for the disturbance-diversity relationship, the nature of the relationship between invasive species and the biodiversity of communities is not always clear-cut (Dukes & Mooney, 1999; Davis et al., 2000; Parker et al., 2006; van Kleunen et al., 2010; Bennett et al., 2011; Radford, 2013).

The field study described in this paper examined the relationships among biodiversity, disturbance, and invasive species. The study included plant communities in five fields covering a range of disturbance regimes. This study served as a final project for a non-majors’ course in global-change biology, and it comprised four main learning outcomes: At the end of the project, students should be able to 1) communicate the importance of biodiversity; 2) explain the connections between biodiversity, disturbance, and invasive species; 3) demonstrate proficiency using the scientific method to address an important question in conservation biology; and 4) use
Excel to calculate a variety of diversity-related metrics and construct graphs. Achievement of these learning outcomes was assessed through a comprehensive lab report, which was written in a standard style for a journal article in ecology. In their papers, students were required to include the following components: 1) introduction of the questions and hypotheses addressed in the study, citing relevant articles; 2) clear explanation of the methods; 3) correct analysis of data; 4) professional-quality graphs; and 5) clear interpretation and communication of the results and their broader implications.

METHODS

The field activity described in this paper was designed for the course INQ 250: Biology on a Changing Planet. This is a non-science majors’ course in the general education, or “Inquiry,” curriculum at Roanoke College, a selective liberal arts college of ~2000 students in Salem, VA, USA. The focus of the course was how technological innovations and environmental changes affect humans and non-human life across the globe. The general requirements for an INQ 250 course include a quantitative aspect, reading of scientific literature, and a writing assignment in the format of a scientific study (i.e., a lab report or journal article). The Biology on a Changing Planet section of INQ 250 was taught in the spring semesters of 2011, 2012 and 2014, and each section contained 24 students. The class met for three one-hour “lecture” periods and for one three-hour lab period per week.

My preparation for the activity mainly involved reconnaissance work to locate suitable field sites. These sites had to be close to campus, publicly accessible, and encompass a range of disturbance levels. Each site had to contain a community of plants that were easily counted and could be recognized by non-experts. Mid-April worked well for data-collection in southwestern Virginia, as many of the spring-ephemeral wildflowers were in bloom. With a field guide in hand, I surveyed the sites and made a list of the plant species I found. For simplicity, I did not include grasses, trees, or shrubs. I thus only considered forbs, or broad-leaved, herbaceous angiosperms.

I settled on five field sites within two larger locations near the Roanoke College campus—a public park in Roanoke County (Green Hill Park, or “GHP”) and a Nature Conservancy-owned preserve in Montgomery County (Falls Ridge Preserve, or “FRP”). I chose three sites within ~0.5 km of each other at GHP: 1) a section of a nature trail within but near the edge of a wooded area; 2) an open field that is mowed or hayed approximately bimonthly during the summer and fall; and 3) a waste area that serves as a location for dirt to be used for fills or construction. The soil in the waste area is plowed into new piles annually, which completely removes most of the existing vegetation. I refer to these three sites as “protected,” “mowed,” and “ruderal,” respectively. I chose two sites within ~0.1 km of each other at FRP that were very similar in ecology and disturbance regime to the first two sites at GHP, and I also refer to them as “protected” and “mowed.”

For illustration, I will describe the methods and results from 2012 only. I took half of the class to GHP during our lab meeting on April 10, and the other half of the class to FRP on April 17. Upon reaching a site, I kept the students together as a group to point out the boundaries of the site and discuss the type and frequencies of disturbances the site had undergone. As we stood together, I asked students to look around and point out a plant as they noticed it. A few students were familiar with some plants, so I made sure to give them an opportunity to demonstrate their knowledge before I spoke up. Once we had found and discussed all the species on my list, each student (or pair of students) was assigned to be responsible for one or more plant species.
The students were charged with counting as many individuals of their species as they were able across the site, being careful to stay within the designated boundaries of the site. I used the opportunity to discuss the distinction between a genet (a genetic individual) and a ramet (a physically distinct plant with its own main stem). For example, a patch of ten trillium ramets could be descended from ten different seeds, or they could all be clonal copies of a single genet, originating from a single seed. For the purpose of assessing community-level diversity, we were interested in how many stems of a species occupied the space. Therefore, we defined an individual plant as a separate main stem, and thus students counted ramets irrespective of genets.

Once all species were assigned, students were released simultaneously to count their plants as quickly, but carefully, as they could. During the counting period, I circulated among students to answer questions and help with identifications. I stopped the counting period once students began to exhaust their counting (which ranged from 4-11 minutes per site). This sampling scheme was not intended to provide a precise count of the total number of plants. However, assuming the students worked with comparable diligence, the data should represent reliable estimates of the relative numbers of individual plants for each species (Appendix 1).

All of the analyses were performed using Excel. We met in a computer lab during class so that I could assist students with the analyses. Students were provided with a spreadsheet with five groups of rows—one group for each site (Figure 1). Within each site was a list of the species’ names and the number of individuals counted. Students first had to calculate the relative abundance for each of the species, which is defined as the proportion of the total number of individuals counted in a site that is made up of each species. (The subscript, \( i \), is used to designate that there is a separate value for each species.)

Students then made rank-abundance graphs, which are used to visualize several aspects of a community’s structure. Within a site, the species are first ranked according to relative abundance, with the most abundant species ranked “1.” Then the relative abundances are graphed (on the y-axis).
against the rankings (on the x-axis). In Excel, a good choice for the “chart” type is “scatter with straight lines and markers.” It is standard for a rank-abundance graph to display the Y-axis on a logarithmic scale, which can be accomplished in Excel by choosing the “logarithmic axis” button on the format axis menu. The default option of “base 10” for the logarithm is most straightforward and easy to explain to students. While students can make separate graphs for each site, they should eventually make a single graph containing separate curves for all the sites (Fig. 2).

The most basic descriptor for community structure is the number of different species present, which is called the species richness \( S \). The species richness for a site can be quickly read from a rank-abundance graph by looking at the rank number on the x-axis that is associated with (i.e., is directly below) the rightmost point on the curve for that site.

While species richness is consistent with our notion of the diversity of a community, it does not tell the whole story. Specifically, richness gives no insight into another fundamental aspect of diversity—how “even” the relative abundances are among species. For instance, consider two communities that each contains 10 different species. The individuals of the first community may be composed of 99.1% members of just one species, and 0.1% of each of the other nine. In contrast, the species in the second community might each make up 10% of the total community. While both communities have the same richness, the second is more diverse because it has a much greater evenness.

Ecologists have devised a variety of diversity metrics that incorporate both richness and evenness. One such metric is the Simpson’s reciprocal index, which can be calculated with the following formula:

\[
1/D = 1 \div \sum_{i=1}^{S} (p_i^2)
\]

Where \( \Sigma \) indicates the sum across all species, \( p_i \) is the proportion of a sample that is made up species \( i \), and \( S \) is species richness. The larger the value of \( 1/D \), the greater the diversity of the community. The Simpson’s reciprocal index can conveniently be calculated from the same spreadsheet as the relative abundances. A column can be added to the right of the \( p_i \) column to calculate the squares of the \( p_i \) values (see Fig. 2).

**Fig. 2.** Rank-abundance graph for plant communities in the five field sites. Filled circles represent native species, and open circles represent alien species.
Column F in Fig. 1). The sum of these squares can be calculated in a cell at the bottom of the column, and the reciprocal of these squares can be calculated in a separate cell. This value is the Simpson’s reciprocal index for the site.

The relative evenness of different communities can be observed on a rank-abundance graph, where a steeper slope generally indicates a lower relative evenness. The evenness ($E$) can also be quantified by factoring the richness component out of the diversity index. Specifically, a community’s evenness is calculated by dividing the Simpson’s reciprocal index by species richness: $E = 1/(DS)$. (See Cell F16 in Fig. 1.)

A final goal was to quantify the relative influence of alien species on the plant communities. Rather than just counting the number of alien species present, I desired a metric that gave a better sense of the proportion of the total community made up by alien individuals. Two additional columns were required in the Excel spreadsheet. Cells in the first column simply indicate whether the species was “Alien” or “Native” (Column H in Fig. 1). If a species was alien, then the relative abundance of the species would be copied into the next column (Column I in Fig. 1). The sum of the values in the second column was called the “alien index,” and it could range from 0 if there were no alien species in the community, to 1 if every individual plant was of an alien species.

### RESULTS AND DISCUSSION

Students counted 4776 individual plants representing 49 different species (Appendix 1). The species richness of the forb communities varied more than threefold across the five sites, from a low of 6 in the GHP mowed site to a high of 22 in the FRP protected site (Fig. 2; Table 1). Disturbance had a negative effect on species richness, with the two low-disturbance, protected sites having the greatest richness, and the two mowed sites having the lowest richness. While the ruderal site at GHP had the most severe disturbance, this site had an intermediate richness value—closer to the protected than the mowed site at GHP. Notably, the complete clearing of the land in the ruderal site opened up opportunities for many species that were good dispersers to colonize the site. In contrast, the more-frequent but less-severe disturbance of mowing encouraged the establishment of competitive grass species, leaving less open space for colonization by forb species.

Disturbance had a less-consistent effect on species evenness of the forb communities. Nevertheless, the community with the lowest evenness was at a mowed site, and the community with the highest evenness was at a protected site (Table 1). These patterns can be seen on the rank-abundance graph, as the GHP mowed site had the curve with the steepest slope, and the GHP protected site had the curve with the most-gentle slope (Fig. 2). Low values of evenness are generally associated with community structure being dominated by one or a small number of species. For

<table>
<thead>
<tr>
<th>Field Site</th>
<th>Species Richness</th>
<th>Species Evenness</th>
<th>Simpson’s Recip. Ind.</th>
<th>Alien Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHP Protected</td>
<td>17</td>
<td>0.43</td>
<td>7.25</td>
<td>0.14</td>
</tr>
<tr>
<td>GHP Mowed</td>
<td>6</td>
<td>0.30</td>
<td>1.79</td>
<td>1.00</td>
</tr>
<tr>
<td>GHP Ruderal</td>
<td>15</td>
<td>0.37</td>
<td>5.51</td>
<td>0.81</td>
</tr>
<tr>
<td>FRP Protected</td>
<td>22</td>
<td>0.34</td>
<td>7.56</td>
<td>0.33</td>
</tr>
<tr>
<td>FRP Mowed</td>
<td>10</td>
<td>0.36</td>
<td>3.63</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Table 1: Summary of biodiversity metrics for the five sites at Green Hill Park (GHP) and Falls Ridge Preserve (FRP).
instance, the GHP mowed site was dominated by common buttercup, which made up 73% of the total number of individuals of forbs (Appendix 1). In contrast, the most abundant species in the GHP protected site (large-flowered trillium) made up just 23% of the total number of individual forbs.

The Simpson’s reciprocal index gives a more complete story of diversity because it incorporates both richness and evenness. The two protected sites had similarly high diversity indices ($1/D > 7.0$), while the two mowed sites had much lower diversity indices ($1/D = 1.8$ and 3.6). The ruderal site had an intermediate diversity index of 5.5 (Table 1).

The effects of disturbance on invasibility were even more striking. In particular, 16 of the 17 forb species in the protected site at GHP were native, and 19 of the 22 forb species at the protected site at FRP were native (Appendix 1). In contrast, all six of the forb species in the mowed site at GHP were alien, eight of the 11 forb species in the mowed site at FRP were alien, and 12 of the 15 species in the ruderal site at GHP were alien. Thus disturbance, regardless of the frequency or severity, seemed to open up a site to colonization by non-native species.

Moreover, some of the alien species tended to be inordinately abundant, as reflected in the alien-indices. In the ruderal and the two mowed sites, respectively, 81%, 63%, and 100% of the individual ramets were of alien species (Table 1). It was quite clear that disturbance made the sites more susceptible to invasive alien species, including white clover, winter cress, common buttercup, spring vetch, and common plantain. The low-disturbance sites were not immune to invasive species, however, with purple dead-nettle and stinging nettle combining to make up ~30% of the individuals in the FRP protected site, and garlic mustard making up ~14% of the individuals in the GHP protected site (Appendix 1).

The effect of disturbance on biodiversity is very much scale-dependent (van der Maarel, 1993; Hamer & Hill, 2000; Woods et al., 2016). Specifically, at the within-site scale in this study, disturbance had a negative impact on plant-community diversity. However, if one looks at a larger scale, then disturbance can be interpreted to have increased plant-community diversity. For example, consider what the forb community would look like if the entire land area of Green Hill Park had been left undisturbed. The community composition for the whole park would likely be very similar to what was found in just the protected site. Different disturbance regimes created more habitat types and new niches that could be filled by a wider variety of species. Thus, an important lesson is that disturbance can have one effect on biodiversity when considered on a local scale, and an opposite effect when considered on a regional scale. Whether disturbance is “good” or “bad” for conservation is largely determined by the perspective and goals of the observer.

CONCLUSION

All factors considered, this field activity was a resounding success. I believe that the feature that most contributed to the success was the method used to collect field data. Although our quick-and-dirty counting method did not provide the most precise data, I am confident that the results were representative of reality. Moreover, the results were interpretable by the students, who were thus able to tell a coherent and compelling story in their reports. Because we used real-world data, the results were not trivial or obvious in advance—a feature that increased the students’ interest in their data. Furthermore, the students seemed to have a lot of fun with the activity. Rather than the tedium often associated with data collection, the technique we used came across more like a scavenger hunt. Most of the students enjoyed a chance to spend the lab outside, and several seemed to appreciate learning to
identify some flowering plants—a skill that they will be able to build upon and show off long after the end of this course.

Although this activity worked very well as the final lab project for a spring-semester course in southwestern Virginia, it might be problematic for use in more northern areas, where not many plants will be in flower until after the spring semester ends. However, the activity should be easily adaptable for a course in May or June. I expect it would work in the fall as long as data are collected early in the semester. Certainly, the set of plant species will be different, but plenty of species flower in autumn. Furthermore, earlier-flowering species may still be identifiable from their fruits or leaves.

While this activity was designed for a non-science majors’ course, it could be refined for upper-level biology courses. For instance, an ecology class might be interested in employing more-precise sampling techniques (e.g., quadrats or transects), including more quantitative measures (e.g., Sorensen’s coefficient of community, percent similarity, and gamma diversity), and analyzing data with statistical tests. A conservation-biology class might be interested in a wider range of disturbance regimes, including looking at restoration sites. Students in a field botany class could be given more autonomy by choosing their own sites and doing their own plant identifications.

ACKNOWLEDGEMENTS
I thank the students of Roanoke College who participated in collecting data, and the Biology Department for support during the writing of this paper.

REFERENCES


**Appendix 1. Summary of plant counts for the five field sites.** The counts were numbers of individual ramets (or separate stems) of plant species found at the sites within a specified timeframe.

### Green Hill Park - Protected Site

(1773 individuals counted in 7 minutes)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Common Name</th>
<th>Status</th>
<th>Count</th>
<th>Relative Abund.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usnea perlata</td>
<td>perlulate bellwort</td>
<td>native</td>
<td>7</td>
<td>0.65%</td>
</tr>
<tr>
<td>Polygonatum biflorum</td>
<td>Solomon’s seal</td>
<td>native</td>
<td>11</td>
<td>1.02%</td>
</tr>
<tr>
<td>Trillium grandiflorum</td>
<td>large-flowered trillium</td>
<td>native</td>
<td>252</td>
<td>23.44%</td>
</tr>
<tr>
<td>Asarum canadense</td>
<td>wild ginger</td>
<td>native</td>
<td>18</td>
<td>1.67%</td>
</tr>
<tr>
<td>Caulophyllum thalictroides</td>
<td>blue cohosh</td>
<td>native</td>
<td>9</td>
<td>0.84%</td>
</tr>
<tr>
<td>Jeffersonia dubia</td>
<td>parryi</td>
<td>native</td>
<td>20</td>
<td>1.86%</td>
</tr>
<tr>
<td>Podophyllum peltatum</td>
<td>may-apple</td>
<td>native</td>
<td>211</td>
<td>19.63%</td>
</tr>
<tr>
<td>Saxifraga canadensis</td>
<td>bloodroot</td>
<td>native</td>
<td>88</td>
<td>8.19%</td>
</tr>
<tr>
<td>Alliaria officinalis</td>
<td>garlic mustard</td>
<td>alien</td>
<td>146</td>
<td>13.58%</td>
</tr>
<tr>
<td>Dentaria buchtiana</td>
<td>cut-leaved toothwort</td>
<td>native</td>
<td>11</td>
<td>1.02%</td>
</tr>
<tr>
<td>Fragaria virginiana</td>
<td>common strawberry</td>
<td>native</td>
<td>30</td>
<td>2.79%</td>
</tr>
<tr>
<td>Thalictrum advenum</td>
<td>goldilocks</td>
<td>native</td>
<td>6</td>
<td>0.66%</td>
</tr>
<tr>
<td>Viola papilionacea</td>
<td>common blue violet</td>
<td>native</td>
<td>100</td>
<td>9.26%</td>
</tr>
<tr>
<td>Viola canadensis</td>
<td>Canada violet</td>
<td>native</td>
<td>70</td>
<td>6.51%</td>
</tr>
<tr>
<td>Osmorhiza longifolia</td>
<td>spice-root</td>
<td>native</td>
<td>72</td>
<td>6.70%</td>
</tr>
<tr>
<td>Galium aparine</td>
<td>cleavers</td>
<td>native</td>
<td>13</td>
<td>1.21%</td>
</tr>
<tr>
<td>Erigeron pulchellus</td>
<td>robin’s plantain</td>
<td>native</td>
<td>11</td>
<td>1.02%</td>
</tr>
</tbody>
</table>

### Fols Ridge Preserve - Protected Site

(827 individuals counted in 8 minutes)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Common Name</th>
<th>Status</th>
<th>Count</th>
<th>Relative Abund.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anicema triphylla</td>
<td>jack-in-the-pulpit</td>
<td>native</td>
<td>38</td>
<td>2.09%</td>
</tr>
<tr>
<td>Smilacina racemosa</td>
<td>Solomon’s plume</td>
<td>native</td>
<td>3</td>
<td>0.17%</td>
</tr>
<tr>
<td>Trillium grandiflorum</td>
<td>large-flowered trillium</td>
<td>native</td>
<td>25</td>
<td>1.38%</td>
</tr>
<tr>
<td>Urtica dioica</td>
<td>stinging nettle</td>
<td>alien</td>
<td>111</td>
<td>6.27%</td>
</tr>
<tr>
<td>Acantholimon nutans</td>
<td>kidneyleaf buttercup</td>
<td>native</td>
<td>10</td>
<td>0.55%</td>
</tr>
<tr>
<td>Thalidium dicroicum</td>
<td>early meadow rue</td>
<td>native</td>
<td>8</td>
<td>0.44%</td>
</tr>
<tr>
<td>Aquilegia canadensis</td>
<td>columbine</td>
<td>native</td>
<td>24</td>
<td>1.22%</td>
</tr>
<tr>
<td>Actaea pachypoda</td>
<td>white baneberry</td>
<td>native</td>
<td>124</td>
<td>6.28%</td>
</tr>
<tr>
<td>Jeffersonia dubia</td>
<td>twinleaf</td>
<td>native</td>
<td>30</td>
<td>1.63%</td>
</tr>
<tr>
<td>Corydalis inflata</td>
<td>yellow corydalis</td>
<td>native</td>
<td>31</td>
<td>1.52%</td>
</tr>
<tr>
<td>Dentaria buchtiana</td>
<td>cut-leaved toothwort</td>
<td>native</td>
<td>77</td>
<td>4.24%</td>
</tr>
<tr>
<td>Viola dafila</td>
<td>medwort</td>
<td>native</td>
<td>47</td>
<td>2.59%</td>
</tr>
<tr>
<td>Viola papilionacea</td>
<td>common blue violet</td>
<td>native</td>
<td>42</td>
<td>2.31%</td>
</tr>
<tr>
<td>Viola parietata</td>
<td>pale violet</td>
<td>native</td>
<td>417</td>
<td>22.65%</td>
</tr>
<tr>
<td>Galium aparine</td>
<td>cleavers</td>
<td>native</td>
<td>32</td>
<td>1.76%</td>
</tr>
<tr>
<td>Solanum gigantea</td>
<td>late goldenrod</td>
<td>native</td>
<td>46</td>
<td>2.35%</td>
</tr>
<tr>
<td>Actinemia sternifolia</td>
<td>wingstem</td>
<td>native</td>
<td>25</td>
<td>1.38%</td>
</tr>
</tbody>
</table>

### Green Hill Park - Mowed Site

(760 individuals counted in 4 minutes)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Common Name</th>
<th>Status</th>
<th>Count</th>
<th>Relative Abund.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sparganium rubra</td>
<td>sand spurry</td>
<td>alien</td>
<td>55</td>
<td>7.79%</td>
</tr>
<tr>
<td>Arenaria serpyllifolia</td>
<td>thyme-leaved sandwort</td>
<td>alien</td>
<td>2</td>
<td>0.28%</td>
</tr>
<tr>
<td>Ranunculus arceus</td>
<td>tall buttercup</td>
<td>alien</td>
<td>516</td>
<td>73.09%</td>
</tr>
<tr>
<td>Viola zulva</td>
<td>spring vetch</td>
<td>alien</td>
<td>73</td>
<td>11.05%</td>
</tr>
<tr>
<td>Veronica serpyllifolia</td>
<td>thyme-leaved speedwell</td>
<td>alien</td>
<td>4</td>
<td>0.57%</td>
</tr>
<tr>
<td>Plantago major</td>
<td>common plantain</td>
<td>alien</td>
<td>51</td>
<td>7.21%</td>
</tr>
</tbody>
</table>

### Fols Ridge Preserve - Mowed Site

(1342 individuals counted in 8 minutes)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Common Name</th>
<th>Status</th>
<th>Count</th>
<th>Relative Abund.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arenaria serpyllifolia</td>
<td>thyme-leaved sandwort</td>
<td>alien</td>
<td>52</td>
<td>3.87%</td>
</tr>
<tr>
<td>Ranunculus arceus</td>
<td>tall buttercup</td>
<td>alien</td>
<td>10</td>
<td>0.76%</td>
</tr>
<tr>
<td>Solanum gigantea</td>
<td>late goldenrod</td>
<td>alien</td>
<td>490</td>
<td>36.51%</td>
</tr>
<tr>
<td>Melilotus officinalis</td>
<td>yellow sweet cover</td>
<td>alien</td>
<td>85</td>
<td>6.41%</td>
</tr>
<tr>
<td>Gladiolus hederacea</td>
<td>ground ivy</td>
<td>alien</td>
<td>52</td>
<td>3.87%</td>
</tr>
<tr>
<td>Plantago major</td>
<td>common plantain</td>
<td>alien</td>
<td>141</td>
<td>10.51%</td>
</tr>
<tr>
<td>Silene lyra</td>
<td>lyreleaf sage</td>
<td>native</td>
<td>472</td>
<td>35.17%</td>
</tr>
<tr>
<td>Erigeron philadelphicus</td>
<td>common tansieabane</td>
<td>native</td>
<td>26</td>
<td>1.94%</td>
</tr>
<tr>
<td>Taraxacum officinale</td>
<td>common dandelion</td>
<td>alien</td>
<td>11</td>
<td>0.82%</td>
</tr>
</tbody>
</table>

### Green Hill Park - Rudeal Site

(836 individuals counted in 10 minutes)

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Common Name</th>
<th>Status</th>
<th>Count</th>
<th>Relative Abund.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kauera crusas</td>
<td>curled dock</td>
<td>alien</td>
<td>6</td>
<td>0.71%</td>
</tr>
<tr>
<td>Physalis americana</td>
<td>pokeweed</td>
<td>native</td>
<td>20</td>
<td>2.59%</td>
</tr>
<tr>
<td>Ranunculus arceus</td>
<td>tall buttercup</td>
<td>alien</td>
<td>1</td>
<td>0.12%</td>
</tr>
<tr>
<td>Alliaria officinalis</td>
<td>garlic mustard</td>
<td>alien</td>
<td>56</td>
<td>7.58%</td>
</tr>
<tr>
<td>Brassica nigra</td>
<td>field mustard</td>
<td>alien</td>
<td>2</td>
<td>0.24%</td>
</tr>
<tr>
<td>Barbarea vulgaris</td>
<td>early winter cress</td>
<td>alien</td>
<td>50</td>
<td>6.06%</td>
</tr>
<tr>
<td>Barbarea vulgaris</td>
<td>winter cress</td>
<td>alien</td>
<td>350</td>
<td>35.89%</td>
</tr>
<tr>
<td>Viola zulva</td>
<td>spring vetch</td>
<td>alien</td>
<td>63</td>
<td>7.75%</td>
</tr>
<tr>
<td>Asclepias syriaca</td>
<td>common milkweed</td>
<td>native</td>
<td>12</td>
<td>1.44%</td>
</tr>
<tr>
<td>Glechoma hederacea</td>
<td>ground ivy</td>
<td>alien</td>
<td>14</td>
<td>1.67%</td>
</tr>
<tr>
<td>Lamium purpureum</td>
<td>purple dead nettle</td>
<td>alien</td>
<td>79</td>
<td>9.56%</td>
</tr>
<tr>
<td>Datura stramonium</td>
<td>jimsonweed</td>
<td>alien</td>
<td>22</td>
<td>2.61%</td>
</tr>
<tr>
<td>Veronica serpyllifolia</td>
<td>thyme-leaved speedwell</td>
<td>alien</td>
<td>51</td>
<td>6.17%</td>
</tr>
<tr>
<td>Solidago gigantea</td>
<td>late goldenrod</td>
<td>native</td>
<td>125</td>
<td>14.85%</td>
</tr>
<tr>
<td>Taraxacum officinale</td>
<td>common dandelion</td>
<td>alien</td>
<td>15</td>
<td>1.87%</td>
</tr>
</tbody>
</table>
INNOVATIONS

Engaging Non-Science Majors by Integrating Biology and the Liberal Arts

Donna M. Bozzone\textsuperscript{1*} and Mary Beth Doyle\textsuperscript{2}

Department of Biology\textsuperscript{1}, Department of Education\textsuperscript{2}
Saint Michael’s College, 1 Winooski Park, Colchester, Vermont, 05439

*Corresponding Author: dbozzone@smcvt.edu

Abstract: We describe a pair of fully integrated courses designed to teach biology to non-majors in a manner that connects authentically to the liberal arts. The co-taught courses were organized around the question: What does it mean to be human? Students investigated this question in the context of three topics: dis/ability, race, and sex and gender. In addition, a lab program was integrated in the courses to enhance student understanding of the scientific process and to underscore the necessity of evidence to support all claims and assertions. We also implemented a weekly afterschool science club with children from the Pomerleau Boys and Girls Club. Students, many of whom were science averse prior to taking these courses, thrived. Based on the quality of their writing and class discussion, it was clear that students became increasingly adept at connecting biology to other ways of knowing and to larger issues in their lives. Similarly, they became more skillful at “doing” science in laboratory. Not only did students design and implement interesting experiments, they effectively guided children in their own explorations.

Key Words: co-taught, multidisciplinary, non-major, disability, race, sex and gender

INTRODUCTION

We describe a co-taught, multidisciplinary, integrated pair of courses that invited non-science majors to explore biology in the context of a broad view of the liberal arts. We are convinced that everyone should have a basic understanding of biology and the process of science to function as fully engaged members of society (Holt, 2006).

We designed our integrated courses with non-science majors in mind. As Tobias (1990) characterized in her germinal work, students who do not major in science “are not dumb, they’re different.” While the focus of her research was to explore how to make the study of science and pursuit of scientific careers more welcoming to a wider swath of students, one can also look at her work in the context of non-science majors who take a science course in order to fulfill a general education requirement or who simply choose to take one because of interest alone. According to Tobias (1990), non-science majors who seriously audited introductory chemistry or physics generally did well in the courses but expressed feeling a lack of engagement in their classroom community. In addition, they wished they had learned more about the connections between science and significant social issues and questions. We recognized that our courses needed to be taught differently than what might be the case for biology majors (Knight and Smith, 2010). The difference in instruction was not a relinquishment of rigor, but rather an acknowledgment that non-majors’ biology courses are discrete; there is no expectation that additional biology courses will be taken. In contrast, an introductory biology sequence designed
for majors is intended to be the first in a series of courses (Wright, 2005).

We took seriously the need to connect the biology content to broader concerns in meaningful ways (Gilbert & Fausto-Sterling, 2003). One of our goals was to foster an appreciation that biology is a central aspect of modern life. We are convinced that the integration of knowledge—within biology and among the natural sciences, social sciences, humanities, and the arts—is essential for meeting the challenges we all face (Orzel, 2015).

Most students who graduate from college are not science majors; thus, non-majors are the principal pipeline of college graduates entering society (Korn, 2015). In fact, they will be the majority of individuals with the potential to play important roles in helping to find solutions to the problems we must confront such as climate change, emerging diseases, overpopulation, and biodiversity.

Non-science major courses, therefore, serve to prepare better informed citizens rather than to produce professional scientists. Science represents one way of asking questions and evaluating the answers; it is not the only one. Nevertheless, the manner in which scientists explore and learn about the natural world is powerful and effective. Moreover, as a way of thinking, it is a successful approach for many questions, not just scientific ones (Bozzone & Green, 2013).

The primary objective of our integrated courses was to highlight the connections and interdependence among biology, the process of science, and different ways of knowing. We reasoned that understanding biology well insists upon a consideration of the ways that biology connects to the larger culture. In addition, we assert that understanding our culture fully requires familiarity with biology. Indeed, biological research, ideas, and knowledge anastomose with global issues, ethics, and social responsibility (Bozzone & Green, 2013; Fausto-Sterling, 2003). Our aspiration was to teach non-science majors about biology in a manner that will resonate meaningfully in their lives (Pain, 2010). The main goal of this paper is to provide instructors with a potential pedagogical approach to help them capture more fully the interests of their non-science major students.

METHODS
Course Design and Implementation

At Saint Michael’s College, a full-time course load is the equivalent of 16 credits per semester. Courses are typically four credits; therefore, full-time students take 4 courses per term. All students are required to take a First-Year Seminar and a lab science course as part of their general education. The course described in this paper is a fully integrated combination of First Year Seminar (4 credits) and Biology Lab Science (4 credits). It is important to note that while the courses are integrated both in their design and implementation, students earn two separate grades. The individual grades are linked to objectives and assignments that are specific to the individual courses. This division was necessary in order to align with the traditional college structure related to student assessment and transcript records.

Each individual class met twice per week for 95 minutes. The two courses were scheduled to meet consecutively in the same classroom equaling total class meetings of two continuous 190 minute sessions per week. Given the structure of the course, the lab was integrated within the meetings. We had the opportunity to teach the entire course in a laboratory that was also suitable for discussion. Consequently, we were able to weave laboratory investigations into every class meeting.

As we designed the course, we had several specific teaching objectives in mind. First, we chose to help students enhance their understanding of the process of science. In order to do so, we explored topics using an inquiry-based approach. In addition, students engaged in hands-on discovery and investigation in laboratory. Second, we were determined for students to
have the opportunity to enhance their appreciation of the human dimension of science (Chamany, et al., 2008). We wanted them to appreciate that everything ever discovered or solved is literally the result of a person or many people thinking that the question being pursued was the most interesting and important thing to be found. They simply had to work on this problem—it was like an itch that had to be scratched. We wanted students to feel the emotional connection that people can have with learning and discovery, and hopefully to experience it themselves (Olitsky & Milne, 2012). And third, we wished to emphasize and have students understand that the integration of knowledge not simply within biology, but also among the sciences and the liberal arts in general, is essential in the world of the 21st century (Bozzone & Green, 2013).

To achieve these objectives, the course focused on the question: What does it mean to be human? More specifically, is humanness a socially constructed entity, is it biologically determined, or an emergent property that is a consequence of both? We taught students how to examine these questions through a lens of determinism versus one of potential. Determinism is a perspective that focuses on limits. If something is determined, there is no altering the fate or outcome. Many students think, incorrectly, that biology operates this way. In contrast, looking at a situation from the stance of potential means fewer limits. Consider this example: Suppose a person was born with all of the biological risk factors in place for becoming an alcoholic. Some might see this person as doomed to abuse alcohol because they are biologically determined to do so. But what if this person was an observant Mormon and therefore never drank alcohol? They would never abuse alcohol. So, to be more accurate, this person had the potential to be a substance abuser, they were not determined to be so.

We recognized that while considering a problem with a reductionist set of tools is powerful, it does not provide the whole picture; we designed and taught the course accordingly. Similarly, examination of a question like the meaning of humanness from a singular vantage point (e.g. biology, sociology, history) is insufficient. Instead, we privileged attention to the interactions of life science, social science, and humanities in the exploration of this question.

We designed three specific topic units to animate our exploration of the questions about being human: dis/ability; race; and sex and gender. For each unit, students were assigned a book length narrative to ground our investigations in the experiences of actual lives (Appendix 1). In addition, students read and discussed historical narratives to answer the questions: “What did learned people once think about this issue? Why? What did these learned people once think were facts?” Students examined these questions from both social and biological perspectives.

Next, students read and discussed current accounts of what learned people “know”. Within this framework, students explored both the sociological and biological explanations of our time. Once again, we prompted students to consider the intersections of schools of thought therein making explicit connections between potential versus deterministic argumentation.

Finally, having learned from historical and modern narratives, students were challenged to answer the questions: “Is there a biological basis to the characteristics we are considering? Whether or not there is, how does the characteristic influence the human experience? Can you imagine how learned people in the future might consider these questions? What are you left wondering about? What part of your answers are you confident in versus what is provisional?”

**Biological Concepts**

Students were introduced to specific biological concepts at appropriate junctures. From our perspectives, student
understanding of biological topics was foundational for a substantive examination and analysis of the big question of what it means to be human, as well as the particular topics of each course unit. To have a multidimensional understanding of Down syndrome, the specific dis/ability upon which we focused in the first topic unit, students needed to learn about cells, inheritance, meiosis, mutation, information transfer from DNA to protein, how phenotypes arise, and human development. We returned to many of these concepts in our Race, as well as Sex and Gender units, thus reinforcing understanding and comfort with these biological topics. The Race unit also warranted consideration of evolution, as well as a direct look at whether there is a biological basis to race at all. The Sex and Gender unit invited an examination of sexual development, gene expression, and how hormones elicit biological responses.

Biological concepts (Table 1) were woven into the course by a series of mini-lectures, hands-on activities, simulations, directed readings, and writing assignments. For example, in our consideration of Down syndrome, students were provided direct instruction about typical and atypical meiosis. These concepts were reinforced

<table>
<thead>
<tr>
<th>Table 1. Examples of Biology and Science Concepts Integrated in the Course</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foundational Unit</strong></td>
</tr>
<tr>
<td>• Process of science</td>
</tr>
<tr>
<td>• Biological determinism</td>
</tr>
<tr>
<td>• Biological potential</td>
</tr>
<tr>
<td>• Evolutionary contribution to social behavior in humans</td>
</tr>
<tr>
<td>• Eugenics</td>
</tr>
<tr>
<td>• Meiosis</td>
</tr>
<tr>
<td>• Inheritance</td>
</tr>
<tr>
<td>• Human embryogenesis</td>
</tr>
<tr>
<td>• Biology of Down syndrome</td>
</tr>
<tr>
<td>• Central dogma</td>
</tr>
<tr>
<td>• Relationship between genes and phenotype</td>
</tr>
<tr>
<td><strong>Dis/ability</strong></td>
</tr>
<tr>
<td>• Evolution</td>
</tr>
<tr>
<td>• Human variation</td>
</tr>
<tr>
<td>• Biology of skin color</td>
</tr>
<tr>
<td>• Biology of race</td>
</tr>
<tr>
<td>• Mitosis</td>
</tr>
<tr>
<td>• Cancer</td>
</tr>
<tr>
<td><strong>Race</strong></td>
</tr>
<tr>
<td>• Historical views of women’s bodies and development</td>
</tr>
<tr>
<td>• Sexual development</td>
</tr>
<tr>
<td>• Disorders of or differences in sexual development: Androgen</td>
</tr>
<tr>
<td>- insensitivity syndrome (AIS), Congenital adrenal hyperplasia</td>
</tr>
<tr>
<td>- CAH, Guevedoces (5-alpha reductase deficiency)</td>
</tr>
<tr>
<td>• Sexual orientation</td>
</tr>
<tr>
<td>• Transgender people</td>
</tr>
<tr>
<td>• Sex verification tests in sports</td>
</tr>
</tbody>
</table>
with a hands-on exercise in which students used physical manipulatives (i.e., pipe cleaners) to demonstrate their understanding of this type of cell division. The directed readings in this included the book length narrative (i.e., *The Shape of the Eye*) and specific readings pertaining to biological, medical, and social aspects of Down syndrome (Appendix 1). Examples of student products from this unit included a pamphlet about Down syndrome intended for community outreach and a poster presentation (Table 2). This biological knowledge formed a significant and essential component of our working vocabulary providing us with a common language.

**Laboratory Program**

The best way to learn about the process of science authentically is to actually “do” it. Given our emphasis on the power of science to address certain types of questions and its insistence for empirical validation of claims, we designed a lab program, which allowed students to do original investigations, fostered a healthy skepticism, and reinforced the practice of providing evidence to support assertions (Table 3). This habit of thought served as an anchor for the entire course as it helped students to ask, when confronting an assertion in the readings (assigned or otherwise), in discussion, or even in conversation—*How do we know this? Is this statement supported by reliable evidence?* By practicing science—making

<table>
<thead>
<tr>
<th>Table 2. Examples of Student Products</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foundational Unit</strong></td>
</tr>
<tr>
<td>- Essay: What does educational research reveal about whether class attendance is important?</td>
</tr>
<tr>
<td>- Essay: What does it mean to “other” someone? On what bases do we other?</td>
</tr>
<tr>
<td>- Essay: Compare and contrast the concepts of biological determinism and biological potential</td>
</tr>
<tr>
<td>- Essay: Reflect on the question of what it means to be “normal”.</td>
</tr>
<tr>
<td><strong>Dis/ability</strong></td>
</tr>
<tr>
<td>- Notebook: Write two chronologies of the events described in <em>The Shape of the Eye</em></td>
</tr>
<tr>
<td>- Pamphlet: What is Down syndrome?</td>
</tr>
<tr>
<td>- Short, reflective essay for every class</td>
</tr>
<tr>
<td><strong>Race</strong></td>
</tr>
<tr>
<td>- Book Club: Prepare for discussion of <em>The Immortal Life of Henrietta Lacks</em></td>
</tr>
<tr>
<td>- Debate: prepare material to debate whether there is a biological basis to race</td>
</tr>
<tr>
<td>- Short, reflective essay for every class</td>
</tr>
<tr>
<td><strong>Sex and Gender</strong></td>
</tr>
<tr>
<td>- Discussion preparation: Lead discussion of specific chapters of <em>Sex/Culture: Biology in a Social World</em></td>
</tr>
<tr>
<td>- Debate: Prepare materials to debate whether sex testing of elite female athletes is necessary for fair competition</td>
</tr>
<tr>
<td>- Short, reflective essay for every class</td>
</tr>
<tr>
<td><strong>Lab Program</strong></td>
</tr>
<tr>
<td>- Lab notebook with all records of experimental work including science fair projects</td>
</tr>
<tr>
<td>- <em>Physarum</em> research poster</td>
</tr>
<tr>
<td>- Sow bug research poster</td>
</tr>
<tr>
<td>- Bess bug research poster</td>
</tr>
<tr>
<td>- Science Fair Poster</td>
</tr>
</tbody>
</table>
observations; wondering; exploring; posing testable questions; formulating hypotheses; implementing studies to test hypotheses; analyzing results; and formulating new questions—students enhanced their capacities to reason analytically.

The laboratory program consisted of four units (Table 3). During the first unit, which was three weeks in length, students explored the growth and development of the plasmodial slime mold *Physarum polycephalum*. We chose *Physarum* as a study organism because it is easy to culture and handle and therefore suitable for novice students (Bozzone, 2005). Moreover, we reasoned that *Physarum* would engender student interest because it displays interesting and easy to measure behaviors such as chemotaxis, phototaxis, and simple problem solving such as avoiding barriers, completing mapping problems, and negotiating mazes (Adamatzky & Jones, 2010; Bohland *et al*., 2011; Nakagaki, *et al*., 2000).

During the first week of the unit, students made observations of *Physarum* and set up basic experiments to address questions about chemotaxis (Bozzone, 2005). The main objective of this work was to introduce students to the process of science. The second week of the unit entailed setting up experiments to address new questions that derived from their initial results. During the third week, students analyzed their data, discussed their findings with the entire class, and prepared a research poster to display their work.

Units two and three of the lab program followed a similar plan: introduction to an organism; simple experimentation to learn how to handle the organism; designing experiments; collecting data; analyzing data; articulating and addressing another experimental question; and presenting the results of their work in the forms of lab reports and posters. For unit two, students explored *Porcellio laevis* (sow bugs) behaviors (Mikula, 2000; Olsson, 2004) and for unit three, *Passalus cornutus* (bess bugs) (Anon, 2016; Gardner, 2005).

**Community Connection**

One important feature of the lab program was our engagement with a community partner, the Pomerleau Boys and Girls Club.
of Burlington, Vermont. We engaged in lab work every class. The first meeting of each week involved the college students undertaking their explorations and experiments. In the second meeting, they were joined by middle school children from the Boys and Girls Club (ages 9-12). This afterschool science program was scheduled to coincide with the Club’s afterschool activities. The ratio of college students to children was 2:1. The rationale for including a community partner was that we wanted our students to reinforce their learning by teaching others, to experience that learning is also about giving not just taking, and to feel the confidence that comes from being an expert.

The culminating event of the lab program was a science fair. Our students mentored the children each of whom completed an original investigation with one of the three experimental systems we studied: Physarum, sow bugs, or bess bugs. The science fair was held at the College. We invited families and friends of the children, as well as staff and administrators from the Boys and Girls Club. In addition, we welcomed students, faculty, and administrators from the College.

**First Year Seminar Objectives**

The First Year Seminar (FYS) program at our college is rooted in the combination of writing and discourse. The topics of the FYS program vary (e.g., Peace and Justice, Robotics, the Examined Life), but the instructional objectives are the same. All sections include an emphasis on writing and the topics studied encourage examination of large questions within an interdisciplinary dimension. The courses require frequent writing, at least twice per week. The writing is both formal and informal.

We used writing as a key tool for teaching and learning (Stockwell, 2016). With respect to the writing process, we had specific goals woven within our integrated FYS/BI course. First, we wanted to enhance students’ abilities to manage the writing process (i.e., prewriting, drafting, feedback, revision, editing, and proofreading) in order to produce finished products. Second, we worked with students to improve their abilities to generate a thesis on their own and to support it with convincing evidence and reasoning in a formal academic essay that has cohesion, coherence, and voice. Third, we taught students how to apply basic research skills (e.g., library research, archival research, construction of thesis).

We taught students how to engage in active reading (e.g., reverse outlining, text to speech software, summarizing) and how to write for different purposes (e.g., review of literature, expository writing, and reflective essays). We assessed learning by evaluating student work at various stages of completion; students generated writing portfolios. The assessment tool used for all written pieces was the College approved writing rubric.

**OUTCOMES**

There were four overarching objectives for this course, which were re-visited for each unit, allowing students to deepen both their content knowledge and ability to engage with complex information. Following are descriptions of each learning objective and the corresponding evidence that students met them.

The first objective was students will generate connections between biology, the liberal arts, and their lived experiences. Because we led with narrative, embedded each topic in an historical context, and intentionally connected the biology to actual lives and the larger world, students became skillful at migrating between various ways of knowing and seeing the bigger, interconnected picture. For example, our considerations of race transformed the views that students had about the biological basis of this human characteristic. They came to understand the fundamental unity of life at the biological level. They made connections between what they learned about cells, cell division, and cancer with the lived experiences of Henrietta Lacks. In doing so,
they saw, for the first time, the inseparable connections between biology and the lived experiences of all people. As one student wrote, “The ways we relate the scientific aspect to the relevant issues in society are insightful and eye opening.” Yet another wrote, “Our in-class discussions were thoughtful and thought provoking and now I understand science and biology in a way that I hadn’t prior to the class.” These quotes were illustrative of the comments on all of the course evaluations. As a matter of fact, students rated this course combination higher than the College mean or either of the authors’ department means, on every parameter. With respect to suggestions for course or instructor(s) improvement, students did not offer any and were unanimous in wishing that there were more courses designed and taught this way.

The second objective was students will demonstrate the process of science and inquiry. While the lab program was the most explicit way in which students met this objective, the type of analysis and reasoning developed therein raised the quality of student writing and discussion. With respect to the lab, students were able to pose testable questions, design and implement experiments to address them, and to analyze and interpret their data. Most important, they were able to generate new questions based upon their results, as demonstrated by novel experiments. Moreover, lab notebooks and final posters were graded for content accuracy, analysis, and presentation. One student wrote, “Throughout this semester, I feel as though I have gotten better (in science) and am able to teach children, even if I did not believe that I was very good at science in high school.”

The third objective was students will write for a variety of audiences and purposes at the college level. Students generated a rich array of writing products including reflective essays, research essays, notes based on reading and research, data tables and figures, posters, and educational pamphlets (Table 2).

The fourth objective was students will engage in community outreach in the form of an after-school science club. Ten children from the Boys and Girls Club participated in a weekly science club led by the college students. Both the children and college students derived benefit from the experience. Children from the Boys and Girls Club had been participating at the College for the four previous years. The activities during that time focused on assistance with homework followed by play. Historically, attendance was inconsistent and periodically the children exhibited behavioral challenges. Since we initiated the science club, the children simply never missed. As one college student observed, “At first I thought they (Club kids) had no interest. However, they clearly progressed and became more involved and engaged… in the beginning it was obvious children were not comfortable, in the end they wanted to do all of it themselves and they were coming up with questions without prompting.” Moreover, because there were a limited number of slots, there was a waiting list for additional children.

The college students took seriously the importance of preparation so that they knew, understood, and practiced the biology concepts and experiments in order to be effective for the children. Furthermore, the science club enhanced the learning experiences of the college students. For example, one student wrote, “Having to use the scientific process in a way to help the kids learn the experiments helped me learn the scientific process to a greater extent.” Another student wrote, “Working with the Club kids has been a great opportunity to pass on my new-found appreciation of science. I was so thrilled by the results of the science fair and the fact that the kids loved showing off their projects.”

CONCLUSION

Our experiences with this integrated course were more successful for both our students and for us than we had imagined.
they could be. We think that the principle reasons for this success were our decisions to focus on the power of narrative and our commitment to co-teaching. In doing so, we observed that students engaged in thoughtful informed discussion. Interestingly, it was the focus on the stories of lived experiences that prompted students to ask substantive questions about biology and the process of science in order to become more informed about the topics within the narratives. Over time, their questions sharpened and became more nuanced and sophisticated. As they moved from unit to unit through the course, they became increasingly skillful at investigating and mastering the biological concepts and foundations pertaining to the topics we were discussing. With reference to the co-teaching, students benefitted from the shared preparation, delivery, and assessment of every unit. Class discussions were enriched markedly because of the two lenses (life science and social science) through which we approached each topic.

It was a surprise to us to see that students were able to achieve analysis and synthesis levels of understanding without engaging in rote memorization. In fact, they demonstrated their capacities to access the content necessary to push the discussions and research further than we had planned. Over time, this was reinforced in our deliberate questioning cycle: How do you know this? What else do you need to know? What would happen if? (Figure 1) What was astounding to us was the impact of this approach on student curiosity and desire to learn.

Also surprising was the impact on us as faculty with a combined tenure of more than 50 years of teaching at the college level. This course combination opened up the opportunity for us to engage in new fields of study, integrate those areas of study into our own territories of expertise, and learn new pedagogical approaches and techniques.

Looking to the future, we will continue to offer this course and investigate the short and long term effects of this approach on student motivation for and attitudes toward studying science (Cook & Mulvihill, 2008; Glynn et al., 2009; Handelsman et al., 2005; Lovelace & Brickman, 2013; Moore & Foy, 1997). Finally, under the auspices of the Center for Teaching and Learning at our college, we have established a faculty discussion group on the topics of cross-disciplinary co-teaching and collaboration in higher education.

![Fig. 1. Questioning Cycle](image)

**ACKNOWLEDGMENTS**

We would like to thank Dottie Dearborn of the Pomerleau Boys and Girls Club of Burlington Vermont for her tireless advocacy for the children and youth of the community.

**REFERENCES**


Appendix 1. Examples of Assigned Readings and Instructional Resources

<table>
<thead>
<tr>
<th>Reading Assignments:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Foundational Unit</td>
<td></td>
</tr>
<tr>
<td>Additional Resources:</td>
<td></td>
</tr>
<tr>
<td>• Association of American Colleges &amp; Universities description of a liberal education: <a href="https://www.aacu.org/leap/what-is-a-liberal-education">https://www.aacu.org/leap/what-is-a-liberal-education</a></td>
<td></td>
</tr>
<tr>
<td>• Rethinking ‘normal’ and ‘abnormal’: <a href="https://www.psychologytoday.com/blog/rethinking-psychology/201111/what-do-we-mean-normal">https://www.psychologytoday.com/blog/rethinking-psychology/201111/what-do-we-mean-normal</a></td>
<td></td>
</tr>
<tr>
<td>Dis/ability</td>
<td></td>
</tr>
<tr>
<td>Reading Assignments:</td>
<td></td>
</tr>
<tr>
<td>Additional Resources:</td>
<td></td>
</tr>
<tr>
<td>Media portrayals of people with Down syndrome:</td>
<td></td>
</tr>
<tr>
<td>• TED Talk: <a href="https://www.youtube.com/watch?v=SxrS7-I_sMQ">https://www.youtube.com/watch?v=SxrS7-I_sMQ</a></td>
<td></td>
</tr>
<tr>
<td>• Down Syndrome: <a href="https://vimeo.com/165816886">https://vimeo.com/165816886</a></td>
<td></td>
</tr>
<tr>
<td>• Down Syndrome: <a href="https://www.popsugar.com/beauty/Model-Down-Syndrome-Beauty-Interview-Video-40985630">https://www.popsugar.com/beauty/Model-Down-Syndrome-Beauty-Interview-Video-40985630</a></td>
<td></td>
</tr>
<tr>
<td>• Down Syndrome: <a href="https://modernmessy.wordpress.com/category/portrayals-of-down-syndrome-in-media/">https://modernmessy.wordpress.com/category/portrayals-of-down-syndrome-in-media/</a></td>
<td></td>
</tr>
</tbody>
</table>
University and Academic site resources:
- Vanderbilt University: https://iris.peabody.vanderbilt.edu/films/
- Otterbein College: http://www.otterbein.edu/public/Library/erin-mckenzie/dedication.aspx
- University of Washington: https://disabilitystudies.washington.edu/
- Cold Spring Harbor Laboratory: http://www.eugenicsarchive.org/eugenics/
- University of Virginia: http://exhibits.hsl.virginia.edu/eugenics/3-buckvbell/

National Organizations:
- National Down Syndrome Society: http://www.ndss.org/About-NDSS/Media-Kit/
- Howard Hughes Medical Institute: http://www.hhmi.org/biointeractive/human-embryonic-development
- Centers for Disease Control: https://www.cdc.gov/ncbddd/birthdefects/downsyndrome/data.htm

Race

Reading Assignments:

Additional Resources:
Media portrayals:
- Henry Louis Gates, Jr.: https://www.youtube.com/watch?v=phcqu8rNZ9Q
- Henry Louis Gates, Jr.: https://www.youtube.com/watch?v=mw43kWEKjn8

University and Academic Resources:
- Howard Hughes Medical Institute: https://www.youtube.com/watch?v=VC0TL_IYlm8
- Science of Skin Color: https://www.youtube.com/watch?v=VC0TL_IYlm8
- Myth of Race: https://www.youtube.com/watch?v=VnfKgffCZ7U
- Patenting Human Gene: https://www.youtube.com/watch?v=r_XV-M0KPo0
- TED Talk: https://www.youtube.com/watch?v=_r4c2NT4naQ

Sex and Gender

Reading Assignments:

Additional Resources:
Media Portrayals:
• Nature vs Nurture: https://www.psychologytoday.com/blog/sexing-the-body/201007/nature-versus-nurture-part-1-it-s-time-withdraw-war
• Sexuality: https://www.psychologytoday.com/blog/sexing-the-body/201111/are-we-born-gay.
• Guevodoes: https://vimeo.com/145344626
Using a Thyroid Case Study and Error Plausibility to Introduce Basic Lab Skills

Samantha Browning, Margaret Urschler, Katherine Meidl, Brenda Peculis and Mark Milanick*

Department of Medical Pharmacology and Physiology, University of Missouri, Columbia MO 65212

*Corresponding Author: milanickm@missouri.edu

Abstract: We describe a 3-hour session that provides students with the opportunity to review basic lab concepts and important techniques using real life scenarios. We began with two separate student-engaged discussions to remind/reinforce some basic concepts in physiology and review calculations with respect to chemical compounds. This was followed by activities designed to have the students examine and identify a wide variety of errors that can be made when taking/prescribing medication. This ultimately led to a discussion of whether a particular error can be considered “significant”. In our (teaching laboratory/medical) context, the term “significant” meant an error or mistake that demands attention, as it is consequential towards the outcome. Hands-on experience of making solutions allowed the students to critically assess and attribute error prone steps to specific techniques including: calculations (including dimensional analysis), weighing out material (accuracy in weighing and the precision limits of the balance) and the role solubility can play in making homogeneous solutions. The pipetting activity gave the students hands on and scenario based opportunities to distinguish between accuracy and precision and to identify sources.

Keywords: thyroid hormone, laboratory skills, laboratory mistakes

INTRODUCTION

Not surprisingly, many studies show that students are more actively engaged in their learning when they see real life examples. Comprehension of abstract concepts is more complete when they can visualize a real life-example of an actual application or that abstraction. For example, a scenario demonstrating the chemistry of recreational drugs helped the students to appreciate the relevance of the science they are learning (Fergus et al., 2015). Popil (2011) has reviewed how real life scenarios that provide information to be analyzed and ask open-ended questions can be used to promote critical thinking.

Currently, many of the STEM enrolled college students in the United States are interested in future careers in the health field. We realized a need for real life scenarios for students in introductory classes that would reinforce abstract concepts that involved health field related issues. Adding one or two laboratory sessions could help the students learn some basic lab techniques while reinforcing the fundamental concepts. In this lab, using real life scenarios, the students learn the importance of good lab practices and the consequences that can occur from errors due to poor lab skills.

We focused on thyroid hormone and thyroid disease because over 10% of Americans are expected to have a thyroid condition in their lifetime. Thyroid hormone dosages also lend themselves well as a subject for in-class activities. Students who want to pursue a career in the health field are more likely to become engaged in the mathematical applications of unit conversions, dimensional analysis and potential source of errors than if they simply
are to calculate the answer to the problem in the book. We were also inspired by the thyroid detective case developed for teaching physiology (Lellis-Santos, et al., 2011).

Parent et al., (2010) point out that "students who are asked to generate a prescribed outcome from completing a protocol generally don't care much why they are doing each step as long as they get the "right" answer." Because of this, "students begin to believe that science is about the answer and not about the process. When aiming only for the end result students are less likely to be engaged and as such miss the opportunity for understanding of both the scientific process and underlying scientific concepts" (Parent et al., 2010). Our approach and a key part of this lab was to have the students evaluate what types of errors are likely to occur and which type of errors is quite unlikely. Another significant contribution of this lab design is that some of the real life scenarios emphasize the importance of learning good lab techniques and the consequences that can occur from errors due to poor lab skills.

METHODS

We began the three-hour lab with two separate (but topic-related) student-engaged discussions to remind/reinforce some basic concepts in physiology and review calculations with respect to chemical compounds. We finished the lab period with activities designed to have the students examine and identify a wide variety of errors that can be made when taking/prescribing medication. This ultimately led to a discussion of whether a particular error can be considered “significant”. It was explained to students that statistics has a particular use of the word “significant”; typically a difference is statistically significant if it could occur by chance less than 5% of the time. In our (teaching laboratory/medical) context, the term “significant” meant an error or mistake that demands attention, as it is consequential towards the outcome.

Discussion One, Part A: Understanding physiology of medication.

The students were divided into small groups and were given following two paragraphs. They were encouraged to have discussions amongst themselves concerning the medication dosage, to clarify the physiological response to, and the chemical nature of, the active ingredient in each tablet (active molecule versus chemical form present in tablet). The patient scenarios are based on the real-life experiences of the authors’ relatives.

Patient #1 needs to take thyroxine (a form of thyroid hormone) every day. Recently, she went to her Health Care Provider because she had been experiencing weight gain, irritability, memory problems, and constant feelings of cold. These are symptoms consistent with having too little thyroid hormone. The Health Care Provider looked at her recent prescriptions and noted that the patient was usually given a dose of 10 mg of thyroxine. Her most recent prescription contained 10 mg of sodium thyroxine. The Health Care Provider suspected this might be part of the problem.

Patient #2 needs to take calcium pills in order to allow his parathyroid glands to recover. He went to his health care provider because he was experiencing muscle twitching. The Health Care Provider acknowledged it was consistent with low blood calcium levels but wanted to confirm that the patient was still taking his prescription. The patient said he had changed from the prescription Citracal to Tums. Tums is cheaper and over-the-counter. The Health Care Provider checked the labels and noted that Citracal’ s label says the active ingredient, calcium, is present at 600 mg per tablet. The TUMS label says its active ingredient is calcium carbonate at 600 mg per tablet. The Health
Care Provider suspected not taking the Citracal might be the problem.

For each patient: Identify the chemical differences in the drugs prescribed and taken. Identify the chemically important molecule in each treatment and discuss how the physiology/symptoms of the patient could be related to the drug taken (or not taken).

Discussion One, Part B: Molecular basis for different concentrations of active ingredients

After the above discussion, students were presented with the three alternative analogies (below). Once the students had read the cases and the possible analogies, they were encouraged to have discussions within their groups to reach an agreement on which analogy fits each of the two patient scenarios they have discussed.

Analogy A: Thyroxine (or calcium) was like an apple, while sodium thyroxine (or calcium carbonate) was like an apple with an orange attached. In this case, there are more apples in the 1 kg of just apples than in the 1 kg of joined apple-oranges.

Analogy B: Thyroxine or calcium was like an apple while sodium thyroxine or calcium carbonate was like an apple with a leaf and stem. In this case, 1 kg of apples has almost the same number of apples whether or not the apples have a stem and a leaf.

Analogy C: Thyroxine or calcium was like an apple while sodium thyroxine or calcium carbonate was like an apple sitting in a large, dense pottery bowl. In this case, there are more apples in 1 kg of apples than 1 kg of apples plus the large dense pottery bowl.

Discussion One, Part C: concentration of active ingredient in the medication.

At this point, the students understand the physiology of the drug with respect to the symptoms. They have identified the differences in the chemical composition of the medication taken versus that prescribed. They have also used the analogies to predict whether the dosage of the required active molecule was higher or lower than anticipated. Students are now told to calculate the number of moles of the active component in each of the tablets taken by patients #1 (thyroxine vs sodium thyroxine) and #2 (calcium versus calcium carbonate) and determine whether the change in the form of the medicine actually changed the dosage. Was there a ‘significant’ difference in the number of moles in the medication actually changed the dosage? Was there a ‘significant’ difference in the number of moles in the medication they were supposed to be taking, compared to the form they were taking?

Each student group presented their data and consensus opinion to the rest of the class. These were tallied on the chalkboard/white board/smart board and differences in data or opinions were discussed by the entire class to identify potential significant errors in the thought process, the calculation, or in understanding and applying the analogies.

Discussion Two: Drug dosages and micrograms vs. milligrams.

The next discussion was based on a scenario from a literature case (Narula, 2012). Students are presented with the following scenario:

A group of families went on a camping trip to a remote wilderness area. After 3 days of canoeing away from civilization, family A discovered that they had lost mom’s thyroid medicine and in a panic, told the rest of the group. The mom needs her pills every day, and it would take 3 days to get back to their car to drive to a pharmacy and get the pills. Family B said their dog also takes thyroid pills, and they brought some extra.

Questions for student discussions in small groups:
- Can mom just take the dog pills?
- Does it make a difference whether the dog is very large (70 kg) or very small (5 kg)?
• If the human pills contain 50 ug and the
dog pills 0.5 mg, is it OK if the campers
just determine the number of dog pills
required to be equivalent to the human
pills?
• Does it matter how much mom weighs?
Defend your answer.

In preparation for the first two activities, the
students were provided the following
scenario.

Two patients are suing their thyroid
medication manufacturers concerning the
strength/dosage of the thyroid pills they
were taking. In response to this lawsuit, the
company’s scientists have test results that
seem to confirm the amount of active
ingredient in the pills that were prescribed.
In contrast, the plaintiffs’ consulting
scientists have test results showing that the
pills seem to be of incorrect strength. Some
of the scientists, possibly on both sides, may
have made mistakes along the way. As part
of this lab, you [the students] will weigh
some powders and pipet some solutions.
This will give you practice doing these
essential lab activities and as you do them,
we want you to evaluate what types of
mistakes are plausible and which ones are
highly unlikely.

**Activity One: Weights and Scales**

**Goals:** For students to be able to identify
sources of error that can occur when making
solutions. Hands-on experience will allow
students to critically assess and attribute
error prone steps to specific techniques
including: calculations (including
dimensional analysis), weighing out material
(accuracy in weighing and the precision
limits of the balance) and the role solubility
can play in making homogeneous solutions.
Students can individually make a solution
corresponding to each powder.

Students are told to perform the
following tasks then answer/discuss these
questions:

A. Make a solution by weighing out 1 gram
of a white powder and bring that up to a
total of 50 mL with water in the supplied
conical tubes. When weighing, take care
to be as accurate as possible; do not be
off by more than 10% of the desired
amount of the white powder. Calculate
the error range first, and then weigh the
sample using a balance). What is the
accuracy of the 1 gram? What is the
accuracy of the 50 mL?

B. While you are weighing out your
powder, be aware of the potential for
weighing and/or recording errors that
may have been made by the scientists
testing the various pills above.

C. Based on the solutions you did make,
can you predict which white powders
would still dissolve if a person
inadvertently weighed out 10 times the
intended amount?

**Notes to instructors:** Options for the
white powders can be: artificial
sweetener, baking soda, calcium chloride
for canning, citric acid for canning
tomatoes, white corn meal, white flour,
and/or table salt.

**Additional Questions for students**

• One cross-examining lawyer thought a
scientist could have made up ten times
too much, because they misread the
number, misunderstood the units or had
a balance that was not accurate enough.
Another thought a scientist could have
misunderstood 50 mg vs. 0.50 grams.

• Which of these powders dissolved at a
concentration of 1 gram per 50 mL?
• Which dissolve at a ten times more
concentrated solution?
• Is it possible someone might not notice
whether a powder was not completely
dissolved?
• How likely do you think each of these
types of mistakes would be? Does it
make a difference whether the scientist
was experienced or new to the lab?
Activity Two. Pipetting for accuracy and precision

Goals: Students will be able to distinguish between accuracy and precision. In addition, students should be able to identify sources of error in a method. Hands-on experience will allow students to critically assess and attribute error prone steps to specific steps.

The tasks in activity two were:
A. Determine the accuracy level of a Pipetman™, that is, if the Pipetman™ is set at 1.00 ml does it deliver 1.00 ml? It is probably best to compare the P1000 Pipetman™ with a 1 ml syringe and the P200 Pipetman™ with the plastic pipet.
B. Determine if you can pipet the same amount (within 10%) 3 times in a row, that is, how precise are you?
C. Determine whether pipet droppers are as precise as the Pipetman™.
D. Determine whether 1 ml syringes are as precise as the Pipetman™. Are the syringes accurate?
E. Imagine you have to use one P-1000 Pipetman™ or plastic syringes to pipet 1.0 ml of solution A and then 0.3 ml of solution B. Which one allows you to change volume faster? Are both within 10% accuracy?

Questions for students to consider before going on to activity three.
- Are the plastic droppers or syringes as reproducible as the expensive pipets? What is the volume of one drop? Can you deliver the same volume 3 times in a row?
- FYI, the disposable droppers or syringes cost less than just the tips for the pipets; the pipets themselves cost about $250. Do you think that it is a "good" use of taxpayer dollars (or of your tuition dollars) to have every school buy pipets? Why or why not and under what circumstances?
- Could a scientist accidentally use a P20 instead of a P200? A P200 instead of a P1000? How likely is this to happen?

Activity three: Creating and evaluating the unknowns, relate to physiological response.

Goals: In addition to the chemical and physiological understanding the students gained above, we thought it was important for the students to realize that symptoms related to thyroid problems and/or thyroid medication levels can be difficult to distinguish. The symptoms could correlate with a change in medication but may not be caused by the medication. Someone with normal thyroid levels could easily gain weight, be irritable and have been having trouble remembering everyday tasks, especially if they were stressed. While rapid

<table>
<thead>
<tr>
<th>Table 1: Simulated blood sample preparation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2 stock purple or blue food coloring stock</td>
</tr>
<tr>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>High purple 600 ul 600 ul</td>
</tr>
<tr>
<td>High blue 200 ul 500 ul</td>
</tr>
<tr>
<td>Normal purple 200 ul 600 ul</td>
</tr>
<tr>
<td>Normal blue 100 ul 500 ul</td>
</tr>
<tr>
<td>Low purple 50 ul 600 ul</td>
</tr>
<tr>
<td>Low blue 25 ul 500 ul</td>
</tr>
<tr>
<td>Your unknown</td>
</tr>
</tbody>
</table>

Using a Thyroid Case to Introduce Basic Lab Skills  Bioscene  33
heartbeats, nervousness, weight loss, and trouble sleeping can be signs of too high thyroid levels, the stress of college life and reliance on caffeine could also account for those symptoms.

In this section, students (in groups) created one simulated blood sample (their choice, using Table 1). Working in groups, students generated a series of controls and also assayed their unknown (made by another group). The unknown was compared to the controls to identify whether a patient had too little thyroid hormone, too much thyroid hormone or the right amount of thyroid activity.

The students also read and analyzed the data in the 2 scenarios below, being able to decipher from the data provided who had a physiological disorder caused by hormonal imbalance and who has similar symptoms that are not related to their thyroid activity.

Scenarios:
A mother brings her two teenage daughters, Abby and Beth, into the health care provider’s office worried about the wellbeing of her family as a whole because both of her daughters seem to have all of the same health problems. They are both having extreme weight fluctuations and are very fatigued and can’t seem to even remember what they had for breakfast that morning. Blood tests were ordered. Based on the thyroid hormone blood levels, the health care provider concluded that Abby’s symptoms were due to low thyroid gland thyroid hormone production and the Beth’s symptoms were caused by her acne medicine.

Eric and Frank, two 19-year-old college students go to the doctor together after discussing similar symptoms that are making it very hard to keep up with their vigorous and stressful lives. They are both in their second year of very difficult classes at college and wonder if it is all caused by stress but would like to know for sure. They are experiencing rapid heartbeat, nervousness or anxiety, trouble sleeping and hand tremors. Blood tests were run. Based on the test results, the health care provider decides that Eric’s symptoms are due to an overly active thyroid gland, but otherwise a normal feedback loop. Frank’s symptoms are due to taking Adderall. What would the health provider have found as values for Eric’s thyroid hormone levels? What do you predict were the results for Frank’s thyroid hormone levels?

For this activity, we used vitamin B2 fluorescence to mimic the fluorescence one would measure for an immunoassay for thyroid hormone. In order to hide the vitamin B2 color, the students had the choice of using either purple or blue food coloring. The tasks in activity three were:

- Students in each group made up 3 control samples using the table below, labeled H, N, and L. They also made up one additional sample, the same as one of the controls as the patient’s sample and labeled it U.
- Students received a set of controls and the unknown sample from another group. They assayed the 3 control samples in parallel with the unknown using a blacklight.

Questions for students to answer:
From your samples that were assayed:
- Was your unknown high, low or normal hormone activity? How do you know?
- Which patient(s) could have provided the sample? Why?
- Was the blue or purple stock solution diluted more?
- Would it be possible for a scientist to pipet a wrong amount by misreading a row?
- Is there a better way to construct the table/instructions to reduce the chance of a mistake?

Significance has different meanings in statistics and in lay use. In this lab, significant error was used in the sense
that it is likely to have made such a difference in the amount of medication that a person would feel symptoms.

For most drugs, the ability to have an effect depends upon the concentration, which is the ratio of the number of molecules (moles) to the amount of solvent.

Units are very important. If a hamburger costs 500 would you buy it? What if it were 500 cents? The little 9 on the gas prices are mills with 1,000 mills in a dollar. The U.S. used to have tokens worth one mill (https://en.wikipedia.org/wiki/Mill_(currency)#United_States). If we still used the term mill, we might call a gas price of $2.99 as 2 dollars and 999 mills. If we skipped cents and converted between dollars and mills, we would probably make fewer mistakes converting milligrams to grams.

Below we have a list of likelihoods and a list of possible errors. From your experience, how would you rank the likelihood of the following errors? Might others disagree? Can you understand why there might be disagreements? What other possible mistakes did you discover were possible? What other types of theoretical mistakes the opposing lawyer might suggest did you discover that you think are almost impossible or highly unlikely?

- Almost impossible
- Highly unlikely
- Unlikely
- Possible
- Plausible
- Likely
- Very likely

- Not notice that a powder is not dissolved
- Misrecord a scale reading, such as writing down 50 mg for 0.5 g
- Misread or miswrite mg and ug or ml and ul

- For a pipet to be accurate but not precise? precise but not accurate
- Make significant errors when using a syringe instead of a Pipetman™ for delivering a set amount of volume
- Use a P1000 instead of a P200
- Use a P200 instead of a P100
- Misread the amount to be delivered on a Pipetman™
- Misjudge fluorescence amounts

Summary activity
While the students found these discussions and activities interesting and were actively engaged in all the activities, in retrospect, we feel that providing a summary of the expected learning goals or major concepts to them in advance of the exercise would probably have been helpful to their understanding of why they were doing these exercises. One has to be careful with the objectives and learning outcomes: we are not trying to dictate answers. Rather we want the students to examine their own methodology and assess the process, not just “get the right answer”.

DISCUSSION
Our laboratory training exercise focused on examining the types of errors that can occur in the lab setting. There are a number of references that suggest ways to train people to avoid pipetting errors (Epstein et al., 2003), but as far as we can determine, our exercise is the only one to consider an analysis of the types of errors that can occur in training novice students in lab techniques. Certainly, many have promoted the examination of errors as a didactic advantage. For example, textbook errors can be used as an advantage for teaching (Binder, 1984).

We have found that a combination of questions with clear right answers and questions that ask the students opinion is helpful to have in the discussions. Some students are uncomfortable and annoyed if none of the questions have a clear correct answer and other students become so
focused if all the discussion questions have correct answers that they miss the big picture. In addition, most students respond very positively to being asked their opinion, but they need to learn to justify a reply with ‘facts’ or an understanding of process and methodology. 

In this revised version, implemented with a new group of students, the analogies in Discussion one, Part B are consistent in that, in all 3 cases, an apple is analogous to the therapeutic chemical. In the original version, each analogy (see footnote) had different objects and some students found this confusing. When students were given both sets of analogies, all students (9 out of 9) preferred the apple analogies, though they were ok with the original analogies. This discussion led a few of the students to suggest that they could come up with better analogies. This led to a great discussion and the students recognized that different students preferred different analogies. For example, one student suggested an ant as the therapeutic chemical because an ant can carry ten times its weight. Another student did not find that helpful because they didn’t have a sense of things so small, and she suggested monkeys and bananas. As you might expect, an analogy generated by a student was more effective for that student than analogies by the instructor or peers and obviously constructing an analogy involves more active and critical thinking than evaluating another’s analogy.

In discussion one, we have tried it both with and without supplying the molecular weights. Particularly for students with little or no background, we found it effective not to include molecular weights. They then based their answers to the sodium thyroxine and calcium carbonate cases on nebulous factors. When given the analogies, they started to make argue about which scenario matched which analogy and the discussion led them to “discover” that they need to know the weights. One that had not yet had chemistry asked, how much does calcium and carbonate weigh? This allowed others to explain the concept of moles. We have found the word moles often makes the students think about the small burrowing animals and lose track of the chemistry. In addition, \(6 \times 10^{23}\) is pretty daunting to some. We prefer to introduce the idea of a set number of molecules and ask them if they understand the terms kilobyte, megabyte and gigabyte. Then we say that a mole is 600 zetamolecules and they seem to grasp that more easily than scientific notation.

Most of the students liked having real world thyroid related cases. One commented that he or she was particularly engaged, because he or she had a thyroid problem, and another said that they had a friend who had thyroid problems. Rather than having the instructors make up the unknowns, groups made up the unknowns for peer groups. Many thought made the lab more interesting than if the instructor made up the unknowns, using words and phrases that included: “effective”, “interesting”, “fun”, “gave more insight”, and “made me feel like a mini scientist”. We have found that students enjoy examining the tubes with a black light. By giving them a choice of using a purple or blue solution, some groups choose purple and see a clear yellow fluorescence and other choose blue and see a green fluorescence and allows them to think about why that occurs.

In summary, engaging the students in a health-related problem helped them appreciate the importance of chemistry and of learning proper lab techniques. In addition, most students enjoyed observing fluorescence and making up unknowns for another group. This lab activity also improved their appreciation of the types of errors that can occur in a lab and the importance of understanding basic chemical concepts and techniques in order to avoid these errors.

**Footnote:** The original analogies were: Original Analogy #1: Thyroxine or calcium was like a blue LEGO brick, while sodium...
thyroxine or calcium carbonate was like a blue LEGO brick with a green LEGO brick attached. In this case, 1 kg of green and blue LEGO bricks has fewer green LEGO bricks than a 1 kg of green LEGOs bricks.

Original Analogy #2: Thyroxine or calcium was like an oatmeal cookie and sodium thyroxine or calcium carbonate was like an oatmeal cookie with raisins. In this case, 1 kg of oatmeal cookies has almost the same number of oatmeal cookies whether or not the cookies have raisins.

Original Analogy #3: Thyroxine or calcium was like a robot, and that sodium thyroxine or calcium carbonate was like a robot with a very heavy backpack. In this case 1,000 kg of robots has a lot more robots than a 1,000 kg of robots wearing heavy back packs.

ACKNOWLEDGEMENTS
We thank Frank Schmidt for helpful comments on the manuscript and lab and especially for developing the revised analogies.

REFERENCES


A New Approach in Examining the Influence of Drugs on Pulsation Rates in Blackworms (*Lumbriculus variegatus*).

Amy B. Ryan and Nancy L. Elwess*

Department of Biological Sciences, State University of New York at Plattsburgh, Plattsburgh, NY 12901

*Corresponding Author: elwessnl@plattsburgh.edu

Abstract: This investigative laboratory activity engages students in observing, recording, graphing and analyzing pulsation rates in a commonly used laboratory organism, blackworms. This activity stresses how various drugs can impact the pulsation rate in blackworms at varying concentrations. In addition, we have incorporated two new ways to view the blackworms under the microscope.

Key words: Blackworms, pulsation rate, *Lumbriculus variegatus*, blood vessels, capillary tubes

INTRODUCTION

*Lumbriculus variegatus*, or blackworms, are freshwater oligochaetes in phylum Annelida. They are an excellent organism for studying the regeneration of body parts, regulation of reflex activities, bioaccumulation and toxicity of environmental pollutants, and regulation of blood vessel pulsations (Drewes & Fournier, 1990; Veltz et al., 1996; Bohrer, 2006; Fillafer & Schneider, 2013).

Like other annelids, blackworms have a closed circulatory system (Fig. 1). Blackworm blood is red, due to a hemoglobin-like pigment called erythrocrurorin dissolved in the blood plasma (Jamieson, 1981). Two major blood vessels, one dorsal and one ventral, extend the length of the blackworm. Pulsations along the dorsal blood vessel (DBV) propel blood through the circulatory system. Because the body wall of the blackworm is transparent, it is possible to visualize the pulsation of the DBV using light microscopy (Lesiuk & Drewes, 1999). As in humans, the pulsation rate is controlled by the nervous and endocrine systems. Many drugs affect these systems and can have an immediate impact on the pulsation rate, based in part on how quickly they can diffuse through the blackworm’s skin. Due to their simple body plan and ease with which they can be treated with compounds and the subsequent pulsation rate measured, black worms are an excellent model organism for the lab activity described below.

![Fig.1. A lateral cross section image of a closed circulatory system found in blackworms. Included in this image are major blood vessels and the internal anatomy. The pulsation rates can be determined by counting the pulsation waves at one location on the dorsal blood vessel. Image created by Sophie Kim.](image-url)
This investigative laboratory, designed for a college freshman general biology course, takes a fresh look at a standard blackworm laboratory activity that was first published in 1999 (Lesiuk & Drewes) and again in 2006 (Bohrer, 2006). Lesiuk and Drewes describe how blackworms can be used as a model system to demonstrate the effects of nicotine and caffeine on blood vessel pulsation and explain how to make the blackworm viewing chambers. Bohrer provides a more in-depth background as to how the Lesiuk and Drewes preparation can be incorporated into the curriculum, by including timelines, materials, methods, and a suggested grading rubric. We have developed two new approaches for viewing the blackworms under the microscope (Worm Viewing Chambers under Procedures) and have added three drugs to those from the original publications. This activity was done over three weeks. Week 1 (Wk 1) instructed the students on blackworm handling and behavior, as well as determining the pulsation rate under control and experimental conditions (varying caffeine concentration). Wk1 served as the practice week for procedures done in week 2. Week 2 (Wk 2) was inquiry, with each pair of students exposing their worms to one of three new treatments (cinnamon, celery seed extract, and valerian root). Wk 2 served as the application week. Both Wk 1 and Wk 2 stressed laboratory skills, including scientific inquiry, data collection, and microscopy. Scientific inquiry included the students becoming skilled at stating a hypothesis (Wk 1), determining the controls (Wks 1 & 2), calculating drug concentrations (Wks 1 & 2), determining results (Wks 1 & 2), and in Week 3, graphing and data analysis used in reaching their conclusions. The laboratory protocol can be easily altered for an advanced biology activity by involving more chemicals, examining reaction to a variety of stimuli (i.e. temperature), and regeneration rates.

**PROCEDURES**

**Blackworm Care**

Blackworms were obtained from Carolina Biological and kept in a small tank containing approximately 2 inches of aerated spring water and strips of brown paper towel. They were fed fish food flakes every two weeks. When not in use, the tank was placed in the dark.

**Worm Viewing Chambers**

We came up with two very distinct, but easy to use viewing chambers for the blackworms. In the original publication (Lesiuk & Drewes, 1999), a viewing chamber was made by using six layers of Parafilm bonded onto a microscope slide using heat. The trough, which held the blackworm, was made by cutting the Parafilm with a razor blade. Using a 3D printer, we designed a plastic slide with the trough embedded, and simply glued this onto a microscope slide (Figs. 2 & 3). A Makerbot Replicator 2 and the Solidworks 3D CAD software program was used to generate the viewing slide. The dimensions for the viewing slide was 7.5 cm long x 2.5 cm wide x 0.2 cm high, and the trough slot embedded within the slide was 4 cm long x 0.2 cm wide x 0.2 cm high. Once these dimensions were entered into the software program, it was exported into

---

**Fig. 2.** At the top is the traditional parafilm made trough as described in Lesiuk and Drewes (1999). In the middle is our 3D made trough and at the bottom are 100 µl capillary tubes. All can be used for viewing blackworms under the microscope. Photo taken by N.L. Elwes.
Makerbot’s software. Our second viewing chamber was a 100 µl glass capillary tube (Figs. 2 & 4) with a diameter of 1.35 mm. A worm can be easily transferred with a plastic Pasteur pipette into the capillary tube (Fig. 4). The capillary tube was then placed directly onto the microscope stage, where it could be easily rotated to obtain the best view of the DBV.

Prior to Starting this Laboratory Activity

The week prior to starting this laboratory activity, students were given a pre-lab assignment that was due the first day of this lab. Included in this pre-lab assignment were questions students needed to answer based on their reading of the introductory material in their laboratory manual. These questions covered their knowledge of why blackworms would make a good model organism for determining pulsation rates, parts of a dissecting microscope, and asked the students to provide a hypothesis for the effect of caffeine on blood vessel pulsation. The laboratory activity prior to this experiment introduced students to the nature of science, scientific inquiry, and basic experimental design terminology. This activity we felt was a good follow up to build on their understanding of those concepts. This article focuses on improvements made for the viewing of the blackworms and some suggestions for new experimental approaches to those previously published (Lesiuk & Drewes, 1999; Bohrer, 2006). Bohrer (2006) does an excellent job describing the lab set-up, student learning objectives, materials needed, and a suggested grading rubric.

Week 1

During Wk 1, the students became familiar with handling the blackworms and determining the basal pulsation rate. Each pair of students selected three blackworms from the tank and transferred them, using a plastic Pasteur pipette, into three separate petri dishes. Once students became comfortable with handling the blackworms, they started counting the DBV pulsation rate for each blackworm; each pulsation rate was done in triplicate. Students viewed the blackworms under a dissecting microscope at 20x magnification. Four different mM concentrations of caffeine were used (0.1, 1, 5, and 10). Working in pairs, students counted and recorded the basal pulse rate for each worm, this served as a control, and then tested one of the four caffeine concentrations. Students made 30 mL of the test solution by diluting a 20mM caffeine stock solution. Each worm was placed in 10mL of test solution. A blackworm was exposed to the test solution for 15 minutes prior to counting the pulsation rate. Students recorded and shared their data using Table 1.
**Week 2**

Three different compounds were used to determine if they had an influence on pulsation rate. All lab groups repeated the same approach as in Wk 1, but in Wk 2 instead of testing caffeine, they tested two concentrations (0.1 mg/mL and 1.0 mg/mL) of Cinnamon, Celery seed extract, or Valerian root. Three worms were observed at each concentration and each blackworm was placed in a single petri dish. Cinnamon, a spice widely used in traditional medicine, has been linked to a reduction in cardiovascular disease due to its effects on excitability (Alvarez-Collazo et al., 2014). Celery seed extract, which has been used in the Eastern world for thousands of years, is a diuretic used in the treatment of high blood pressure (Moghadam, et al., 2013). Valerian root is an herbal supplement used to reduce blood pressure and prevent arrhythmias (Chen et al., 2015). Students calculated the appropriate dilution needed to make 30 mL of test solution from the commercially purchased stock solutions of cinnamon (905.7 mg/mL), celery root extract (870 mg/mL), and valerian root (1000 mg/mL). Students recorded and shared their data using Table 2.

**Week 3**

Each student generated graphs of the average pulsation rates for each experiment.

---

**Table 1: Effect of Caffeine on Pulsation Rate in Lumbricus variegatus**

<table>
<thead>
<tr>
<th>Worm 1</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Table 2: Effect of Drug on Pulsation Rate in Lumbricus variegatus**

<table>
<thead>
<tr>
<th>Worm 1</th>
<th>Control (bpm)</th>
<th>0.1 mg/mL (bpm)</th>
<th>Control (bpm)</th>
<th>1.0 mg/mL (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
results and discussion

Overall, the updated worm viewing chambers used in this lab allowed students to better manipulate the worms under the microscope for optimal viewing of vessel pulsation. The 3D generated viewing chamber worked well for viewing larger blackworms, and the capillary tubes worked well with any size blackworm. The second week of the activity, where a novel compound was tested for its effect on pulsation, provided students the opportunity to compare treatment groups and perform statistical analyses. The inclusion of novel compounds also required the students to perform literature searches for candidate molecules and gave them the opportunity to develop testable hypotheses and make predictions based on their findings. As an experimental modification, students could also research and select the novel compound that they will assess, and design their own experiments, thereby introducing another component of scientific inquiry. They could also assess the effect of their compound on additional parameters, including blackworm behavior, reflex activity, or regeneration.

acknowledgements

We thank Dr. Michael Walters, Assistant Professor in the Physics Department at the State University of New York at Plattsburgh, for the design and making of the trough slides via a 3D printer. We would also like to thank Sophie Kim for the creation of Figure 1.

references

BOHRER, K.E. 2006. Effects of drugs on pulsation rate of *Lumbriculus variegatus*. 
*Tested Studies for Laboratory Teaching*, 27:127-146.  
http://www.ableweb.org/volumes/vol-27/07_Bohrer.pdf

https://doi.org/10.1155/2015/947619

*Developmental Biology* 138:94-103.


https://doi.org/10.2307/4450609

https://doi.org/10.1089/jmf.2012.2664

I. Submissions to *Bioscene*

*Bioscene: Journal of College Biology Teaching* is a refereed quarterly publication of the Association of College and University Biology Educators (ACUBE). Submissions should reflect the interests of the membership of ACUBE. Appropriate submissions include:

- **Articles**: Course and curriculum development, innovative and workable teaching strategies that include *some type of assessment* of the impact of those strategies on student learning.
- **Innovations**: Laboratory and field studies that work, innovative and money-saving techniques for the lab or classroom. These do not ordinarily include assessment of the techniques’ effectiveness on student learning.
- **Perspectives**: Reflections on general topics that include philosophical discussion of biology teaching and other topical aspects of pedagogy as it relates to biology.
- **Reviews**: Web site, software, and book reviews
- **Information**: Technological advice, professional school advice, and funding sources
- **Letters to the Editor**: Letters should deal with pedagogical issues facing college and university biology educators

II. Preparation of Articles, Innovations and Perspectives

Submissions can vary in length, but articles should be between 1500 and 5000 words in length. This includes references and tables, but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. Topics designated as acceptable as articles are described above. The formats for all submissions are as follows:

A. **Abstract**: The first page of the manuscript should contain the title of the manuscript, the names of the authors and institutional addresses, a brief abstract (200 words or less) or important points in the manuscript, and keywords in that order.

B. **Manuscript Text**: The introduction to the manuscript begins on the second page. No subheading is needed for this section. This supply sufficient background for readers to appreciate the work without referring to previously published references dealing with the subject. Citations should be reports of credible scientific or pedagogical research.

The body follows the introduction. Articles describing some type of research should be broken into sections with appropriate subheadings including Materials and Methods, Results, and Discussion. Some flexibility is permitted here depending upon the type of article being submitted. Articles describing a laboratory or class exercise that works should be broken into sections following the introduction as procedure, assessment, and discussion.

Acknowledgment of any financial support or personal contributions should be made at the end of the body in an Acknowledgement section, with financial acknowledgements preceding personal acknowledgements. Disclaimers and endorsements (government, corporate, etc.) will be deleted by the editor.

A variety of writing styles can be used depending upon the type of article. Active voice is encouraged whenever possible. Past tense is recommended for descriptions of events...
that occurred in the past such as methods, observations, and data collection. Present tense can be used for your conclusions and accepted facts. Because *Bioscene* has readers from a variety of biological specialties, authors should avoid extremely technical language and define all specialized terms. Also, gimmicks such as capitalization, underlining, italics, or boldface are discouraged. All weights and measures should be recorded in the SI (metric) system.

In-text citations should be done in the following manner:

**Single Author:**
"... when fruit flies were reared on media of sugar, tomatoes, and grapes"
(Jaenike, 1986).

**Two Authors:**
“...assay was performed as described previously (Roffner & Danzig, 2004).

**Multiple Authors:**
“...similar results have been reported previously (Baehr et al., 1999).

C. References: References cited within the text should be included alphabetically by the author's last name at the end of the manuscript text with an appropriate subheading. All listed references must be cited in the text and come from published materials in the literature or the Internet. The following examples indicate *Bioscene's* style format for articles, books, book chapters, and web sites:

(1) Articles-
(a) Single author:
(b) Multi-authored:

(2) Books-

(3) Book chapters-

(4) Web sites-

For references with more than five authors, note the first five authors followed by et al.
D. Tables
Tables should be submitted as individual electronic files in Word (2003+) or RTF format. Placement of tables should be indicated within the body of the manuscript. All tables should be accompanied by a descriptive legend using the following format:

Table 1. A comparison of student pre-test and post-test scores in a non-majors' biology class.

E. Figures
Figures should be submitted as high resolution (≥ 300dpi) individual electronic files, either TIFF or JPEG. Placement of figures should be indicated within the body of the manuscript. Figures only include graphs and/or images. Figures consisting entirely of text will not be allowed and should be submitted as fables. All figures should be accompanied by a descriptive legend using the following format:

Fig. 1. Polytene chromosomes of Drosophila melanogaster.

Color figures: When color is involved in a figure, it should be encoded as RGB and the resolution should be 300 dpi. Manuscripts that include color figures accepted for the May issue (online only) will appear in color at no charge to the author(s). For color reproduction in the December issue (print and online), there will be a page charge of $300. Author(s) will be notified of the costs and will have the option of either delaying publication until the May issue or paying the page charge. There is no fee for color in an image used on the cover of Bioscene.

III. Letters to the Editor
Letters should be brief (400 words or less) and direct. Letters may be edited for length, clarity, and style. Authors must include institution address, contact phone number, and a signature.

IV. Other Submissions
Reviews and informational submissions may be edited for clarity, length, general interest, and timeliness. Guidelines for citations and references are the same for articles described above.

V. Manuscript Submissions
All manuscripts are to be sent to the editor electronically. Authors must clearly designate which type of article they are submitting (see Section I) or their manuscript will not be considered for publication. Emails should include information such as the title of the article, the number of words in the manuscript, the corresponding author's name, and all co-authors. Each author's name should be accompanied by complete postal and email addresses, as well as telephone and FAX numbers. Email will be the primary method of communication with the editors of Bioscene.

Communicating authors will receive confirmation of the submission within three days. Manuscripts should be submitted either as a Microsoft Word or RTF (Rich Text File) to facilitate distribution of the manuscript to reviewers and for revisions. A single-email is required to submit electronically, as the review process is not necessarily blind unless requested by an author. If the article has a number of high resolution graphics, separate
emails to the editor may be required. The editors recommend that authors complete and remit the [Bioscene Author Checklist](#) with their submission in order to expedite the review process.

VI. Editorial Review and Acceptance

For manuscripts to be sent out for review, at least one author must be a member of ACUBE. Otherwise, by submitting the manuscript without membership, the corresponding author agrees to page charges. Charges will be the membership fee at the time of submission per page. Once the authors' membership or page charge status has been cleared, the manuscripts will be sent to two anonymous reviewers as coordinated through the Editorial Board. Authors’ names will be withheld from the reviewers. The associate editors will examine the article for compliance with the guidelines stated above. If the manuscript is not in compliance or the authors have not agreed to the page cost provisions stated above, manuscripts will be returned to authors until compliance is met or the page cost conditions have been met. Reviewers will examine the submission for:

- **Suitability**: The manuscript relates to teaching biology at the college and university level.
- **Coherence**: The manuscript is well-written with a minimum of typographical errors, spelling and grammatical errors, with the information presented in an organized and thoughtful manner.
- **Novelty**: The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

Once the article has been reviewed, the corresponding author will receive a notification of whether the article has been accepted for publication in *Bioscene*. All notices will be accompanied by suggestions and comments from the reviewers. Acknowledgement of the reviewers' comments and suggestions must be made for resubmission and acceptance. Further revisions should be made within six months if called for. Manuscripts requiring revision that are submitted after six months will be treated as a new submission. Should manuscripts requiring revision be resubmitted without corrections, the associate editors will return the article until the requested revisions have been made. Upon acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website. Time from acceptance to publication may take between twelve and eighteen months.

VII. Revision Checklist

Manuscripts will be returned to authors for failure to follow through on the following:

A. Send a copy of the revised article back to the associate editor, along with an email stating how reviewers’ concerns were addressed.
B. Make sure that references are formatted appropriately.
C. Make sure that recommended changes have been made.
D. Figures and legends sent separately, but placement in manuscript should be clearly delimited.

VIII. Editorial Policy and Copyright

It is the policy of *Bioscene* that authors retain copyright of their published material.