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A STUDY OF THE REMOVAL OF HEAVY METALS IN THE ENVIRONMENT THROUGH PHYTOREMEDIATION

By

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ABSTRACT

A STUDY OF THE REMOVAL OF HEAVY METALS IN THE ENVIRONMENT THROUGH PHYTOREMEDIATION

By

Karen A. Gould

This unit was taught to an eleventh grade Integrated Science class at Flint Southwestern Academy, in Flint, Michigan. The intent of the unit was to educate the students on the implications of hazardous materials in the environment and the use of plants as an alternative remediation device to clean contaminated sites. Through the utilization of experiments and models that provided hands-on experience and solutions to a real world problem, this goal was successfully met by addressing the requirements of the State Educational Benchmarks regarding environmental issues. Through the execution of a series of habitat models that utilized plants and animals, toxicity was explored using heavy metals as a reference, as well as the pathways that the toxins take in the environment. The analysis of collected data from the models indicated that as concentrations of the contaminant increased, the living organisms began to experience stress, especially if they did not have mechanisms that allowed for survival. In searching for a solution to the issue of toxicity and current practices of remediation, the idea of plant application for removal of metals was investigated. As the class worked with the experimental models, they gained knowledge, as indicated by their post test scores which had a range of 38-54% increase over pre test scores.

ACKNOWLEDGEMENTS

The completion of this degree was not possible without the supporting hands of many individuals, who either with intent or by default, had a great impact on me, making the road traveled less arduous. Foremost, I would like to extend my deepest appreciation to Dr. Merle Heidemann and Dr. Ken Nadler. Your patience and easy giving of "what you know" has shaped me into the educator that I have become, altered my thinking in only the best way. Thanks too, to Dr. Clayton Rugh for helping with the development of an environmental model that brought nature to the classroom. Margaret and Linda – many thanks. To my classmates Deb, Angie and Ken – thank you for your brains, your patience and mostly, your laughter, when I had forgotten how.

This wonder that fuels my work was ignited by my parents. My Dad Dale, who weaved tales of nature and opened the door to thinking outside of the box, and my Mom Joyce, whose faith and encouraging words helped me to see "possible" and started the way of looking for answers. Thanks to my family for their love and encouraging words, Bud and Gary, you remain with me still and Annie – a deep bow of appreciation for walking the road, cooking dinner, and wiping tears. JEA, your silence and space meant more to me than you know.

Finally, I am truly grateful to Southwestern Academy for supporting the research and I am honored and humbled by the students of the Integrated Science Class (2003-2004) for being willing.

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Introduction

Rationale

In response to teaching in a public school system for seven years, and finding a general sense of apathy and lack of knowledge regarding environmental issues, a contamination and remediation unit was developed. Although exhibited by a young adult population, the absence of solid knowledge regarding human impact on the environment is a mirror of society as a whole. As industrialization has replaced an economy based on agricultural practices, humans have moved away from a sense of connectedness to the Earth, and consequently have lost a sense of ownership and responsibility to the land on which they live (Botkin and Keller, 1982). Complicating the issue further, the adoption of a linear system of thinking – one in which events occur in a straight line, ignorant of webs of interaction have contributed to a massive global environmental crisis. Application of "band-aid" measures that treat the symptoms as opposed to correcting root causes, allowing governmental decisions to be made that favor business at the cost of exhausting natural resources, and believing that as humans we control nature have also added to this crisis state (Chiras, 1994). Essential to changing the current state of environmental health is educating young people (who will become tomorrow's leaders and decision makers), and assisting them in developing a sense of interconnectedness to the world in which they live.

The basic tenet of the unit was to demonstrate the application of phytoremediation techniques in the context of contaminated soil treatment. Although the 1980's brought the development of the Superfund Act (created by the Comprehensive Environmental Response, Compensation and Liability Act – CERCLA) which addressed the clean-up or remediation of contaminated sites through legal processes, public involvement has diminished in recent years (Botkin and Keller, 1982). Coupled with reduced federal dollars, many of the techniques that have been used in the past have suggest environmental irresponsibility. For instance, ocean dumping and incineration of wastes have increased pollution due to changes that occur during the recycling process and have resulted in chemicals that are as harmful to living organisms as the original toxin, i.e. acid rain (Botkin and Keller, 1982). Consequently it has become necessary to develop alternative techniques that not only stop further contamination, but assist in the degradation of toxins while benefiting the environment. Thus the study of phytoremediation (using metal tolerant plants to sequester or remove heavy metals from soil) was introduced in the classroom, focusing on the mutual benefit of removing the contaminant, as well as creating a healthier habitat for the organisms that live in an affected area. Through the application of problem based inquiry and cooperative learning, the students gained an understanding of how heavy metals and other pollutants enter the environment and become toxic.

Focus

Believing that as educators it is our responsibility to raise the awareness of our student population, and reflecting on the need to cover benchmarks that are not commonly addressed (evolution III.4 and ecosystems III.1 – III.5) the remediation unit focused on the impact that human activity has on both habitat and the organisms that live within that space. Expanding on the concept of utilizing environmentally friendly remediation techniques, the unit was taught in an Integrated Science class, a curriculum that was designed to prepare the students for standardized tests by reviewing all of the benchmarks from 8^{th} – 10^{th} grade and fulfilling the third year science requirement for those students who were not candidates for advanced sciences.

Taught primarily to minority students who often experience decreased academic success due to personal and cultural learning differences, low academic rewards for efforts put forth, and lack of general support from their peers and family base, the classroom environment was designed to address these specific issues (Golba, 1998). As stated by Kathleen Cotton, schools that are effective in teaching urban youth, "were characterized by features that focused on basic skill acquisition for all students, high expectations of students, teachers who took responsibility for their students' learning and adapted instruction to make sure that learning was taking place (in a) safe and orderly school environment" (Cotton, 7/2004). Additionally, students within an urban classroom often have limited involvement with the natural world, lacking hands-on experience with agricultural settings, wetlands, water systems and the soil. Of particular interest to the students in my classroom was the influence of industrial activity (in this case General Motors and several iron works plants) on the general health of local land and water ways. These local industries assist in the degradation of environmental quality because they release carcinogenic chemicals, as well as heavy metals into the surrounding area. This same area is where the students live and work, which increases the likelihood of the student population being exposed to those chemicals (i.e. metals) that are largely neurotoxins, absorbed through inhalation and the gastrointestinal tract, via daily living. The presentation of the hazardous material naturally led into the investigation of techniques used to remove these substances. Taking into consideration soil type, which can prohibit or exacerbate the accumulation of metals, traditional removal techniques include site caps which prevent the toxin from becoming airborne, sequestering the toxin in a landfill or applying the relatively new technique of using plants to remediate a hazardous site. The problem with teaching phytoremediation in an urban setting is that there are no local fields to explore where the technique is being applied, thus the learning becomes theoretical unless alternative teaching methods are used. An additional challenge is engaging the students and increasing their connection of personal responsibility for sustaining a healthy environment. In response to these challenges inquiry based and cooperative learning techniques and theory were applied within the classroom.

Teaching Theory

Current scientific teaching methods recognize the difficulty in reaching a population of students who are removed from daily experiences that activate investigative thinking. Additionally, diverse student populations create the necessity of using examples, models and teaching tools that hold some relationship to the student's personal life (Clark, 1999). Problem or inquiry based learning meets this challenge because it "encourages students to solve or find solutions to real world problems (in this case contaminated sites) by themselves or in groups, rather than relying on learning primarily through lectures or textbooks" (Sonmez & Lee, 2003). As with guided inquiry, the teacher acts only in guiding or assisting the students with the investigations (Martin, 2002).

Proposed Solution

Working from this theory, two long term models (one a wetland tank and the other a Red worm soil column) were established in the class that represented habitats that had been contaminated with a heavy metal, similar to industrial waste. There were no defined answers as to why the wetland plants were experiencing stress, indicated by growth retardation, poor photosynthesis or plant death. The class relied on their group's support to find solutions by activating prior knowledge (Sonmez & Lee, 2003). Providing the student's with the opportunity to direct their own learning while developing critical thinking skills through investigation also aided in building their confidence.

The interdependency on each other as a source of both inspiration and knowledge is especially crucial to not only building self esteem within each individual, but also in developing shared understanding among students that hold very different background information and experiences. The class as a whole was split into 5 groups of 5-6 students that progressed through the unit together. The groups were developed based on communication skills that were exhibited among members, the mixing of varying cognitive ability and learning styles (auditory vs. motor) and the tolerance level each member had for the other members. Because knowledge is built on preexisting frameworks of reference, by grouping the student's with similar communication skills, but different backgrounds of experience, the group's members were able to assimilate new information that they learned from the class work, as well as from each other (Ginn, 1997). As a collective (cooperative) group moving through the learning exercises each member was able to contribute his or her best ideas which in turn increased the understanding of the whole group. By helping teammates learn the students themselves created an "atmosphere of achievement" for the entire group (AbiSamra, 2001). Using cooperative learning in the classroom has been documented to improve academic achievement, individual behavior and attendance, as well as increase self-confidence and motivation, both to the individual and the entire class.

Moving away from individual competition, cooperative learning incites an atmosphere of support, one in which the entire group benefits from the actions of all members of a team. Reducing the threat of not reaching a goal, in this case academic success, by relying on the strengths of individuals, self esteem builds due to each member feeling that his/her input is both valuable and valued (Johnson and Johnson, 1989). This is especially the case when teaching a class that has special needs or inclusion students in attendance, as in the case of Southwestern Academy where the unit was taught. Often individuals with disabilities are "tracked" out of technical or main-streamed courses because it is believed that they cannot function safely in a laboratory setting (Schwartz, 1987). The school is the POHI (Physically or Otherwise Health Impaired) center for the Flint District, incorporating all levels of physical/mental ability into a general education classroom. This incorporation includes individuals with dependencies on medication to function daily, visual and auditory impairments, and physical impairments that require the use of motorized wheelchairs. This incorporation generally benefits all students, but also creates an atmosphere that could potentially cause separation among the class because of prejudice and judgment. This potential issue is therefore addressed by the incorporation of cooperative learning groups.

One characteristic of this learning technique is heterogeneity, in that groups are developed based on differences between team members as opposed to likenesses. Applied to the classroom, a team member that is lower functioning due to medication can excel in the group because he/she is contributing the ideas that he/she knows the best. Further, the entire group processes information to assess their level of productivity in meeting a set goal, becoming accountable for their own individual responsibilities and recognizing the interdependence that is established in being a member of a team. In regard to the unit, the students acted as a team in constructing the two models, delegated individual responsibilities in collecting twice weekly data, and when confronting a problem in the investigative process, discussed the matter collectively. Once established, the connectivity between team members was evidenced in independent work such as discussion panels. Instead of individual opinions being criticized, the class more readily accepted each others views and used them as spring boards for deeper understanding. The face to face interaction that the cooperative groups experienced developed trust among team members, as well as communication and leadership skills (Johnson & Johnson, 1989).

"Constructivism in science and mathematics education has held a broad influence on the educational field; curriculum, National Science Education Standards, in a broader audience, politics, applied as a world view" (Matthews, 2005). While having its origin with Piaget and presently asserted by Ernst von Glasersfeld, constructivism is taught in educational theory classes and commonly used within the science classroom. Relying heavily on the intake of information that is gathered by the senses, constructivism allows the individual to interact with his/her environment by seeing, hearing, touching, smelling and tasting. These messages provide learners with information that allows them to create a picture of the world, thus bringing out a personal experience that resides within the individual (Lorsbach & Tobin, 1992). Although a general theory may be taught in the classroom, its meaning and therefore its application is influenced by the learner. Knowledge becomes personal and ownership of the process increases because of the development of independent thought processes. A form of pragmatism, constructivist learning emphasizes practical results in exploring science, as opposed to theoretical ideology. Esoteric information becomes real as the learner applies the information on a personal level and identifies with it. This increased connectivity enmeshes the learner in the investigative process, granting the student permission to further seek answers to commonly posed problems. For instance, in the analysis of the heavy metal lab (wetland tanks) the students identified with long term exposure to a toxic substance and projected the outcome on a human level, even though the lab specifically dealt with plants. Further, by constructing meaning from the experiment, although the idea was not specifically addressed, the students were able to conceptualize tolerance of a metal and predetermine an outcome when applied to a different situation. This skill is the beauty of the constructivist theory. Perhaps the most difficult aspect of using constructivism as an instructor is in "helping learners to construct models for themselves, to appreciate their domains of applicability and, within such domains, to use them" (Matthews, 2005).

Regardless of the challenges that constructivism presents to the instructor, the theory is vital and necessary for generating an interest and commitment to maintaining a healthy environment, to an otherwise disinterested group of individuals. Though state benchmarks mandate that environmental concepts be taught within the classroom, often the student remains aloof to the necessity of becoming educated in both the cause and effect relating to the release of hazardous material. Further, the students do not perceive that they can become empowered to make a difference when governmental decisions (on this topic) are handed down to the general populace. Constructivism allows the student to use previous conceptions and change them to fit their current schema of knowledge, to trouble their own thinking in rectifying a conflict and connecting the student to the current situation or problem (Ishii, 2003). By creating personal reference to a situation the student moves from a place of apathy to a commitment to the outcome, in this case the sustainability of the Earth. Combined with the esteem that is gained from cooperative learning, and the success experienced in inquiry based exploration, students carry not only science lessons with them into the world, but life lessons as well.

Finally, as enunciated by Jean Piaget, cognitive structures change through the process of adaptation, assimilation and accommodation. The interpretation of events in terms of existing cognitive structure and the changes that ensue to make sense of the circumstances gives way to a gain in knowledge and more importantly, a growth of personal experience (www.tip.psychology.org, Piaget, 2/2005). Applied to the classroom, this would indicate that when the students are tested before a learning unit and then retested, a substantial percent of growth should occur.

Target Group

A more in depth perspective of the daily activities of the classroom is included in the implementation of the unit, and with that, a clearer understanding of the commitment made by the students to move through the material. The unit was taught in the Flint School District, a school system that is located within an urban environment and has a total of 18,955 students. While the district was at one time a showcase for educational practice with expanding student populations, employee wages, and building growth, it has in recent years suffered due to decreased economic stability of the area. This has in turn resulted in lower student population and diminishing educational resources. Within the district there are yearly lay-offs of teaching and support staff, and instability within the Board of Education members. Additionally, the unemployment rate in Genesee County was 8.3% as of October 28, 2004, markedly above the state average of 6.2% (U.S. Census Bureau). The economic depression is evident in the student body with 69% of the district's students qualifying for free or reduced lunch.

The impact of the economic status of the area is evidenced in the extremely high mobility rate. Nearly 40 % of all enrolled children in the district either change schools within the district in an academic year or leave the district altogether. Not only do the students experience housing changes, but their academic foundation is altered as they move from classroom to classroom where the same subject may be taught at a different pace or in a different timeframe. Consequently, they may be exposed to the same subject/topic repeatedly or they may continually be exposed to new information, never having the opportunity to gain mastery of the subject.

The depressed state of the district is also experienced in the curriculum. Although one of the five district high schools is designated as a "magnet school", offering advanced classes in science, and the district has a high school academy, current environmental sciences such as forensic science, environmental studies and ecology are not offered. The issue with the lack of alternative science offerings is that most standardized tests require a general knowledge of these subjects to be successful on the exams. Due to the time constraints of a school year that is only 189 days in length, and the necessity of covering approximately 33 State Benchmarks in science, alternative studies though required, are often overlooked. The unit was taught at Southwestern Academy, the only high school in the Flint District that requires the students to carry a minimum of a 2.5 grade average. Although the Academy has relatively high expectations of its 905 students, has the lowest (10%) mobility rate of the district, and the greatest diversity (67.7% African American, 28.9% Caucasian, and 3.4% Asian, Latino and American Indian), there is not the reassurance that all students will experience success. This is evidenced in the "prerequisite" for enrollment into the Integrated Science class (where the unit was taught) in that the student's must have achieved a grade of either an E or a D in their 9th and 10th grade science classes. This type of academic background leaves the students with compromised scientific knowledge, as well as limited laboratory skills and low academic achievement. With this in mind, the unit was designed to address the student's needs, while achieving the goal of increasing the student's understanding of contamination, the techniques used to address these issues, and the impact that human's have on their environment.

Implementation

The implementation of the use of plants as an environmental remediation technique and related topics, and the effect that heavy metals have on living organisms within a habitat is outlined in the following pages. The unit spanned seven school weeks, although the last week was shortened by Thanksgiving break. Table 1 outlines the daily activities in a general manner, with more description given in the text, as well as in Appendices A and B.

Remediation of toxic sites is rarely taught outside of an environmental science class, although it is expected that high school students are familiar with the process according to the Michigan Science Content Benchmarks (III.5.4, III.5.6,IV.1.1) (Appendix A). This unit was designed to address the pathways that contaminants take and their subsequent impact on the environment. Designed in the summer of 2004 at Michigan State University, all of the experiments were newly created, focusing on increasing student understanding of the subject, as well as improving laboratory skills and communication techniques, both verbal and written. The study was focused on metal toxins and the use of plants to remove or sequester these contaminants as an alternative to traditional remediation techniques such as landfills and hazardous site caps. Activities such as leaky pipe joints; run-off from farms, backyards, and golf courses; untreated or inadequately treated sewage and nutrient over load (due to over fertilization) were used as examples of human actions that contribute to chemical overload in drinking water, as well as natural water systems and soils.

Taught in a constructivist manner, the 11th grade class of 13 males and 14 females was broken into groups of 5-6 individuals, based on the ability of the members of the group to support each other in the learning process. The participating class, Integrated Science, is designed to revisit and reinforce all of the Michigan State Benchmarks that are taught to public education students from middle school through the 10th grade high school standards. The unit required six weeks, focusing primarily on two in-depth models that simulated environmental conditions. Most of the class activities involved the observation and testing of the models. Research, notes and class discussions added dimension to the students understanding and knowledge base. Much of the fundamental knowledge regarding the environment as a system and the interdependency of all parts had been previously taught, at least minimally in 10th grade biology. This foundation allows for a more expansive, current - issue based classroom. Although specifically designed to ready the students for standardized test situations such as the ACT and MEAP, the instructional premise is that if the students are taught basic science knowledge that is applied to everyday human issues, the knowledge and learning become less institutionalized, and the students attain success. One of the greatest challenges that we faced as a class was that we had no text books for either reading or conceptual images. Consequently, a number of days consisted of note taking, class discussion, reading adopted reference material and interpreting instructor generated drawings.

The principal assessment tool that was used to measure student comprehension and knowledge growth was a pre and post test. The series of ten questions addressed key concepts that formed the foundation of the unit. All of the questions were constructed responses, which provided the students with the opportunity to express their own individual understanding of contamination, remediation and its impact on the natural world. This information was analyzed statistically using a paired student *t* –test and used to measure the success of the unit. However, a journal which contained the student's observations, personal opinions, laboratory reports and data analysis was also considered in the student's final grade, and analysis for this project. Appendix P-1 shows the journal rubric, expectations and point scale. The students were encouraged to record their daily thoughts about the laboratory work in which they were involved, evaluate their own growth, and answer their own questions through classroom investigations. Not only did the journal keep all of their work in a central location, it provided a guide to the progression of the investigations and illustrated a more advanced approach to record keeping (when compared to 9^{th} and 10^{th} grade science classes). Appendices D-O includes student assignments and reference notes for both the students and the teacher, and the pre/post test is found in Appendix C-1.

	Monday	Tuesday	Wednesday	Thursday	Friday
WK 1	Heavy Metal Lab Introduced Unit intent, Pre-Test	Tank Construction, Journal Entry Expectations	Professional Development	Tank Construction, Mineral Requirement Notes	Field Trip Protocol, Heavy Metal Definition/discussion Self-sustaining mechanisms
WK 2	Field Trip to Bull Frog Pond	Plants Placed in Tanks, Planting Techniques Taught	Remediation & Contamination Discussion, Bull Frog Pond Questions-Analysis	Macro/micro Nutrient Notes, Plant Physiology Drawing (lab books)	Soil Test from Bull Frog Pond
WK 3	Tank Monitoring $CuSO_4$ addition to tanks	Research Computer Lab – Scorecard.com	Remediation Notes/Discussion	Remediation Notes Finished, Discussion of Local Impact	Plant Count, Soil Test Protocol, Red Worm Lab Construction
WK 4	$CuSO_4$ to Worm Jars, Tank Care	Plant Count, $CuSO_4$ Water Test, Bio-accumulation Activity	Red Worm Count, Toxicology Pathways – Student Discussion	Scorecard, toxicology pathways Association Activity, EPA Reading	Red Worm Population Count
WK 5	Red Worm and Plant Count, $CuSO_4$ Water test	Acid/base Lab, Soil Percolation Demo	Red Worm Population Count, Computer Research Project	Computer Research Project	Plant Prep. for $CuSO_4$ Presence Test, Final Plant and Worm Count, Research Project Due
WK 6	Final Red Worm Count, Compile Class Data	Final Plant Count, Deconstruct tanks, $CuSO_4$ Presence Test in Water/Plant	Data Analysis of Heavy Metal Lab, Data Analysis of Red Worm Population	Thanks-giving Holiday	Thanksgiving Holiday
WK 7	Post Test Discuss				

Table 1: Phytoremediation Unit Outline
Activities and Experiments conducted over a seven week period.

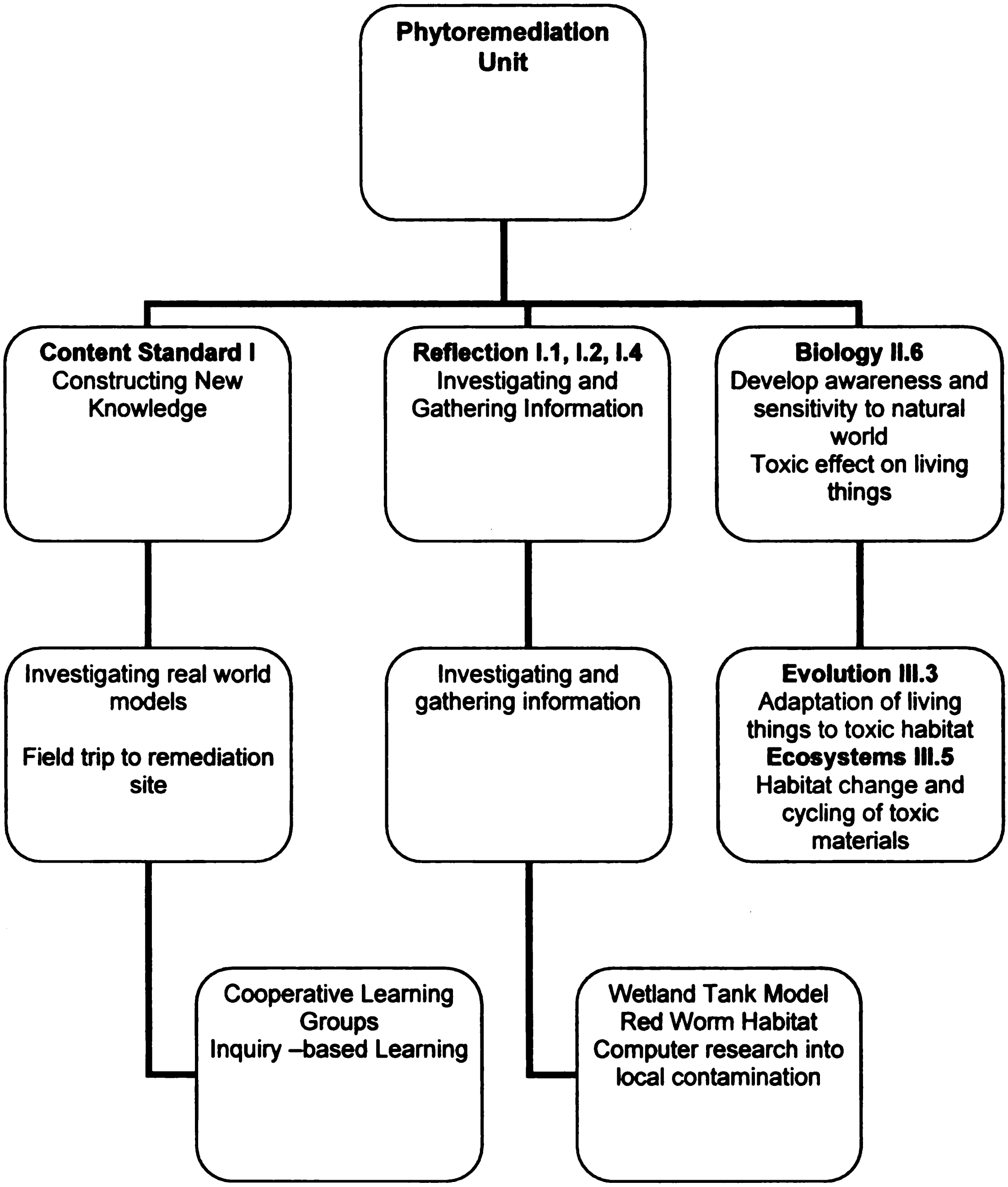

Figure 1: Flow Chart of Content Standards and Main Unit Ideas

The Flow Chart above connects the main ideas of the unit to the Michigan Content Standards and Benchmarks. The descriptions are condensed, and explained in greater detail in the body of the text.

Week One

The song "Rescue Me" performed by Dougie MacLean opened the unit. The song was written from the perspective of a farmer who after a number of poor harvests and some investigation, learns that the individuals who had farmed the land for generations before him had used pesticides that had poisoned the land and infiltrated the water supply of the surrounding area. This song demonstrated that contamination is not always deliberate, that it is a global issue and that the aftermath of chemical exposure can be toxic and far reaching for years after the contamination event. After hearing the music students were encouraged to express their opinions and voice prior knowledge that they had about pollution, and the idea that as human beings there is a personal responsibility in making choices that are not harmful to either the environment or the organisms that inhabit it. This introduction and the discussion that followed set the stage for studying phytoremediation of heavy metals. A pre-test taken the first day indicated that over half of the students had no awareness of heavy metals, soil types or remediation techniques.

Tank Construction

The remainder of the first week was spent the constructing model and basic knowledge that would be used throughout the unit. The objective of the model was to recreate a living environment that mimicked a natural habitat that had been contaminated by a heavy metal (copper sulfate). The tanks for the Heavy Metal lab (Appendix D-1) were assembled in groups of 5-6 student's using 5 gallon fish tanks, wooden dowels and landscape fabric to illustrate a water/land environment and required two days to construct. The students used the remaining class time to discuss journal entry expectations and to copy reference notes on plant and human mineral requirements (Appendix E). On the final day students were given questions (Appendix B-2) they would be required to ask/answer on the field trip scheduled for the following Monday, students were also provided with a field trip protocol and natural wetland history. As an overview assignment, the class read an essay "Self- Sustaining Mechanisms in an Ecosystem" (Appendix F) and answered questions relevant to the passage. This work gave them a background on both the biotic and abiotic factors that are active in an ecosystem, so that when they went to Bullfrog Pond the following week, they would be able to identify those parts of the system. The radish and lettuce seeds that were to be placed in the land/water tanks were germinated over the weekend.

Week Two

The second week of the unit began with a field trip to a wetland that had been reclaimed after 100 years of farming wheat and corn. Under the Food, Agriculture, Conservation, and Trade Act of 1990 (P.L.101-624) (www.water.usgs.gov/nmsum/WSP2425/legislation.html) land owners of agricultural fields drained of their wetlands who are willing to reestablish the area to its natural state receive tax deferment and assistance in replanting native grasses and flowers. Guided by a representative of the Soil Conservation Department of Michigan, the students spent the school day gathering water and soil samples, both from the marsh site as well as the reclaimed field. Included in the field trip was the opportunity to tour some of the 100 acres, noting varying stages of succession on the land. This led the students to not only answer the required questions, but also to generate their own questions based on observation. The following day the soil from both sites was removed from the collection test tubes and dried in labeled petri dishes.

Plant Placement

The students were assigned to teams of 5-6 students, based on both the ability to cooperate with each other and the intermixing of cognitive levels so that all participants could learn from each other. Each group was then assigned plants, so that as a whole the class would conduct a group experiment over a three week period of time. The plant species varied, based on their ability to withstand exposure to heavy metals. All groups "planted" 40-50 individual *Lemna minor* (a metal tolerant water plant), one group planted lettuce (a metal intolerant plant), one group planted radish (a tolerant plant), two groups planted both lettuce and radish (one group would contaminate with copper sulfate, the other would not), and the final group received only water plants. The groups were instructed to place approximately 60 of their assigned plants into the soil side of the tank models, paying close attention to seed depth and over population in one area of the tank.

The students recorded the experimental data in their journals and also recorded any impressions or opinions that they had developed in response to the tank activity. Because the experiment spanned three weeks, a pattern had to be established as to when the plants from both the water and land environment would be counted and when soil testing for the presence of copper sulfate would be conducted. Once the seedlings had broken the soil surface, counting the plants and conducting the copper sulfate tests occurred every five days and the tanks were aerated using a motorized aerator every three days to reduce the possibility of an anaerobic environment. The next two days included group discussions of the Bullfrog Pond field trip questions, the purpose of remediation techniques as applied to contaminated sites, the definition of contamination, and the transcribing of notes (Appendix J) that generalized the need for specific macro/micro nutrients by plants to maintain health. Additionally, the students illustrated the basic structure of a plant which assisted in creating a model of contaminant uptake. Finally, the students conducted rapid result soil tests on the samples taken from Bullfrog pond. These results were recorded in their journals, along with their responses from the field trip questions

Week Three

Contamination

The week started with the students spending the day monitoring the plant growth in their tanks, recording observations of changes, and adding 300 ml of 0.1M copper sulfate solution to the land portion of their group's tanks, taking care not to saturate the newly emerged plants with the heavy metal solution. Discussions included where situations that were modeled by the tanks would occur in nature, in particular in the students environment. The Flint River is a major water system that is present in the area where the students live so most of them had some exposure to the physical structure of a water/land interface. This exchange of ideas fed into the next day's activity of computer research on polluted sites in Genesee County. The students accessed *Scorecard.org* in the computer lab, a web site that lists all of the industrial businesses that have contributed in some way to polluting the environment. Although the students had no formal assignment associated with this activity, they had the opportunity to view the great number of factors that affect an area and contribute to the overall "wellness" of their environment. Listed on the website are the documented chemicals and their effect on human health, the location of the contamination and the proposed protocol for cleaning the area. This gave the students a greater understanding of human exposure to toxic substances due to unsafe industrial practices and generated interest in the best practices for removing hazardous chemicals. The next two days the class took notes on remediation techniques (Appendix B-5), focusing entirely on the use of plants to remove substances from a contaminated area. This activity threaded the previous knowledge of plant physiology to application, and the students began to understand the uptake mechanism of the plants and how they either sequester or breakdown the toxins. The notes were used to extend class discussion on remediation, and how landfill use is not always the best technique to remedy a contamination problem. The students spent the last day of the third week counting their tank plants, noting not only numbers, but physical condition of the plant such as color, size and leaf growth. The protocol for copper sulfate test was reviewed and the Red worm Lab (Appendix K-1) was read aloud by class members.

Redworm Lab Construction

The intent of the lab was to demonstrate the effect of varying concentrations of a toxin on organisms that live within a habitat. This activity also showed that organisms can develop some level of tolerance based on the organism's physiological mechanisms to tolerate or remove a toxic substance. I demonstrated for the class how to construct the red worm habitats, and to save time I mixed 0.125 gm, 0.250 gm, 0.375 gm, and 0.500 gm of copper sulfate per 100 ml. of water in large labeled beakers so the students could concentrate on measuring and applying the solution to the soil in the habitats. After observing the demonstration, the groups began to construct the red worm vessels. One member of each group weighed soil for five different trials, two other members gathered, counted and weighed the required red worms, and the remaining team members gathered and labeled jars. All of the information from the various team members was gathered and recorded in each individual member's lab sheet. The teams decided to let the worms adjust to their new environment before changing any components of the experiment, so the habitats were constructed with the understanding that the copper sulfate solutions would be added on the first day of the following week. Observations and opinions were noted in the student's journals.

Week Four

The fourth week was spent maintaining and testing the developed experiments. The groups measured required copper sulfate solutions, loosened the soil from the red worm habitats, observed the worms (4-5 per habitat) general condition and added the solutions to the jars. One of the jars was maintained as a control, with only water added. All of the jars were left with open tops to permit oxygen exchange for the worms. The final minutes of the class were used to aerate the water/land tanks, and make observations regarding plant conditions. The next day the students reviewed the protocol for the testing of copper sulfate presence in the water portion of the water/land tanks of the Heavy Metal Effect on Plants Lab (Appendix D-1), and I explained and demonstrated the proper procedure for testing the water (Appendix A-1 teachers edition). Once the students had gathered the needed equipment and had obtained an adequate water sample, they placed one drop of the testing sample in a spot well and one drop of distilled water in an adjacent well to be used as a control and tested with ferric thiocyanate an indicator of copper sulfate. The students looked for presence of copper sulfate which signifies the movement of a heavy metal contaminant through the environment. Most groups showed some degree of copper being present, and all members of the group made note of the color changes (with the clearness of the solution indicating concentration of copper) and concentration numbers in their journals. As this lab progressed for 2 more weeks, the concentration of copper sulfate in the samples increased due to leaching through the environment. This suggests a greater likelihood of lethal effects on the water plants (*Lemna minor*). Ending the day, students acted as individual components of an ecosystem which had experienced the accumulation of a toxin (Bioaccumulation Activity, Appendix L). The following day the students removed their worms from their jars, massed and counted all of them and noted in their journals any observable changes. Many of the groups worms had started to die, with the remaining worms showing increased lack of movement and discoloration in their body. This procedure was to be followed every two days, with the exception of the weekend. Students recorded deaths in their lab charts, and the soil in the jars was stirred to ensure proper aeration. The remainder of the class session was spent discussing toxic pathways such as industrial spills, pesticide and fungicide applications on lawns and fields, and toxins that reach the soil and water through the air. The students generated most of the ideas and were encouraged to visualize the path that the toxins took once they were released in the environment. This informal process created an atmosphere of relaxed imagination, and resulted in innovative ideas, all of which were recorded on the board for future use. The next class period was spent utilizing the information that had been gathered from the previous work (week 3) in the computer lab with Scorecard.org. Comparing the known hazardous material in the local environment, the students used the ideas that they generated on the previous day about contamination pathways and cross referenced the information.

Constructing Knowledge

Beginning with a flow chart, the students mapped the source of the contamination, the type (physical state) of toxins that were produced, the contaminant release point, and the known effects of the toxin. They went on to generate a Venn Diagram that illustrated the interrelatedness of the point of release and the possible pathways that the toxin could take, such as water systems, air pollution or land contamination. In the center of the diagram was where the information crossed over and listed which organisms would be affected by the toxic exposure. Although this was a difficult mental exercise, the students were successful in utilizing the information gathered from the computer and applying it to a real life situation. Finally, the students repeated the process of weighing and counting their red worms, and finished the day by reviewing and writing in their journals.

Week Five

The first day of week five was a maintenance day in which students repeated the copper sulfate water tank test, counted and observed tank plants, weighed and counted red worms, recording all of the information in their journals. The next day opened with an acid/base precipitation lab, "Now You See It, Now You Don't" (Appendix M-1). The purpose of the lab was to show that the acidity of an environment contributes to the bioavailability of metals for plant uptake. The solutions were prepared to save time (teachers version Appendix A-4). Basically, the students counted the drops of sodium hydroxide and hydrochloric acid needed to force the solution to flocculate with the addition of a base and return to the original clarity by adding an acid. The test was repeated to match the original experimental results of flocculation and clarity, but adding a buffer, realizing that the addition of the buffer created the need for a greater amount of both the base and the acid. The questions following the lab asked the students to apply this experiment to an everyday situation where a buffer was present. Post lab discussions covered the importance of lowering the pH in the soil of a contaminated site to assist plants in removing or "taking up" metals from the ground. This exercise brought the lesson back to remediation and was reinforced with a demonstration on soil percolation. "Bottled Water – What is going on with the Ground" (Appendix N) was originally designed to be conducted as a student based lab, but the constraints of time dictated that the lab be transformed into a demonstration. This demonstration showed the type of soil substrate that a hazardous substance moves through dictates the degree of contamination exposure to an ecosystem. The students massed, counted and observed their red worms the next day.

Research Project

Utilizing the background information gained regarding contamination and heavy metals, they embarked on a research project. Based on a series of questions (Appendix I), they used the computer to gather the information about heavy metal toxicity, its effect on plants, the sources and pathways of the contamination and remediation techniques used to remove these substances from the environment. Although this paper was originally intended to be an informal assignment, the end result was a research paper that included the students opinions. This type of inquiry allowed the students to develop their own opinions while following a more formal guideline. The grading rubric for this assignment is found in Appendix I. The last day of week five was spent completing the research document, weighing and counting the red worms, and reviewing the processes needed to complete the plant count from the tank experiment. Additionally, all of the plants were counted and pulled from the tanks and final observations made. The healthiest of the surviving plants were separated out, placed on a labeled watch glass and dried for five seconds in a microwave. This process assisted in removing the water from the plant material, with the remainder of the water being removed over a two day period through air drying. All groups then placed the watch glasses on a shelf that had been labeled with their group name, and left them there to dry over the weekend.

Weeks Six and Seven

The final two weeks of the unit was interrupted by the Thanksgiving holiday, but the core work with the long-term experiments was completed in week six. Groups counted and weighed their worms, recording physical states of the worms as well as deaths and amassing the information on an overhead projected data sheet. All groups had recorded some worm death, with the numbers increasing as the concentration of the copper sulfate increased. This experiment clearly defined for the students the association between contaminant concentration and the impact on living organisms. This was evidenced by their written responses to the lab questions which were completed on the third day of the week. The next day the students deconstructed the plant tanks, and prepared for the final testing of copper sulfate concentration in the plants that were removed from the soil and water (Appendix D-1). All groups tested positive for the presence of copper sulfate in their plant material, with the radish and *Lemna* showing the greatest copper concentration. The lab concluded with a series of questions that used the degree of student comprehension as an assessment to the success of the experiment (Appendix C-2). The students completed the week by compiling data, as well as discussing the results of the water/soil tank experiment.

Returning after the Thanksgiving holiday, the groups reconvened for final discussions on the success of the plant uptake of contaminants in the tank environments and how phytoremediation could be used as an alternative technique for sequestering hazardous substances. The unit was finished when the students completed their post test, placed their final opinions in their journals and turned in all lab work/journals for assessment (Appendix P-1).

To support the implementation of this teaching unit a pre and post test were given to the students to indicate growth in knowledge that would justify the amount of time spent in teaching the remediation unit. Additionally, journals were used to give structure to daily activities, as well as to reinforce Southwestern Academy's commitment to "writing across the curriculum". By utilizing both of these assessments, the pre/post test that gave statistical data and the journals that indicated an increase in writing ability the class was able to fulfill the expectations of the school.

Results

Pre and post test comparison and analysis of the phytoremediation unit can be found in the following pages. Each of the questions in the pre and post test addressed a specific objective that was taught in the unit, and the students answered each question as a constructed response (objectives for constructed responses in Appendix C-2, rubric in Appendix P-3). All of the students showed improvement in their test scores, some significantly more than others. Student performance per question as an overall class average is presented in the final pages of this chapter. Figure 1 graphically summarizes student performance per test question. Table 2 summarizes the results of the Paired Student *t*-test, which indicates the rejection of the null hypothesis.

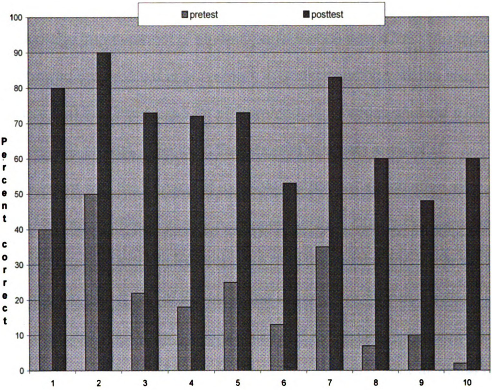

Figure 2: Comparison of Pre and Post Test Scores. n=20

Test Question	T value per question	Probability value per question
1. Define heavy metals	4.29	0.000
2. Define toxic	2.99	0.008
3. Toxic substance	6.89	0.000
4. Toxin pathways	5.29	0.000
5. Lower organisms	4.97	0.000
6. Soil types	4.66	0.000
7. Define remediation	5.15	0.000
8. Phytoremediation	6.24	0.000
9. Natural remediation	2.78	0.012
10. Recycled plants	5.88	0.000
All questions considered	12.6	0.000

Table 2: Results of testing for the rejection or acceptance of the null hypothesis.

In the analysis of the paired student *t* –tests, 0.05 was used as the limit for acceptable data. The probability for all test questions was below the acceptable limit, indicating that the data was valid.

The average improvement of student performance was 47%. The topic that showed the greatest improvement in understanding was the recycling of plants that had been used for phytoremediation, which showed a 58% gain over the pretest. The topic that showed the least amount of improvement was the naming of examples of natural remediation sites, which had only a 38% increase in comprehension. Due to the question being written in a constructed response manner, most of the students responded in giving part of the expected answer, but did not provide a comprehensive response. Each question will be analyzed separately and discussed, and the paired t-test results will be provided. For all of the pre and post test questions, the null hypothesis was rejected with the p value ranging from 0.000 to 0.012, indicating that there had been a gain in students' understanding for all objectives.

Question 1: What is meant by "heavy metals"? How do they differ from other metals?

This concept was not part of the students prior knowledge. Over half of the students left this question blank on the pretest and only 40% of the class recognized that heavy metals had a higher density than other metals. This idea was vital to the unit in that copper (considered a heavy metal because of its ability to accumulate in the environment) was used in both the Red Worm Lab and The Water/Land Interface Lab as the hazardous contaminate. On the post test however, 80% of the students answered the question correctly with responses such as "metals with high density at a low concentration, which become toxic to the environment", and "heavy metals are dense metals that effect [sic] the environment".

Question 2: Define toxic.

Fifty percent of the students answered this question correctly on the pre test, in part because the term "toxic" has a relatively broad application to life and most of them had prior knowledge. The critical idea in this question, however, was that any substance can become toxic if it is able to reach a concentration that causes it to accumulate and leaves the affected organism unable to tolerate its presence. Not only was this concept taught in both of the major labs (Red Worm and Water/Land Interface) but was reinforced in the "Bioaccumulation Activity". As a result of these lessons, 90% of the class correctly responded to this question with responses such as "something that is poisonous to humans and other organisms" and "something at low concentrations that is harmful".

Question 3: Describe how a substance can become toxic.

This question relied on the understanding that any substance can become toxic if it is able to reach a level of concentration within a system (organismal or environmental) where it cannot be disposed or removed from the system, if the substance is not inert. The concept also established a connection between a substance entering the environment and the techniques used to remove or sequester it. In analyzing the pre and post test data, there was a 51% increase in correct answers, with the pretest showing 22% comprehension and the post test showing 73%. Key to the students understanding of this idea was the Red Worm lab, in which the student's observed and collected data of the effects of varying concentrations of copper sulfate on the health of the worms.

Question 4: Name three different ways that heavy metals are known to enter the environment.

The expected responses to this question were broad, in that there are multiple ways for a contaminant to enter the environment. However, there are general pathways that are the result of human activities such as industrial contributions, car exhaust, fertilizer application and the destruction of natural remediation sites like wetlands. As with question #3, the student's showed an increase in regards to understanding, with a gain of 54% of correct answers for the overall class. While some of the students' named the phase that the heavy metal may be found in "solid and liquid" as a pathway, most of the students successfully listed the activities that contributed to environmental pollution, such as "landfills, oil spills, agricultural activities". It is interesting to note that despite the field trip to a restored wetland the students did not readily name agricultural activity as a contributing source. In part, this may be due to the class having an urban background.

Question 5: Explain why lower organisms, such as plants and invertebrates are the first living things to be affected by toxic contamination.

This concept was also not a part of the student's prior knowledge, as it is an ecological idea that is not taught in a general biology class. The question was not intended to imply that all plants are lower organisms, rather to activate the students thinking of living organisms that are not human. With that, 25% of the class responded to this question correctly on the pretest, with a 48% growth shown on the post test or 73% correct responses. The basic point of this question was to assess whether the students realized that by the time a toxic material is shown to affect the human population, multiple organisms and plants have already been exposed to the substance. More importantly, based on the laboratory exercises, the students should have made the connection between the toxic substance being present and how the plant or organism deals with it. This was successfully shown in the post test responses, such as "toxic contamination can occur in the soil and water. Plants take up the toxin through their roots", and "they are closest to the environment".

Question 6: Describe the different soil types and explain why soil composition affects the toxicity of a contaminant.

The general responses given by the students indicated that they had gained an understanding of particle compaction and that the amount of space between these particles leaves room for contaminants to accumulate. The change of 40% between the pretest percentage of 13% and the post test percentage of 53% supports overall success of the student's comprehension on this subject. However, on the post-test most of the students were unable to describe the different types of soil. This was possibly due to the lack of laboratory activities that related to the subject. Other than one comparative demonstration between sand, soil and a sand/soil mix, the class was not exposed to varying soil types.

Question 7: Define remediation and explain why it is important.

Thirty five percent of the class had some idea of how remediation was defined and its implications to human health prior to the unit being taught, as indicated by the pretest. As this was an idea that was central to the unit it was expected that the class would gain a solid understanding of the process of containing and removing a toxin from an area. With the post test result of 83% correct answers and student responses such as "cleaning the environment" and "allowing things to remain alive", even the lowest performing student gained some understanding of the community benefit of remediation.

Question 8: Define phytoremediation and explain how plants are able to "take up" metals through their roots into the shoots, stems and leaves.

This question addresses a more sophisticated understanding of remediation in that it requires the student to not only comprehend the technique of remediation, but specifically the use of plants in this process. Additionally, basic plant physiology must be used to successfully answer this question. With that, only 7% of the class was able to answer this on the pretest, indicated by only three of the 20 students answering the question at all. However, there was a 53% increase in correct answers on the post test, with 60% of the class responding in an expected manner. This was encouraging, because it signified a comprehensive understanding of a number of concepts, namely, that once a contaminant enters the environment there are a number of processes that can be utilized to remedy the situation. This understanding was exhibited by student responses that included, "the plants take them (toxins) up through their roots, taking them into their stems and leaves, and removing them from the soil".

Question 9: Give an example of a natural remediation site that can be found in nature.

It was expected that this question would have the greatest gain in acceptable answers when compared to all other test questions. This expectation was based on the fact that all of the students that took the pre and post test also went on the field trip to a local wetland. They discussed at length the role that a wetland plays in the remediation or cleaning of a contaminated area. It was surprising that there was only a 38% increase in the test scores, the lowest gain of all ten questions. On the pretest only three students attempted to answer the question, resulting in a 10% correct score. The post test did show a gain, with 48% of the students answering correctly. With hands on learning, it was expected that the students would show greater growth than they did. In review of the student answers, there appears to be a misunderstanding of the term "natural remediation sites" since "a water treatment plant" was a commonly given response.

Question10: Can plants used for phytoremediation be recycled? How?

The final question of the test was basically an extension question, one in which the students were required in the post test to use the knowledge to which they had recently been exposed and extend it into an unknown situation. The post test indicated that all of the students gained knowledge, either through the lessons that were taught in the unit or their own research that they had conducted on heavy metals and phytoremediation techniques. This gain in understanding was exhibited by an overall increase of 58% in test scores, changing from the 2% pretest scores to the 60% post test score. Only one student attempted to respond to this question on the pretest. Although there were six students that did not respond on the post test, most of those who did received full credit for their answers. None of the class remembered the discussion that focused on the technique of removing the metals from plants used for remediation and the "reclaiming" the metals for future use. However, some did state that "because the plants could release the toxins into the air (phytovolitilization) they could be reused for cleaning the ground".

Remediation Unit Evaluation

A unit evaluation was given to the students as a measure of what the students felt was most helpful and what components of the unit they disliked. None of these questions were rated on a point scale, so the results were compiled from the survey as the "most frequently given response". This is a subjective evaluation, but worthy of consideration as it allows the students to voice their opinion and aides in judging the most effective techniques used to teach the unit.

Question1: Did you learn anything about how toxins in the environment can harm living organisms?

All students answered yes to this question.

Questions 2: Are there natural systems in the environment that can clean toxins out of the soil and water?

90 % of students answered yes.

Question 3: List three things that you learned from this unit

a. Adaptations by living organisms

b. Soil toxicity and toxicity of chemicals in the environment

c. Plant removal of toxins

d. Tolerance of worms

e. Ability of the environment to clean itself

f. Effect of toxins on water and how to keep it clean

g. Industrial impact on environment

Question 4: Did your opinion of the impact of humans on the environment change after this unit? If yes, how?

10 students answered yes, 14 answered no. None of those responded indicated how their opinion had changed.

Question 5: Did you know before the unit that plants have the ability to clean up contaminants from the environment?

5 students had prior knowledge, 19 did not.

Question 6: If you had to decide if an area was contaminated, what part of the environment/habitat would you look at first and why?

a. Soil – 10 student responses

b. Water – 7 student responses

c. Plants – 3 student responses

Question 7: What activities that you were involved in helped you learn the most? Why?

a. Bullfrog Pond – 13 responses "easier to understand"

b. Red worm Lab – 12 responses "adaptation", "how toxins effect the soil", "fun", "hands-on", "taught how to keep the worms safe".

c. Wetland Tanks – 5 responses "watched the plants grow", "a real environment"

d. Soil Column Demo. – 0 responses

e. Precipitation Lab – 1 response "hands-on"

f. Research Paper – 3 responses – no reason given

Question 8: What was the best part of this unit and why? (Ranked in order of preference)

a. Redworm lab

b. Bullfrog Pond Field Trip

c. Tanks

d. Research

All students responded that these activities were fun and the easiest way to learn.

Question 9: What was the worst part of this unit and why? (Listed in order of most commonly given answer)

a. Worm death

b. Research

c. Tanks difficult to understand

d. Time involved (length of labs)

e. Work too advanced

f. Clean up

g. Notes

Question 10: Give one suggestion to make this unit better when it is taught again.

The responses that the students gave mirrored the responses from question 9.

Discussion

Environmental concepts and ideas are most commonly taught in 10th grade biology class, with very little attention given to citizen responsibility and action. Additionally, as a tax payer we are required to support environmental clean-up procedures, but generally as a whole we remain uneducated (Chiras, 1994) about where and how our tax dollars are being spent. It is in this vein that the phytoremediation unit was developed for Integrated Science. The primary objective was to educate the students on a subject that is not usually taught in a traditional science classroom, with the possible exception being environmental science. The hypothesis in developing this unit was that students would learn about the cause and effect relationship between humans living on the planet, toxic waste that is generated and remediation options that are available. The general take home lesson was that all systems operate under the assumption of balance and that when any part of the system undergoes a change, the system as a whole is affected. In this case, the wetland was the general system and the change occurred when copper sulfate was placed in the models (a water/land tank, and a red worm/soil system). The students observed changes in the organism's health, reproductive ability, growth rate and consequently, death rate. They conducted tests to determine if any of the metal was displaced or taken up by the plants that were present in the tank models, and ultimately conducted population studies on both the plants and the worms in both of the models.

As the students moved through the unit they gained skills in long term record keeping and improved their ability to record laboratory observations. Additionally, they developed advanced laboratory techniques in regards to chemistry, perfecting research techniques and broadening their overall knowledge about human impact on the natural world and the importance of caring for all organisms within the system.

The original intent of the unit was to focus on the use of plants as a remediation technique in removing heavy metals from the environment. As the unit progressed however, it became increasingly clear that as a whole, the unit was broader in its scope. Not only did the unit target the success of plants (to live) in the presence of a toxic substance, but it also encompassed the ability of living organisms (in this case, red worms) to accommodate these same substances. Basically, the unit developed into some aspect of a population study. While this was not intended and certainly not expected, it was a welcomed benefit of learning and instruction. When the students realized that organisms who dwell in the soil are one of the first to be affected when a toxic material is introduced into their habitat, they immediately made the connection to a broader view. That is, a toxic substance that harms or kills plants and invertebrates, may eventually harm humans and other mammals. Many of the discussions that followed the unit centered on the human body and its ability to adapt to exposure to a toxic material. The students used their previous knowledge of body systems by tracing the pathways that a toxin would take, and the organs that were responsible for the sequestering and removal of the material. Subsequently, they also gained a more realistic point of view regarding the fragility of life.

The unit centered around two relatively long-term studies, one a model of a water/land interface and the other a small scale model of a red worm habitat. While the wetland tank model was intended to span a four week period of time, due to the constraints of a holiday weekend and the interruption to the testing schedule, the experiment was shortened by one week. After the subject of toxins was introduced on the first day and the pre-test was given, the students began to construct the tank models for the wetland tank experiment. Most of the subsequent activities took longer than expected, resulting in a number of the projected activities being dropped from the unit. Basically, the students had no experience with self directed learning and to a certain extent felt lost without the instructor directing them throughout every procedure. However, as the unit progressed, they became more confident in their ability and took the initiative to complete the tasks at hand. For instance, the students had no idea how to plant seeds into the soil or that rocks were needed for aeration on the bottom of the tanks to ensure that the plants would receive proper oxygen for growth. Also, it was not until the second week that the class began to show a personal interest in the plants and the effect that the copper sulfate was having on them. As the plants broke the surface of the soil, the class realized that they were dealing with living organisms.

To save time in the future, adult plants would be used so that the root systems would be established sooner allowing the copper sulfate to be added earlier to the tanks and extending the experiment into the fourth week. One other issue that created some anxiety among the class was the complexity of the chemical test for the presence of copper. The students had not been exposed to advanced chemical testing (keeping track of ferric thiocyanate and sodium thiosulfate), were not familiar with the equipment (spot plates). Because they were hesitant to reread the directions, a number of the tests had to be repeated. One possible solution would be to start training the class on laboratory procedures earlier in the year, so that they would feel confident in their ability.

In retrospect, this lab was successful in teaching phytoremediation, in that, when the class compiled their data, it was clear that the tanks that had land plants in them, and particularly radish, had the greatest *Lemna* survival rate. This was the point of the experiment. When metal tolerant plants are placed in soil that has been contaminated, they successfully slow the percolation of the toxin into the surrounding areas (represented by the *Lemna*), ultimately retarding the death rate of surrounding plants. In answering the post lab questions the students generally answered in full statements and with vocabulary that they did not have prior to the experiment. The only consideration for future use would be to conduct this lab after plant physiology and tolerance mechanisms had been taught, so that the students held some prior knowledge to generate solutions that apply to the model.

The students were required to enter information into their lab/composition books on a frequent, if not daily basis. It became clear that they did not have a background that included writing their own opinions down on paper, and for the first few days stumbled on exactly what to say. Initial writings included "we had to put rocks and sand in the tank and filled it up with soil" and "we put blue stuff in the tanks", but eventually progressed to "the tanks are doing good [sic], we put copper sulfate in the jars to see how long the worms can live in there. I think if will be a few days" and "today we took the mass of our worms and we noticed that our mass was getting both higher and lower". This exercise could have benefited from having the students engage in journal writing and scientific observations prior to the unit being taught so that they were both familiar and comfortable with the process. The lack of journal entries also reflects the students' general apathy in following through with long term assignments and required reading of experimental procedures. A consistent theme throughout the unit was that the class did not reread procedures and data requirements which ultimately led to some of the groups having to repeat tests so that reliable data could be collected. Again, this issue could be rectified by practicing the skills prior to utilizing labs that require long term observations.

The field trip to a restored marsh/recovering agricultural field (Bullfrog Pond) was a huge success. The director of the outreach program sponsored by the Genesee County Soil and Conservation Office, Gary Huffman was both knowledgeable and patient with the class as he took them on a tour of the grounds, answering their questions and assisting them in conducting soil and water tests. Upon returning to the classroom, the students retained the information that they had learned, evidenced by correctly answering field questions that they had been asked. The hands-on experience aided the students in understanding the notes (because it gave them a point of reference) on both nutrient requirements for plant growth and sustaining mechanisms, an activity that focused on maintaining the balance within an ecosystem. On the post unit survey the field trip was ranked as one of the classes' favorite activities, in part I believe, because the students were able to construct their own personal meaning. One difficulty that presented itself with the soil testing from Bullfrog Pond was that the rapid soil test capsules that were used in the soil testing did not dissolve well and the directions were difficult for the class to understand. In repeating this exercise, I would type the directions out for greater ease of understanding and perhaps use a more traditional nitrogen, phosphorus and potassium test that did not rely on encapsulated chemicals. Additionally, on the post test, the question that referred to this experience (#9) had the lowest percentage of growth when compared to the pre test. I found this confusing, given that the class had the opportunity to directly interact with a natural wetland/remediation site. However, it is possible that post field trip discussions did not reinforce the natural remediation site concept.

Throughout the unit the acquiring of skills was heavily dependent on class discussion and the voicing of individual opinions. The first class discussion was at best halting, but as the students relaxed with each other and their cooperative teams, they became more vocal. At the end of each activity the class was encouraged to discuss their concerns and understandings. Not only did this create continuity among class members, but allowed each individual to take responsibility for their learning, and impart their knowledge to the class as a whole, filling in the "blanks" for other team members. This was very important for the Integrated Science class because a requirement for entry into the class is that the student maintained a C or lower grade average in their previous science classes. Consequently, many of the students did not have strong backgrounds in basic information such as plant physiology, an issue that was rectified by fellow classmates. The cooperative sharing of information was also evidenced in the groups conducting the Red Worm lab. This lab was shorter in length (two weeks) and provided invaluable base knowledge that the students were able to apply to the wetland tanks. The development of a foundation of knowledge that allows the student to "access that knowledge and apply it to a new situation" (Sonmez & Lee, 2003) is a basic tenet of problem based learning. Due to the shortened length of the lab, the class observed the effect that higher concentrations of copper sulfate had on the worms' health (higher concentrations resulted in increased worm death) and transferred the knowledge to the wetland tanks, watching for the same expected results. The wetland tanks were ill-defined problems. The class had no textbook to rely on for information regarding plant physiology, and although they engaged in note taking that provided them with reference for plant structure, nutrient requirements and uptake mechanisms, the class as a whole had no predefined expectation of what would happen to the plants once exposure to a toxic chemical had occurred. Hence, they relied on questions that were posed by the instructor to guide their observations and pursued various problem finding solutions that were generated by their teammates (Sonmez & Lee, 2003 and Martin, 2001). This lab ended up being one of the favorite activities of the class. Although on the post unit survey there were a number of comments about the Red Worm lab being messy, in general the teams excelled at the twice weekly counting and weighing of the worms. The class members became quite competitive with each other in regards to worm longevity and felt a sense of compassion (this was often vocalized) when the worms died. Most importantly, although the lab was designed to teach the basic principle of metal tolerance and toxic concentration, it was also successful in teaching the impact of hazardous substances on population size and the necessary environmental conditions for good health, such as adequate water and habitat maintenance. The only suggestion for future use would be to use a greater amount of soil (500-750 grams) so that upon the addition of the copper sulfate, the worms would not die due to an overabundance of moisture. Although there was no way to prove that some of the worm death that was experienced was due to this oversight, the class as a whole agreed that perhaps the worms had drowned, because the jars that were used did not contain drainage holes. This issue could be corrected by using plastic containers in which drainage holes could be drilled.

A number of the activities that were developed on campus during the research aspect of my Master's classes were not implemented due to time constraints. One of these that I feel would be beneficial to teaching the unit was the testing for iron presence in both the soil and the water of the wetland tanks. The importance of including this activity in the unit is that the students begin to understand that some metals are naturally present in the environment and do not necessarily build to toxic concentrations. Other developed experiments such as the percolation lab had to be conducted as a demonstration rather than as a class experiment, to save time. In the future, I would use the percolation lab and combine it with the pH experiment so that the class had a solid model of how metals can move through a soil column and accumulate, based on the acidity of the soil. Also, a paper making lab was developed as an introduction to the unit, with the intent of teaching the class recycling methods, how matter recycles, but is not destroyed, similar to toxins in the environment. In re-teaching this unit, I would definitely use this activity to heighten the student's interest in the subject. Additionally, one of the most important changes that I would make to this unit is the placement of it in the school year. The research was conducted approximately five weeks into the first semester, at the beginning of the biology unit. In retrospect, I would teach this unit again at the end of the biology portion of the class so that the student's had full review of all of the biology benchmarks and standards, and could access this knowledge. In an ideal world this unit would be taught as a focal point of an environmental class. Currently, I am in negotiations with the district to adopt such a class into their curriculum.

Finally, the computer research that the students conducted was a success. This was true regardless of the student's academic ability, evidenced by the average grade of a B. Although the class moved as groups through the remediation unit learning new information, individuals were given the opportunity to express their own knowledge in independent activities. Using information that had been gained from researching local environmental hazards, each student investigated different metals that were released into the environment discussing the implications to human, plant and soil health. By "constructing personal meaning" the students built on previous knowledge that they acquired during class investigations and readings and applied it to a new situation. This is the basis of the constructivist theory of teaching and learning.

The class was able to integrate this new information into their existing knowledge and use it as a springboard for their research paper.

The combined activities supported a greater personal understanding for the class. As one student wrote in her journal "you can relate this to your own world". Future activities that would also increase personal knowledge include providing protocols for EPA clean-up sites so that the class would understand how remediation decisions are made on a governmental level, developing a rubric for neighborhood investigation of local contaminants and inviting an environmental activist to visit the classroom to encourage the students to become involved in maintaining the health of the Earth. These suggestions would extend the learning that had been gained in the classroom to a real world experience, thus enhancing personal understanding and activating a sense of responsibility from the student to the community.

As an overview of the unit and its success, it is necessary to look at the results of the data analysis on the pre and post tests, and the final computed class grades. The average grade earned for this unit, which spanned one marking period in length, was a C. While this is not an outstanding average, it reflects the ability of the class as a whole. This grade was computed based on a compiled rubric (Appendix P-2) that included all of the activities of the unit. The largest loss of points came from not completing the lab questions and failure to turn in a research paper. In part, some of the responsibility for this failure falls on my shoulders, due to time constraints and not allowing the students adequate class time to work on completing their labs. I wrongly assumed that the students would take responsibility and finish the work outside of class if they had not completed the assignment. In reviewing the results of the pre and post test questions, there was not one question that did not gain in percentage of correct answers. The students had never learned about contamination and remediation prior to the unit, nor had they had the opportunity to conduct experiments that were of a more advanced nature. The two questions that had lower than a 40% increase in correct answers were the description of soil types and the effect that the soil had on the accumulation of toxins, and the description of a natural remediation site. The soil question had a designed percolation experiment that would have reinforced the understanding of the class. This was changed to a demonstration, which did not assist the students in developing a greater understanding of the topic. Also, the naming of a natural remediation site should have had higher test results (38%) based on the field trip. The problem may have occurred because the field trip was taken in the beginning of the unit, and the topic was not formally revisited as the unit progressed. All other test questions had a gain in correct answers of over 40%, with question #3 (describing how a substance becomes toxic) and #4 (describing three different pathways a heavy metal can enter the environment) experiencing the greatest growth. At 51% and 64% respectively, these two questions attest to the student's comprehension of how any substance, when found in concentrations great enough to cause harm, can enter the environment and cause toxicity.

Although the original intent of the unit was focused on the use of plants to clean a toxic site, and is evidenced by a gain of 53% in correct answers given to question #8 (that asks the student to define and give examples of phytoremediation), it is clear that the learning extended beyond remediation. On a biological level, the students learned that any substance in concentrations that are beyond the tolerance level of the exposed organism can cause harm or death. As a population study, the class gained knowledge of how small numbers of organisms that are affected by a toxin indicate a larger problem. Lastly, is the lesson that some organisms have built in mechanisms that allow them to tolerate a toxic substance and to sequester that substance so that it can no longer move into the environment and continue to cause damage.

When I stand back and reflect upon the unit I realize that as an instructor I expected a great deal of concentration, commitment and dedication from the students to accomplish the goals I had set before them. The laboratory testing was college level and the class did an exceptional job of conducting the chemical tests. Generally, when using this unit in the Fall of 2005, I will relax and enjoy the process, integrate more of the activities that were developed and not used, and spend more time on teaching the class on how to become environmental activists.

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APPENDICES A-R

Appendix A: Michigan Content Standards

A-1: Michigan Content Standards and Benchmarks

Content Standard I
Construct new scientific and personal knowledge.
Reconstruct previously learned knowledge.
Reflect on the nature, adequacy and connection across scientific knowledge, show how common themes apply in a real world context.

Reflection I.I.H.1
Ask questions that can be answered investigated empirically

Reflection I.I.H.2
Conduct scientific investigations

Reflection I.I.H.4
Gather and synthesize information from books, and other sources.

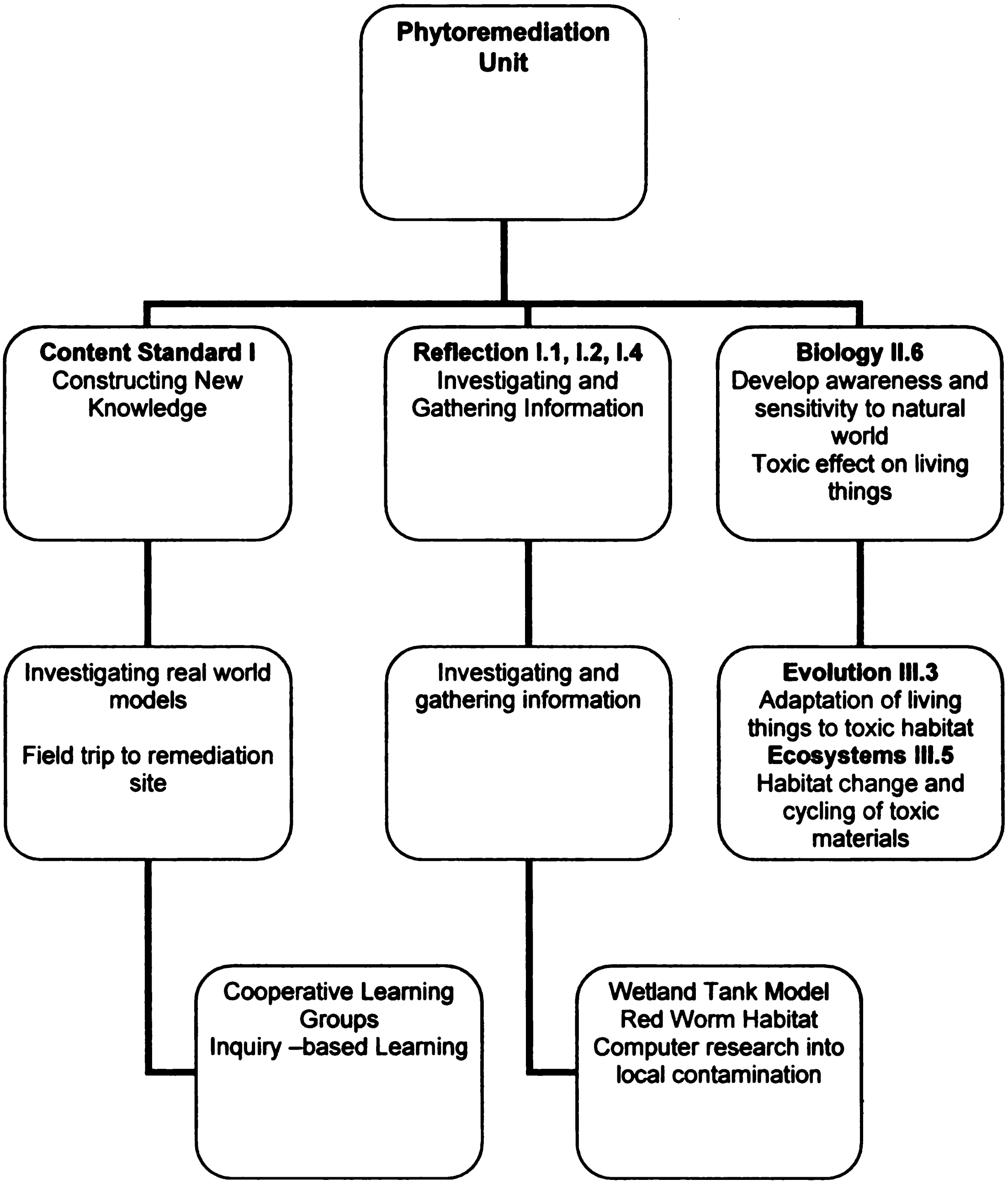
Reflection I.I.H.7
Identify and use safe procedures in science activities.

Biology II.H.6
Develop an awareness of and sensitivity to the natural world.

Evolution III.H.4
All students will compare ways that living organisms are adapted to survive and reproduce in their environments and explain how species change through time.

Ecosystems III.H.5
All students will explain how parts of an ecosystem are related and how they interact.
All students will explain how energy is distributed to living things in an ecosystem.
All students will investigate how communities of living things change over a period of time.
All students will describe how materials cycle through an ecosystem and get reused in the environment.

A-2: Flow Chart of Content Standards and Main Unit Ideas



Appendix B: Consent Forms

Parent and Student Consent Form
Collection of Data for Master's Thesis

Dear Parent/Guardians and Students:

During this semester I will be implementing a unit on the use of plants to clean contaminated areas in the environment. I have developed this unit as the major portion of my Master's thesis at Michigan State University. The students will actively learn about environmental issues, test models in the classroom, and gain a greater understanding about their ability to make a difference in regard to environmental decisions. An important aspect of this work is obtaining data about the effectiveness of this unit, which will in turn be the foundation of my thesis.

In order to evaluate the learning process, data will be collected from pre and post tests, research information that the students have generated, as well as responses from laboratory experiments and surveys that will be given throughout the unit. With your permission I would like to include your child's data in my thesis. Your child's privacy will be protected to the extent that is allowable by law, and at no time will the students' name be used or connected to any part of my thesis paper.

Your child will receive no penalty in regard to their grade should you deny permission for the use of their data. They will be expected to participate in the classroom activities and assignments, however, their data will not be used in my thesis work. At any time during the unit you may request that your childs' data not be analyzed, and your request will be honored.

Please complete the attached form and return it to me as soon as possible. Should you have any questions feel free to contact me at Southwestern Academy, 810-760-1400 or by email at kgould@flintschools.org. If there are any questions that you have about your rights as a study participant, please contact

Sincerely,

Karen A. Gould
Science Teacher – Southwestern Academy

Please complete the following form and return it to me no later than October 1, 2004.

....

I voluntarily agree to have
________________________________participate in this study.
(print student name)

Parent/Guardian Signature ______________________ Date ______________

I voluntarily agree to participate in this study.

Student Signature ______________________________ Date ______________

CONSENT FORM REGARDING RELEASE OF STUDENT INFORMATION

Please print while completing this form.

____

Student's Name   Hour   Grade

____

Student's Home Address

I. Permission to Display Photograph, Audio, Visual or Electronic Images:

I give permission (or do not give consent) for photographs, audio, visual or electronic images of my student, to be used by the Flint Community School District for exhibition, public display, publication, publicity materials, a news media story, or photographic release. I understand that my student's full name may be used with such display except that only my student's first name will be used on the District's website.

____ I give my consent

____ I do not give my consent

II. Permission for News Stories:

I give consent (or do not give consent) for quoted statements given by my student, or photographs, audio, visual or electronic images of my student, with possible identification by full name, to be used for the purpose of news stories or interviews about Flint Community Schools or educational experiences by our area news media.

____ I give consent

____ I do not give consent

____

Signature of Parent or Responsible Custodian/Guardian
Date

____

Printed name of Parent or Responsible Custodian/Guardian

Please complete this form and return to Southwestern Academy

Appendix C: Pre and Post Test

C-1 Pre and Post Test

Name: ______________

Contamination and Remediation

The following questions are designed to help both of us develop an understanding of the knowledge that you have brought with you to this class. Remember that this is a *tool*, not a judgment about what you know. Answer the questions to the best of your ability, using past knowledge and analytical reasoning.

1. What is meant by "heavy metals"? How do they differ from other metals?

2. Define toxic

3. Describe how a substance can become toxic.

4. Name three different ways that heavy metals are known to enter the environment?

5. Explain why lower organisms, such as plants and invertebrates are the first living things to be affected by toxic contamination.

6. Describe the difference in soil types and explain why soil composition affects the toxicity of a contaminant.

7. Define remediation and explain why it is important.

8. Define phytoremediation and explain how plants are able to "take up" metals through their roots into the shoots, stems and leaves.

9. Give an example of a natural remediation site that can be found in nature.

10. Can plants used for phytoremediation be recycled? How?

C-2 Pre Test and Post Test Objectives

The students will be able to summarize these major ideas.

1. What is meant by "heavy metals"? How do they differ from other metals?

- Heavy metals have a higher density and tend to accumulate in the environment, include living organisms, at a higher rate than other metals.

2. Define toxic

- "Toxic" refers to any substance that can cause harm or death when it reaches a critical concentration, a level that is not tolerated by the organism

3. Describe how a substance can become toxic.

- Any substance can become toxic if it accumulates, either in the environment or within an organ system, and cannot be disposed or removed from the system.

4. Name three different ways that heavy metals are known to enter the environment?

- Heavy metals occur naturally in the environment, where they are generally tolerated. Other contributing pathways include: industrial waste (liquid, solid, gaseous), human activity private life (car exhaust, lawn application of fertilizer, septic chemicals, etc.) break down of natural containment areas, pollution.

5. Explain why lower organisms, such as plants and invertebrates are the first
living things to be affected by toxic contamination.

- Toxicity is dependent on concentration of substance and the organism's ability to remove the toxin from its system. Lower organisms are generally smaller in size, their vascular systems are smaller and they live directly in (contact) with the source of the contamination. Due to their inability to move away from the source of toxicity, they are affected first and most often harmed in the greatest way, when contamination occurs.

6. Describe the difference in soil types and explain why soil composition affects
the toxicity of a contaminant.

- There are three main soil types – sand, peat, loam and a mix of all three. Depending on the area of the world (geographically), soil types are different, due to environmental factors such as water exposure, glacial activity, salt concentration, etc, The larger the particle size, the larger the air space between particles. This air space also allows for solid/liquid contaminants to move and be stored in one area. The sandier the soil, the greater the "holding ability" of the soil.

7. Define remediation and explain why it is important.

- Remediation is the process of containing and cleaning an area that has been contaminated by a toxic substance. This can be accomplished a number of ways, and it benefits the environment because it stops the contamination from spreading to other habitats and harming other organisms.

8. Define phytoremediation and explain how plants are able to "take up" metals
through their roots into the shoots, stems and leaves.

- Phytoremediation is the use of plants to contain a toxin in a contaminated area by sequestering the toxin, in this case, heavy metals, through their root systems. Once the metal has entered the root system, it is taken up into the plant through the vascular system and is either contained or volatilized by the plant.

9. Give an example of a natural remediation site that can be found in nature.

- A wetland is a natural remediation site. Contaminants are removed and/or contained by the roots/shoots of the plant and the water is cleaned by the respiration of the plant. Other examples of natural remediators include poplar trees, weeping willow, cat tails and duckweed.

10. Can plants used for phytoremediation be recycled? How?

- Plants that contain metals and other contaminants that have been sequestered can be recycled. Burning the organic material and collecting the ore is one example. Plants can also be removed from the contaminated area and buried in a landfill, adding to the organic structure of the soil.

Appendix D: Heavy Metal Experiment

D1: HEAVY METAL EFFECT ON PLANT SURVIVAL WETLAND TANK MODEL

Purpose: The purpose of this lab is to demonstrate the effect that remediative plants have on an area that is contaminated with heavy metals. The model is that of a soil/water interface, similar to a soil bank and static pool in nature.

Objective: The students will gain a greater understanding of the natural cleaning system that exists in wetland areas, the effect that metals have on a site inhabited by plants and the impact that plants have on a contaminated area.

Materials:
This lab is designed as a group project in that all of the class will contribute to the construction of the class models. Thus, the materials are listed as it applies to the entire class.

- 5 - 5.5 gallon aquarium
- 5 dowels, cut to fit the inside of the aquaria (lengthwise)
- Landscape fabric
- Marine epoxy – quick setting
- Potting soil – 1 large bag (20 lbs.)
- Peat – 1 cubic foot
- Sand – 20 lb bag
- Small rocks – enough to cover the bottom of the tank at a 2 inch depth (used for aeration)
- Plant food – 15,30,15 mix works well
- Duckweed (*Lemna minor)* –250 plants total
- Radish seeds – *(any* plant from the *Brassica* family will work). Two packets is sufficient, pre-germinated
- Lettuce – (any plant that is a fast to germinate). Two packets of seeds are sufficient, pre-germinated.
- Grow lights
- 2000 ml of pond water or tap water
- Copper Sulfate – O.1 M (25 grams $CuSO_4$ per 1 L H_20) – 3000 ml total
- Ferric thiocyanate solution – See instructor
- 0.1 N sodium thiosulfate solution
- 1 N HCl
- Spot plates

Procedure: Building the model

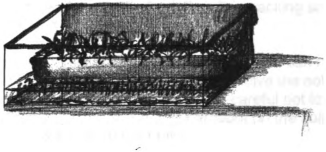
1. Each group of 4-5 students will be given 1 aquarium and 1 dowel. Measure the width of the tank, find the mid-point, and place a mark. Measure the height of the tank, find the mid-point, and place a mark. Repeat the process on the other end of the aquarium.

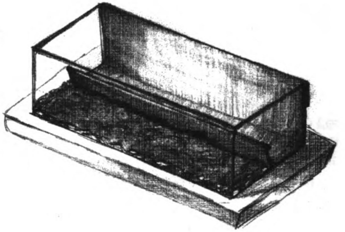
2. Measure and record the length of the aquarium. Measure and record the distance to the bottom of the tank from your mid-mark, the distance from the mid-point of the floor of the tank to the edge and the distance from the edge of the floor to the top of the tank. Total these numbers and add three inches. You now have a general (rectangular) size for your landscape fabric. Measure out on your fabric the width and length needed for the aquarium and cut this rectangle out. .

3. Using the marks that you made as a guide, place epoxy on the marks on the inside of the tank, as well as the ends of the dowels. Move the dowel into the tank (turning diagonally to place inside) and place the ends of the dowel on the marks. Hold the dowel steadily in place until the epoxy has set, approximately 3-6 minutes. See diagram below.

4. Place the landscape fabric inside of the tank, matching up the width of the fabric with the dowel length. Pull the fabric under and then over the dowel creating a hem for the dowel to rest in. You can either staple the fabric edge to the fabric length or stitch it by hand. When you have completed this, the fabric should be attached to the dowel, drape down the floor of the aquarium, up the side of the tank and have a 2-3 inch hang over the edge. See diagram below.

5. Holding onto the landscape fabric, place rocks (to the depth of nearly 2 inches) on the inside of the fabric, leaving one side without rocks and the fabric side with rocks. Sprinkle sand on top of the rocks until they are covered. Sprinkle sand to about ½ inch depth (2 cm) on the non-fabric side. This creates an area that will allow for air spaces.





The top drawing is an example of the finished tank.

The bottom drawing is a representation of the tank prior to adding soil, plants and water.

6. Mix soil in the following proportions: 40% peat, 40% potting soil and 20% sand. The total amount of soil needed is approximately 12 cups or 3000 g of soil per tank. Either mass the soil or use a measuring cup. Loosely place the soil on the fabric side of the aquarium. Once the soil has reaches a level equivalent with the dowel, begin to slowly add more soil so that it angles up the side of the tank. Complete this packing and angling until all of the soil is used.

7. Slowly add ½ teaspoon fertilizer to 2000 ml of water (you can mix this in a two liter pop bottle). Swirl the solution slowly to dissolve the solid. To the sand only side, add the water/fertilizer mix, being careful not to over stimulate the sand bottom. *Sprinkle a small amount on the soil side.* This amount of water is added to all of the tanks.

8. Labeling tanks – each tank will be labeled as follows

- Lemna, lettuce, radish, $CuSO_4$
- Lemna, lettuce, radish, no $CuSO_4$
- Lemna, radish, $CuSO_4$
- Lemna, lettuce, $CuSO_4$.
- Lemna, no plants, $CuSO_4$

Establishing the design model

1. Each group will be given a different mix of plants to place in their aquarium, based on the label the group was given. Gently place 50 Lemna plants (easy to distinguish by their single root) into the (water side) tank. The radish/lettuce tank has two tablespoons of each type of seed, and the remaining tanks have the radish or lettuce seeds (two tablespoons) according to the aquarium label.

2. Sow the seeds in the soil by making small indentions. Once seeds are placed in the soil, sprinkle with water to wet. Allow plants to germinate and take root (under grow lights) – this may take 3-5 days. After the land plants have started to show stem growth, add (by sprinkling with a watering can or jar that has holes punched in the metal top) 600 ml of $CuSO_4$ to four of the five tanks, on the soil side. *Follow the labels on the tanks!*

3. On the data table place the starting date. Once a week or every five days, observations will be made as to the health of the plants (color, wilting, etc.) and the Lemna will be counted. This information will be placed in the data table.

4. The following chemical test will be conducted (once every 5 days) to determine the presence of copper sulfate in the water. Follow the directions carefully.

Copper Presence Test

- Obtain an eyedropper bottle containing ferric thiocyanate and another containing 0.1 N sodium thiosulfate solution from the instructor.
- Each group will withdraw 1 ml of test solution from their aquarium, using a pipette.
- Working with a spot plate, place one drop of distilled water in one plate well and one drop of the test water in the next plate well.
- To each well add 1 drop of sodium thiosulfate solution. One team member will watch the clock, one member will stir the test solutions in the plate (as drops are added) and one member will add 3 drops of ferric thiocyanate solution to each test well. As soon as the ferric thiocyanate solution is added begin timing, counting the seconds until the test water turns from a blood red to a clear colored solution.
- Comparing the time of color dissociation to the chart below, estimate the concentration of $CuSO_4$ in the test water. Record time and estimated concentration in the data table. Carefully rinse the test plates with water and wash hands.

Concentration of copper sulfate	Time to reach clear solution
0.1 M $CuSO_4$ (10^{-1} M)	instantaneous
0.01 M $CuSO_4$ (10^{-2} M)	instantaneous
0.001 M $CuSO_4$ (10^{-3} M)	instantaneous
0.0001 M $CuSO_4$ (10^{-4} M)	3 seconds
0.00001 M $CuSO_4$ (10^{-5} M)	30 seconds

This chart is the result of diluting the original concentration of $CuSO_4$ by one tenth per application. This was accomplished by adding 1 ml of $CuSO_4$ to 9 ml of H_2O (0.01 M). From the remix 1 ml was taken out and added to 9 ml of H_2O to achieve 0.001 M, and so on.

5. Repeat the observations and copper testing once a week for three more weeks. All information is placed in the data table.

6. At the fourth week, plant material will be harvested. Each group will pull 2 of their land plants (4 total for the radish/lettuce mix), as well as a number

of the surviving Lemna. Each plant will be placed on a watch glass and put into a microwave for 5 seconds, driving the water from the tissue. Remove the plant material, allowing it to air dry until crisp (1-2 days).

7. Macerate the plant material until it is finely ground. Place the material into a microfuge tube or a small test tube that has a cap or rubber stopper. It may be beneficial to puncture a hole in the top of the cap to allow for the escape of gas, after inverting the tube. Add 1 ml of 1 N HCL to each tube, invert to mix and let stand for 24 hours (allowing solids to fall to bottom).

8. Pull off effluent with a pipette. Using the procedure for the "testing for copper presence", test all plant material (radish, lettuce and Lemna) for copper concentration. Place information in data table.

9. All data information will be compiled into a class data table. The results will be used to create a bar graph that illustrates the effect of land plants on the metal concentration in the water.

10. Answer the questions following the experiment. If you are missing any information from your data table, please fill in your table using a group member's data.

NAME ________________
HOUR ________________

DATA TABLES FOR EFFECTS OF HEAVY METALS ON PLANT GROWTH

Copper Concentration IN WATER	Initial	Week one	Week Two	Week Three	Week Four	Change
Lemna, $CuSO_4$						
Lemna, radish, lettuce, $CuSO_4$						
Lemna, radish, lettuce, no $CuSO_4$						
Lemna, radish, $CuSO_4$						
Lemna, lettuce, $CuSO_4$						

Copper Concentration IN SOIL	Initial	Week one	Week Two	Week Three	Week Four	Change
Lemna, $CuSO_4$						
Lemna, radish, lettuce, $CuSO_4$						
Lemna, radish, lettuce, no $CuSO_4$						
Lemna, radish, $CuSO_4$						
Lemna, lettuce, $CuSO_4$						

Lemna Count (numbers)	Initial	Week one	Week Two	Week Three	Week Four	Change
Lemna, $CuSO_4$						
Lemna, radish, lettuce, $CuSO_4$						
Lemna, radish, lettuce, no $CuSO_4$						
Lemna, radish, $CuSO_4$						
Lemna, lettuce, $CuSO_4$						

Copper Present in Plant Material at End of Study	Radish	Radish Root	Lettuce	Lettuce Root
Lemna, radish, lettuce, $CuSO_4$				
Lemna, radish, $CuSO_4$				
Lemna, lettuce, $CuSO_4$				

Lab Questions

1. What does the model used in class represent in nature?

   ____

   __

2. Define "heavy metal". Why is copper considered a heavy metal?

   ____

   ____

   ____

   ____

3. Why was the copper put into the soil as a liquid? What would have happened if it had been put into the soil as a solid (its natural form)?

   ____

   ____

   ____

   ____

   ____

4. Explain how plants take up nutrients (remember that copper is a micro nutrient) from the soil.

____
____
____
____

5. Explain how a nutrient can move from being beneficial to being toxic. Hint: what has to happen to the concentration of the nutrient and how the organism handles it?

____
____
____
____
____

6. Looking at the class results, which tank model had the greatest lemna growth? Why did these results occur?

____
____
____

7. Looking at the class results, which tank model was the most toxic to the Lemna? Why did these results occur?

____
____
____
____
___
____
____
____

8. If you were to compare the concentration of copper in the water to the concentration in the soil, what do you think you would find? Describe a way that you could test the amount of copper in the soil.

____
____
____
____
____

9. Which plant was the most tolerant of the copper? How did you know this?

____

____

_____

10. What part of the plant was exposed to the metal? When you tested the plants for copper presence, you used the stem, shoot and leaves. Was this the best choice? Why or why not?

____

____

____

____

____

11. You work for an environmental group and have been notified that there has been a cadmium leak into a local lake. It has leached out from an underground tank, and you are expected to clean it up.

a. What is cadmium?
b. What type of element is cadmium?
c. How would cadmium affect the water plants and the land plants?
d. What animals could you look at to tell you how much cadmium is in the area? Hint: what about their behavior?
e. Describe a clean up model that would take care of the problem. Be certain to give reasons for your choices

D 2: Heavy Metal Effect on Plant Survival
TEACHERS EDITION

Remediation of contaminated sites is a topic that is relevant to high school students. Although they may not see the connection to their existence, the problem of contamination is an issue that will have to be addressed by the next generation. This experiment is a 5 week project that could be started either as an introduction to a heavy metal chemistry or to an environmental unit. It is not necessary to give a lot of background information prior to the set-up of the design model, as plant physiology, nutrient uptake, contamination pathways, and remediation models can be taught as the experiment progresses.

The key point of this lab is that there are alternatives to moving contaminated soil into landfills, and that hazardous waste is not "someone else's problem". Phytoremediation or the use of plants as a natural cleaning tool is not a new science. However, it is not generally taught in the classroom and its validity is important. The students should walk away form this experiment with a clearer understanding of heavy metals, their impact on living organisms, how macronutrients (some of which are metals) can become lethal toxins, normal plant function and how that function lends itself to remediation. By creating 5 different modeled environments, the students will be able to clearly see the effect of contamination by comparing the health of the plants (color, total numbers, death, etc.) with each tank. *An indication of toxicity to the Lemna is that the fronds begin to turn white.*

Five 5.5 liter aquariums are used for the models. The control tank contains all three types of plants and no copper sulfate. If the classroom doesn't have the space for five aquaria of this size, clear plastic shoeboxes could be used, but the volumes of the soil, plant seeds and copper would need to be adjusted accordingly. Landscape fabric works well as a retaining wall for the soil because it allows water (and contaminants) to move across the interface into the water without soil loss.

The construction of the model is as follows: a dowel should be cut to fit inside the length of the tank and securely adhered to the walls at a midpoint (height and width). The fabric width matches the dowel length and is folded over the dowel and stitched (or stapled, but is less secure). The length of the fabric should be long enough to drape down to the floor of the tank, across the tank bottom, up the tank wall and have an over hang of 2-3 inches. In this pouch 2 inches of mid sized rocks, covered with ½ inch of sand and then 8-10 cups of soil are added. The mix of the soil is 40% peat, 40% potting soil and 20 % sand. If the soil is packed too tightly, anaerobic conditions occur and the plants won't grow well. Although it is suggested to put 50 Lemna into each tank, that could be changed at your discretion. The hardest part of this step is that the students tend to not be exact in their Lemna count because the plants are so small. If the lettuce and radish seeds are pre-germinated they will sprout faster and will be stronger when the copper is added.

The brassica family is known to be metal tolerant and includes cauliflower, broccoli, radish and mustard. Lemna is also metal tolerant, and is actually a water plant known to take up metals. This is an important point because it reinforces the idea that all organisms have a level of concentration tolerance, in which a substance moves from being beneficial to lethal. In regards to the lettuce, it was chosen because it is a fast growing plant, but again, it is personal choice as to what plant family to use.

Copper sulfate is added to the soil side of 4 of the 5 tanks in one dose of 600 ml of 0.1 M $CuSO_4$. If you were testing the total concentration of copper in the water and soil over a period of time, you could add more than one dose, however for this lab the focus is on the movement of the metal across the soil/water interface and the effect of the copper on the land/water plants. Additionally, the effectiveness of metal uptake by the radish is also tested by the plant solids being macerated and subject to the copper presence test. It is expected that only the radish shows copper presence, but it is possible that the duckweed will also test positive, due to its uptake ability.

The root system of the land plants and their ability to hinder the movement of metal should be considered and discussed, as this is a vital point in phytostabilization. As the weeks progress, it would be beneficial to discuss and teach the various phytoremediation techniques such as phytovolitilization and phytodegradation.

Finally, when adding water to the all of the tanks it is helpful to use pond water if collecting Lemna from the wild. Generally the Lemna are healthier and reproduce at a greater rate because they are already acclimated to their environment.

Expected Results: This lab will demonstrate that radish tolerates, grows and takes up metals (when macerated is positive for copper), lettuce is intolerant and dies in the presence of metals and Lemna, while tolerant of metal (may be positive for copper), is limited by its presence. Also, the presence of rooted plants in the soil slows down contamination into other areas of the environment when the soil is contaminated first.

In analyzing the data, a collective data table that is displayed on the board, an overhead or a computer screen should be generated so that the students can compare plant numbers across all of the test models. From this data a bar graph will effectively demonstrate the impact of the metal on Lemna numbers and the students can determine the environmental conditions (plant root systems, type of plants, plant tolerance, etc.) that created their results.

CHEMICAL "RECIPES"

Copper Sulfate - Mol. Wt.= 249.68 grams

0.1 M $CuSO_4$ - 25 grams solid copper sulfate dissolved in 1000ml (L) of water
3000 ml needed – 600 ml per aquarium

Copper Presence Test Solution

Sodium Thiosulfate - Mol. Wt = 248.18 grams

0.1 N $Na_2S_2O_3$ – 1.24 grams solid dissolved in 100 ml

- Place the solution in an eyedropper
- One eyedropper per group

Ferric Thiocyanate

1.5 grams – ferric chloride
2.0 grams – potassium thiocyanate
*dissolve both solids in 100 ml of water

- Placed the solution in an eyedropper
- One eyedropper per group

Procedure

- Put one drop of test solution (aquarium water) and a drop of distilled water in adjacent depressions of a spot plate
- Place one drop of ferric thiocyanate into both spot wells, stir with glass rod to mix
- Place three drops of sodium thiosulfate in each well and stir with a glass rod to mix
- The time of decolorization of a copper-free solution is 1.5 – 2 minutes. The decolorization of the test solution containing as little as 1 microgram of copper is almost instantaneous.

The chart below was calculated using a dilution gradient of 0.1 of the copper sulfate solution. It creates a scale that the students can compare the time of their solution decolorization with the standard.

Concentration of copper sulfate	Time to reach clear solution
0.1 M $CuSO_4$ (10^{-1} M)	instantaneous
0.01 M $CuSO_4$ (10^{-2} M)	instantaneous
0.001 M $CuSO_4$ (10^{-3} M)	instantaneous
0.0001 M $CuSO_4$ (10^{-4} M)	3 seconds
0.00001 M $CuSO_4$ (10^{-5} M)	30 seconds

Appendix E: Mineral Requirement Notes

The Role of Minerals in the Human Body

Minerals are inorganic elements that play vital roles in the health of a human being. These elements are extracted from the soil by plants, which in turn are taken up by humans either through eating the plants or by eating the animals that have eaten the plants.

Minerals account for about 4% of the bodies' weight and almost all of them are parts of organic molecules. What this means is that the minerals are a part of something else – iron is part of hemoglobin, phosphorus is part of phospholipids, potassium is part of the nervous system and is vital in sending nervous impulses.

Minerals are present in all cells and make up part of the structure of the body, like the teeth and bones. There are two different classifications of minerals in the body – MACROMINERALS AND MICROMINERALS. Macrominerals get their designation because they comprise 75% of the total minerals in the body. Calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium are all macronutrients – and the trend? Most of them are metals!

Microminerals get their designation because they make up a smaller portion (trace) of the total minerals in the human body. In fact they make up less than 0.005% of the adult body weight. Iron, manganese, copper, iodine, cobalt and zinc are all considered microminerals. Do you see a trend? Again, most of these are metals!

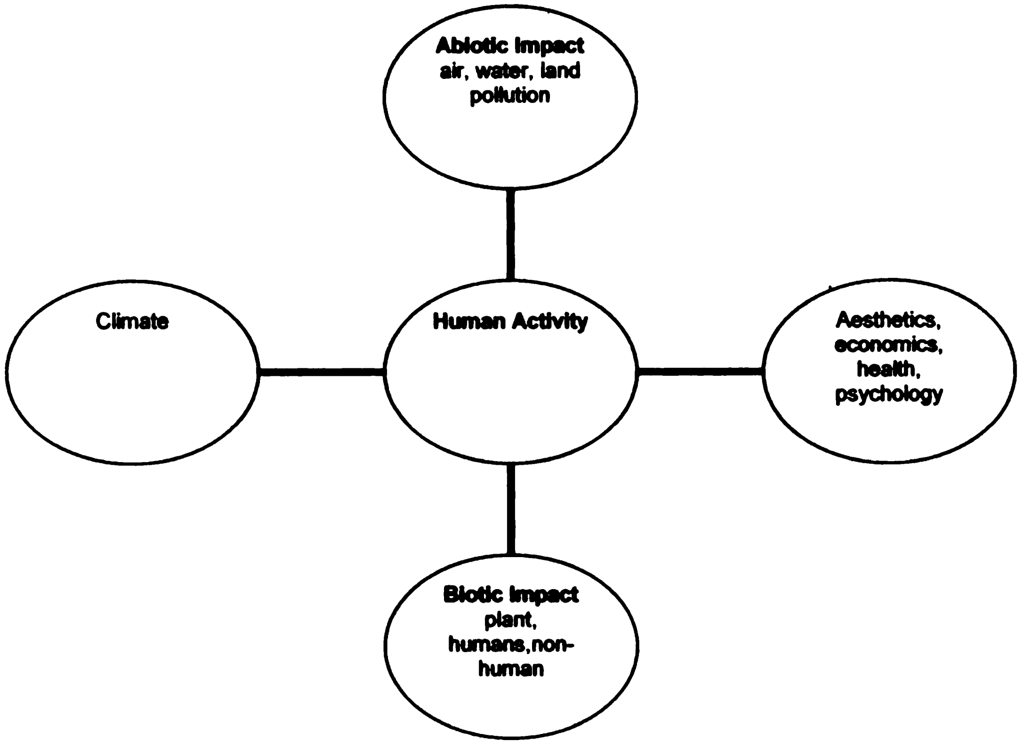
The main point to all of this is that for human bodies to function at full capacity, for nerve impulses to work, for intestines to digest, to grow strong and for muscles to move, it is necessary to keep a certain level of these minerals in the body. As with anything, when things become imbalanced a system has to change to accommodate the imbalance and often this is with sickness, or death. Just the right amount of potassium for instance, and you can remember what you had for lunch. Too much potassium and your system "thinks" its having a stroke.

See the following page for table of nutrients.

Macromineral	**Amount Needed**	**Function**
Calcium	800 mg	Structure of bones and teeth, needed for nerve impulses
Phosphorus	800 mg	Structure of bones and teeth, needed in most metabolic reactions, and for protein synthesis
Potassium	2500 mg	Helps regulate pH and cellular pressure, needed for nerve impulse conduction, and muscle contraction
Sulfur	Not est.	Part of amino acids, insulin, biotin, polysaccharides
Sodium	Not est.	Helps osmotic pressure, regulate water balance and helps with nerve impulses.
Chlorine	Assoc. w/Sodium	Helps with osmotic pressure, regulate water balance and helps with nerve impulses
Magnesium	300 mg	Needed for metabolic reactions, reactions in the mitochondria and assoc. with ATP production
Microminerals		
Iron	1-2 mg	Part of hemoglobin, enzymes and catalyzes vitamin A
Manganese	Not est.	Needed for normal growth and development of skeletal system, connective tissue
Copper	2 mg	Needed for the making of hemoglobin, development of bone, making melanin
Iodine	0.001mg	Big in helping to make thyroid hormones
Cobalt	Not est.	Thought to be necessary in the making of enzymes
Zinc	15 mg	Part of enzymes involved in digestion, respiration, bone and liver metabolism (function)

*This is not a complete list of functions. The information was adapted from "Human Anatomy and Physiology", written by John W. Hole, Jr. *

Self Sustaining Mechanisms in Ecosystems



Part of the responsibility of learning to live on a self-sustaining planet is to learn to correct past mistakes. This must happen not only on an individual level, but also on an industrial level that will require change in daily activities and the way we think of life in general. We are interrupting natural systems and it is necessary to change relationships of humans to the environment. We, as guardians of the Earth's health, must look to the past and anticipate changes that may occur due to our interaction with the environment in which we live.

There are two paths that human activity can take that effect the environment: changes in abiotic and biotic factors. We will look at how we alter these factors, and the impact of those changes.

Abiotic Factors

Abiotic factors are those components of an ecosystem that are not living, that when altered, can cause situations not easily tolerated by living organisms. The most common is chemical disruption, such as sewage that adds nutrients to waterways that alter the natural state of homeostasis. Pollutants can be produced by other activities introducing possible toxic substances that some life forms cannot handle. An example of human produced pollution is chlorofluorocarbons (by products of aerosols) that eat at the ozone and increase global warming due to increased ultraviolet radiation. While awareness has been raised on a global level, CFC's are still produced and their impact is still being felt.

Wastewater treatment plants release a wide range of compounds into rivers. The by-product of the chlorination process used to sterilize treated wastewater, the release of these chemicals can prove to be toxic to fish and other aquatic species. Another example of human pollutants results from the use of pesticides, chemicals that control fungi, insects, viruses and weeds. Although the application of these chemicals might be into the soil, they can also be carried to other areas through wind and water dispersion. Poisoning beneficial species, large ranges of living organisms can be affected by the topical application of pesticides.

One of the best studied pesticides is DDT (dichlordiphenyltrichloroethane). Formerly used by the United States and still in use in other countries, DDT contaminated both aquatic and terrestrial ecosystems and was passed through the food chains from one organism to another. DDT was stored in the body fat of top-level consumers, such as osprey and peregrine falcons, and was deposited in their eggshells, which resulted in thin eggshells that could not support the embryos of the birds. Populations of the birds declined rapidly until their numbers were near extinction.

The DDT incident illustrates a concept known as **biomagnification,** the accumulation of relatively low concentrations of a chemical within a food chain that results in the concentration increasing as it moves up through the trophic (feeding) levels. By the time the chemical has reached top-level consumers, it has become a toxic concentration.

Regardless of the application site, human pollution can branch out into soil, water or air contamination. Due to unfavorable abiotic conditions, species can be reduced or eliminated, which in turn creates an unbalanced ecological system.

Biotic Factors

Human activity can also directly affect, deplete or destroy resources used by other species, thus impacting them directly. Building dams that divert water away from naturally occurring streams and rivers, building housing projects over wetlands and laying concrete over land that has a natural drainage system are all examples of directly altering ecosystems and the organisms that live within them.

The introduction of competitors is one of the most common impacts we have on the biotic community. Many ornamental plants that are placed in yards are non-native species. These plants compete with native species for resources, and may possess adaptations that allow them to tolerate chemicals that the native species cannot. The result is that the competitor thrives at the expense of the native organism. While the loss of these organisms may seem inconsequential, purple loosestrife is not a natural water purifier, a characteristic that the native species holds. Thus plants such as cat-tails have been depleted and the ecosystem the previously was free of contaminates due to the presence of the wetland plants is now becoming increasingly toxic. In other words, we are killing ourselves by our ignorance.

The introduction of competition into an area can also occur in an aquatic environment. In the late 1980's, ships coming into the Great Lakes from the Atlantic ocean carried in their ballasts (systems in the ship interior that emptied excess water so the ship could stay afloat) Zebra Mussels. This exotic species of aquatic mussel attached to pretty much anything that couldn't move away from it, and they reproduced at an alarming rate because there was no efficient predator for them. Consequently, the Zebra Mussels population bloomed, and native species of mussels and other small invertebrates became stressed because the competition for food and habitat was too great.

Other factors that contribute to biotic issues are the introduction of **disease organisms**. Although **pathogens** are a natural part of ecosystems, they are usually held in check by modulating factors. However, humans have unwittingly introduced pathogens into environments that have no natural control, resulting in the loss of species. The American chestnut tree was virtually eliminated between 1910-1940, because of the introduction of a fungus that was carried by the Chinese chestnut tree. Having no resistance to the fungus, the American chestnut became diseased and its numbers were permanently damaged.

Simplifying Ecosystems

Tampering with the abiotic and biotic factors in an ecosystem tends to simplify the system by lowering species diversity. All components of an ecosystem are reliant on one another. Whether the relationship is predator/prey, mutualistic (both species benefit from the presence of the other) or just the toleration of other species, when one of the factors is altered, the system because it works as a whole, must adjust to accommodate the change. Chemicals applied to one area of an ecosystem for instance, will filter to other areas, either through soil or water movement, exposing any species of plant or animal that "gets in the way". The removal of these species through sickness or death causes the system to become unbalanced, leaving itself open for viruses, insect predation and greater competition. Those species that do survive the exposure may become genetically altered, creating a legacy of genetic mutations that leave future generations fighting for survival, unable to adapt to the change in the environment.

Take Home Message

In general, for any ecosystem to remain healthy and thriving it must maintain a balance. While natural disturbances such as floods or high winds may alter larger total populations, the slow or methodical altering of environments through human manipulation has a greater effect on the viability of an ecosystem.

For homeostasis to occur, all parts of a system must be able to adjust to changing living conditions. The imbalance occurs when one component of an ecosystem is devastated (such as contaminated water supply from the soil) and unable to tolerate the disturbance, while another component of the system thrives.

Humans make decisions that affect their lives directly. We tend not to think of the "ripple effect" that happens when we either intentionally or unintentionally change a "part of the whole". One decision (such as not regulating industrial run-off) that does not take into account the overall effect will harm something. That is not in question. Some living component of the system must make way for the incoming changes. Our responsibility is to determine how much effect the decision will have on the environment, what living organism will be affected, how long will the exposure last, and how long will it take to clean the area once the decision has been made.

As responsible inhabitants of the Earth, these are tough questions that we must ask, and be prepared to answer.

*Adapted from "Environmental Science, Action for a Sustainable Future" Fourth edition, Daniel D. Chiras

F-2: Self Sustaining Mechanism Student Questions

Questions for "Self Sustaining Mechanisms in an Ecosystem"

Answer in complete sentences, following essay format.

1. Describe what is meant by **abiotic factors**.

2. Give an example, other than the one in the reading, of human impact on **abiotic factors** in an ecosystem that you are familiar with.

3. Define **biotic factors**, giving an example from the reading.

4. Explain how something (such as a toxic chemical) can accumulate through the food chain. You will need to use your prior knowledge of food chains to answer this. Also, use your text for background information.

5. Which is more important – making a decision regarding the environment on a local (just affecting Flint or Michigan) level or making a decision regarding the environment on a global (affecting the whole Earth) level? Why do you think that a decision that you make here in Flint, Michigan could affect someone or something in England or China? Defend your answer with sound scientific reasoning.

Appendix G: Field Trip Questions

Bull Frog Pond Questions

1. What process happened to allow the wetland to be re-established (what steps were taken to make the pond come back to life)?

2. What is the impact on the ground (soil) from years of farming? What is left over, even though no farming is done on the acreage any longer? How does this impact humans?

3. Why would the State of Michigan want a wetland to be re-established? What purposes do they serve?

4. How long does it take for a wetland to come back to life?

5. What does a wetland do naturally, to an area of soil? Why is it considered a benefit?

- Answers vary according to the student's interpretation.

Appendix H: Macro/micro Nutrient Notes

Essential Elements for Plants

Element	Chemical Symbol	Form Avail. To Plant	% of Plant's Dry Weight
Macroelements			
Hydrogen	H	H_20	6
Carbon	C	CO_2	45
Oxygen	O	O_2, CO_2, H_2O	45
Nitrogen	N	NO_3^-	1.5
Potassium	K	K^+	1.0
Calcium	Ca	Ca^{++}	0.5
Magnesium	Mg	Mg^{++}	0.2
Phosphorus	P	$H_2PO_4^{-2}$, HPO_4^{-2}	0.2
Sulfur	S	SO_4^{-2}	0.1
Micronutrients			
Chlorine	Cl	Cl^-	0.01
Iron	Fe	Fe^{+2}, Fe^{+3}	0.01
Boron	B	BO_3^{-2}, $B_4O_7^{-2}$	0.002
Manganese	Mn	Mn^{+2}	0.005
Zinc	Zn	Zn^{+2}	0.002
Copper	Cu	Cu^+, Cu^{+2}	0.006
Molybdenum	Mo	MoO_4^{-2}	0.00001

Macronutrients are elements that are required by the plant in greater quantities than micronutrients. But in studying the chart above, you can see that the amounts needed for survival are small, regardless of the nutrient.

Plants have an incredible ability to concentrate ions (elements that have lost or gained an electron), absorbing them until they are at a much higher concentration than the surrounding area. This is accomplished by the roots, which diffuse the ions down a concentration gradient, where they enter the xylem, which in turn distributes the ions to various parts of the plant.

Some plants are assisted in the process of taking up metals by the chemicals that they secrete. Phytochelatins (fi-toe-key-la-ton) are a class of chemicals produced by the plant that attach to metals in the soil and make them more soluble (able to dissolve). Plants that are used to *remediate* or clean up a polluted site often have a greater number of phytochelatins.

It is important to note that the presence of root hairs (small hair like extensions that radiate out from the root) helps the plant to take up water and nutrients. The root hairs increase the surface area of the plant, creating a bigger area that can be exposed to the soil.

On the other hand, the root hairs also do a good job of taking up metals in the soil. Although metals are needed by the plant to survive, too much of anything can kill an organism, which is the case with heavy metal exposure. The difference between metals and *heavy* metals is that *heavy* metals have a relatively high density and are toxic or poisonous at *low concentrations*. If the plant is not tolerant or has low tolerance to metals in the soil, this uptake can be lethal to the plant.

Some plants, however, have a high tolerance of heavy metals and successfully store the heavy metals in their roots, shoots, stem and leaves. This creates a situation in which the plants are capable of remediating a contaminated site, either by being purposefully planted in an area or moving into an area naturally through succession. This is known as phytoremediation (phyto = plant).

Adapted from: "Plant Physiology. Mineral Requirements" 10/2004 http://149.152.32.5/Plant physiology/minerals.html

Appendix I: Research Outline

RESEARCH PROJECT

This is a short research project. The purpose of this assignment is for you to gain a clearer understanding of the effect of heavy metals on the environment. The questions below will help to guide you as you look for information on the internet.

1. What are common environmental toxins?
2. What is a heavy metal?
3. What are the effects of heavy metals on plants?
4. What is the effect of exposure to heavy metals on living organisms?
5. What are the causes of heavy metal contamination (how do they get into the environment)?
6. What does hazardous waste do to the environment?
7. What are our options in removing the toxins from the environment

- **Suggested Searches**
- Decontamination techniques for heavy metals
- Heavy metals in the environment
- Impact of heavy metals on living organisms
- Pathways for heavy metal contamination

All of the questions from the guideline must be answered in your paper. You are writing a document that creates a picture of how toxins (in this case heavy metals) get into the environment, their impact on both abiotic and biotic factors, and options for removing these contaminants.

The paper will be written in paragraph form, following traditional essay format. Any direct statements taken out of your reference source must be put into quotation marks and all resources that are used must be listed on a reference page.

Web site suggestions

- www.soils.wisc.edu
- www.environmental-center.com
- www.deq.state.mi.us.gov
- www.epa.gov
- www.usgs.gov
- www.lenntech.com/heavy-metals.htm
- www.luminet.net/~wenonah/hydro/heavmet.html

Grading Rubric for Research project

Questions answered
Comprehensive understanding of subject for reader
Essay format followed, including references 60 points

Some questions answered
Understanding not complete for reader
Spelling errors, improper sentence structure 50 points

Unclear understanding of subject by reader
Many spelling errors, run-on sentences, no references 40 points

Appendix J: Remediation Notes

REMEDIATION, THE TRUTH..................

Generally speaking

Phytoremediation (fy-toe-re-me-dee-a-shun) is the process of using plants to completely or partially clean contaminants from the following:

- Soil
- Sludge – "junk" that has collected at the bottom of a water system
- Sediment – soil and solid matter that has collected at the bottom of a lake or river
- Ground Water – reserves of water found beneath the ground – "fresh water pools"
- Surface Water – water at the surface of a water body, whether it is a river, pond, reservoir, lake, or stream
- Waste Water – water that is the result of human activity – industry and residential

"Contaminant" refers to a chemical that even though on its own it is NOT toxic or only slightly harmful, when combined with other things and put in certain situations, can develop into a harmful substance. A number of factors influence the toxicity of a chemical such as:

- Concentration – the amount (mass/volume) of the chemical in a given area
- Physical state – solid, liquid, or gas form (of chemical)
- Environmental state – did the chemical come in contact with the soil, air or water
- Climatic conditions – air temperature, atmospheric water content, ground temperature
- Type of organism that is exposed – some organisms have a greater tolerance to chemicals than other organisms due to size, coping mechanisms, etc.

Phytoremediation depends on a plant's natural processes to work. This means that the functions used by a plant to live can naturally process toxins out of the environment. Each process has a different function, which in turn creates a different outcome or result.

These processes include:

- Uptake – bringing water and chemicals into the plant
- Metabolism- sugar processing and respiration
- Exudates – enzymes/chemicals released by the plant into the soil – generally makes soil more acidic by taking up metals, which release protons into the soil

- Physical/biochemical impact of roots

Requirements for plants to take up chemicals:

- Root system that takes up water and chemicals in soil
- Xylem – a tube moves chemicals up from the roots, extracts chemicals taken in at roots
- Diffusion across the cell membrane that causes turgor pressure (osmotic pressure) – remember wimpy vs. strong celery
- Oxygen – the plant has to breathe to survive and function
- Chemical must be in solution – either in ground water or soil solution – this means "you can't separate the chemical by passing it through a filter"
  - How hydrophobic a chemical is (how much does it not like water)? (the more hydrophobic a chemical is, the more bound to the root system – the less likely to be taken up by the plant)
  - How easy or hard does the chemical go into solution?
  - How polar (charged) is a chemical?
  - How much mass does the chemical have (its molecular weight)?

DIFFERENT TYPES OF PHYTOREMEDIATION EXPLAINED

Phytoextraction - IT IS A REMOVAL PROCESS

Contaminant uptake by roots, with accumulation in the above ground part of the plant, usually followed by being picked and properly disposed.

Applies to:

- Metals – Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, & Zn
- Metalloids – As, Se
- Radionuclides – Sr, Cs, U
- Non-metals

Target:

- Soils – metals usually don't change when taken in to plant
- Sediments & sludges

Also known as:

- Phytoaccumulation
- Phytoabsorption
- Phytosequestration

Occurs:

- Root zone

Limited by:

- Sorption of metals to soil particles – dependent on pH of soil, and solubility of metals
- Narrowness of application – less successful with organic compounds
- Disposal of biomass – once contaminant is taken up in plant, then what?

Phytostabilization – IN-PLACE INACTIVATION OR IMMOBILIZATION

The use of vegetation to contain soil contaminants in situ, through changing the chemical, biological and physical conditions of the soil.

Applies to:

- Soil, sediments and sludges – reduces transport of contaminants
- Increases absorption and accumulation by roots
- Reduction of erosion (wind & water) – slows movement of toxins
- May reduce or prevent generation of leachate

Target:

- Metals – lead, chromium and mercury – roots stabilize by changing metals from soluble to insoluble oxidized states

Occurs:

- Root zone

Advantages:

- Soil removal is unnecessary
- Disposal of hazardous materials or biomass is not needed
- Cost and amount of disruption to surrounding area is less than with other remediation techniques
- Ecosystem is restored due to vegetation

Disadvantages

- Needs long term maintenance of plants – they should be self sustaining (needed because the toxins can re-release into the environment)
- Requires a metal tolerant plant with roots that grow into the contamination zone AND can change the conditions of the soil
- Possibility of transfer of toxin to a broader environment – heavy metals should not be considered

Rhizofiltration – Removal of contaminants in water by plant roots

Removal of contaminants in surface, ground and waste water by plant roots, by adsorportion onto the roots or absorption into the roots.

Applies to:

- Large bodies of water with low concentrations of contaminants (ppb)

Target:

- Metals – Pb, Cd, Cu, Fe, Ni, Mn, Zn, Cr(VI)
- Radionuclides – Sr, Cs, U

Occurs:

- Root zone
- Above water plant
- Terrestrial plants – roots

Advantages

- Can be conducted in situ to remediate surface water bodies

Disadvantages

- Monitoring and altering pH require time
- Most studies have occurred in a laboratory – not much field testing

Rhizodegradation – Destroys or detoxifies organic contaminants (PAHS)

Enhances naturally occurring biodegradation in soil through plant roots
(and released chemicals) to destroy or decontaminate an organic contaminant – petroleum, pesticides, fertilizers.

Applies to:

- Soils contaminated with organic compounds

Target:

- Organics – fertilizers, polycyclic aromatic hydrocarbons, pesticides, petroleum(oil) spills, industrial waste

Occurs:

- Roots – releases chemicals that breakdown organic molecules into carbon and water or non-toxic compounds
- Roots stimulate microbial activity to assist in the degradation process

Advantages

- Destruction of the contaminant in situ – on site
- Movement of contaminant to the plant or atmosphere very unlikely
- No recycling of the plant is necessary – the plant breaks down the toxin

Disadvantages

- Limit of the depth that the root can move into the soil and affect the contaminant

Phytodegradation – contaminant destruction process

Within the plant the contaminant is degraded through uptake and subsequent break down by the plant

Applies to:

- Soil
- Sediment
- Sludges
- Ground water
- Surface water

Target:

- Organic compounds
- PCP
- DDT & PCB's – pesticides
- TNT – explosive – metals
- Herbicides
- Chlorines

Occurs:

- Through out the plant
- Roots – release chemicals that break down contaminants
- Poplar trees, water plants, willow trees are examples of degraders

Advantages

- Successful metabolism of otherwise "untouchable" compounds

Disadvantages

- Transformation of compound into a more toxic form and re-release into environment are concerns

Phytovolatilization – contaminant removal process

Uptake of contaminant by plant, and release of volatile component into atmosphere (gas part of molecule).

Applies to:

- Ground water
- Soil
- Sediment
- Sludges

Target:

- Mercury
- Selenium
- Organic compounds – TCE

Occurs:

- Roots to leaves – carries contaminants from root contact, throughout the plant and releases the less toxic form of the compound into the atmosphere
- Original compound is transformed through plant metabolism

Disadvantages:

- **Possible transfer of contaminants to atmosphere that can be toxic/harmful to animals and humans**

Adapted from "Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites" by Bruce E. Pivetz, United States Environmental Protection Agency Ground Water Issue

Appendix K: Red Worm Experiment

K1: Student Sheet

Toxicological Effects of Red Worms through Soil Transport of Heavy Metals
A Laboratory Experiment

STUDENT SHEET

As we have discussed earlier, any substance that is at a concentration too high to be tolerated by living organisms is considered a toxic substance. In this experiment we will be testing the impact that copper sulfate, a heavy metal found in fungicides, algaecides and as a by product of industrial processes, has on an environment.

The organisms that we will be testing are red worms or leaf worms. These worms live in the leaf litter of the forest or under the top layer of dead leaves in your yard. They also burrow deeper into the soil, breaking down large chunks of soil into smaller parts and contributing to the aeration (air spaces) of the soil, which helps microorganisms live. Although the red worms appear to be small in size and removed from the human experience, they are an excellent indicator of the health of the environment. When chemicals have an impact on small organisms (those lower on the food chain), then it is important to recognize how more advanced organisms can be affected too.

Metals can find their way into the environment through various pathways. Metal ores occur naturally in the Earth's crust, the application of chemicals onto our lawns and fields, and the waste products of industrial processes also results in an accumulation of metals.

In this experiment, you will create a model of a soil environment by putting soil into a container that has been embedded with worm food and then contaminating the soil with copper sulfate. You will place live red worms into this environment, and observe the effects that the metal has on the livelihood of the worms. Ultimately, you will gain a better understanding of tolerable limits, critical concentrations and the impact that "too much of a good thing" can have on an individuals' life.

Purpose:

Through observations and measurements, the student will gain a greater awareness of the impact of heavy metals on red worms in a modeled soil environment.

Materials:

Material list is based on groups of 3-4 students

- 5 – 1 quart mason jars or 5- 3.8 liter plastic containers, both of these need lids
- 270 grams (dry weight) of soil for mason jars, 500 grams (dry weight) of soil for 3.8 L containers
- 1-2 tablespoons of worm food per container – bread crumbs
- 6-8 red worms per container
- Copper sulfate solution

Procedure:

1. Place soil containers in a row and label one container with one label, ending with each container having a different label. The labels are as follows
   0.125 g/500 g, 0.250g/500g, 0.375 g/500g, 0.500 g/500g and control (no
   $CuSO_4$, only 500 grams of soil).

2. Weigh out 270 grams of soil for the quart container or 500 grams of soil for the 3.8 L container. This amount should be added to all of the containers, including the control.

3. Sprinkle the newly added soil with the worm food, mixing equally. Sprinkle the soil mixture with water so that it is no longer dry, but do not wet it so heavily that it turns into mud.

4. Obtain the copper sulfate solution from the instructor, or mix the solution in the following proportions: place 0.125 grams of $CuSo_4$ into a graduated cylinder and add enough water to the cylinder to equal 100 ml. Allow the $CuSO_4$ to begin to dissolve, aiding the process by slowly swirling the mixture. Slowly pour the dissolved copper sulfate solution over the soil of the container marked 0.125 gm/500gm, mixing the soil with a spatula after all of the solution has been added.

5. Repeat the mixing of $CuSO_4$ and 100 ml of water, dissolving slowly, adding to the correct container of soil slowly and mixing with a spatula for the remaining proportions: 0.250 grams, 0.375 grams, and 0.500 grams.

6. Take 6-8 red worms from the container and gently place them on a weighing paper on the gram scale. Take the mass of the worms and record the total number of worms, total mass of worms and the general appearance of the worms in your data table. Gently place the worms in the soil, allowing them to move deeper into the soil on their own. Repeat this procedure for each of the containers, until you have weighed 5 containers worth of worms.

7. Every two days you will gently move the soil around with a spatula to check for behavioral health, such as movement and color. Record the date and your observations in the data table.

8. On the 5th day you will lay newspaper or some equivalent type of paper on the lab bench. Gently shake the soil onto the paper emptying the entire contents of the container on the table. Using a weighing paper, place the worms on the scale so that you can measure total mass. Record this number in your data table, along with behavioral observations and body count.

9. Using the newspaper as a funnel, pour the soil back into the container. Finish this work by adding the worms back into the soil.

10. Repeat the emptying and massing exercise with all four remaining containers, being certain to record your findings in the data table.

11. Follow the procedure for observing on day #7, and on day #10, empty the contents of the container on newspaper once again, as in step #8.
12. After taking the final mass and a final body count, remove the dead worms and dispose of them, along with the soil, in a plastic bag. Those worms that survived should be placed in a garden or a flower- bed.

1. Rinse out the containers with detergent and wash your hands thoroughly.
2. Proceed by analyzing data, graphing results and answering lab questions.

Name: _______________
Team Members: ____

Data Table for Experiment Observations and Worm Counts

	Team #1					
Container	**Start Day**	**Day 3**	**Day 5**	**Day 7**	**Day 10**	**Change**
Control						
Worm Count						
Total mass of worms						
0.125 gm						
Worm Count						
Total mass of worms						
0.250 gm						
Worm Count						
Total mass of worms						
0.375 gm						
Worm Count						
Total mass of worms						
0.500 gm						
Worm Count						
Total mass of worms						

K-2: Instructor Sheet Red Worm Experiment

Toxicological Effects on Red Worms through Soil Transport of Heavy Metals

INSTRUCTOR SHEET

Metal toxicity through various pathways into the environment affects a broad range of organisms. This assay focuses on the effect of copper sulfate (found in fungicides, algaecides, root inhibitors, and as a by-product of industrial processes) on red worms, which are common soil inhabitants. While the red worms may be small in size and appear to be removed from the human experience, they are in effect an excellent indicator for metal toxicity, regarding behavior, reproductive ability and mortality.

It is the intent of this experiment to give the student a better understanding of how all organisms are affected by the presence of a substance that, outside of tolerable limits, has a lethal effect. This intolerable limit is called a "lethal concentration" and is applicable to any substance that is found in great concentrations. This applies to any nutrient or gas that takes an organism past the point of being able to process it through their system in a healthy manner.

This lab can be performed over a four week period of time, or in as little as two weeks, depending on the concentration of metal that is placed into the model *This lab will be written for the two week class period, extending the testing period will only change the data table.* It assists the student in gaining observation skills, assessing organism behavioral issues such as reproduction and mobility, and determining the mathematical limit of chemical concentration that results in death of the experimental organism. It is suggested that students work in groups of 2-4, limiting the amount of material needed, as well as encouraging group cooperation.

Materials:

- 4 quart/3.8 L plastic shoe boxes (1 quart mason jars can also be used if there are a larger number of students that will be conducting the experiment – adjustments in soil and metal volume must be made) – each student group will use 5 containers
- Red worms – 6-10 per assay
- Soil – a normal mix of 30% peat, 30% sand and 40% potting soil. 270 grams required for 1 quart mason jars and 500 grams for 3.8 liter plastic containers
- Copper sulfate – *The copper sulfate solution can be premixed for the students or can be done by the students themselves, based on student ability. Preparation of the solution is as follows: 0.125 g per 100 ml of water, 0.250 g per 100 ml of water, 0.375 g per 100 ml of water and 0.500 g per 100 ml of water. If mixing in large quantities, be certain to check for dissolution of the copper. This solution will be placed in the containers prior to the worms being placed inside, and should be mixed thoroughly throughout the soil.*
- Bread crumbs for worm food

Procedure:

1. Mix the soil in equal amounts of 30% peat, 30% sand and 30% potting soil. Estimate the total amount of soil needed so that each container holds 270 g of soil for the 1quart mason jars or 500 g of soil (based on dry weight of soil) for the shoe box containers. It is advisable to mix 10% more soil (amount) than is needed.

2. Students should weigh the soil, dry, before placing in the container. Each student will measure soil for 4 containers. Place soil and worm food into each container.

3. Label each container with the appropriate metal concentration.

4. Copper sulfate solution is placed in each container (with the ranges of 0.125mg $CuSO_4$/100ml of water, 0.250 mg $CuSO_4$/100ml of water, 0.375 mg $CuSO_4$/100ml of water, and 0.500 mg $CuSO_4$/100ml of water) taking note of required concentration and mixing thoroughly throughout the soil.

5. Count out 6-10 worms per container, per group. Each group should weigh and record the total mass of their worms.

6. Before worms are placed in the containers, students should note (in the data table) behavior such as mobility, the color of the worms and relative size (based on student opinion).

7. Place worms in each container that has had the soil loosened to allow for the worms to move deeper in to the mix.

8. Students will make observations every 2 days, loosening the soil to check for mobility. On the 5th day, students will remove the soil from the container, placing it on paper (newspaper works well), using plastic gloves. Remove the worms and place the soil back into the proper container. The mass and total count of the worms will be recorded, as well as any behavioral changes, such as slower movement and death. Any worms that have died should be discarded.

9. Continue observations for 4 more days, keeping to the two day schedule. On the 10th day of the experiment, the soil should once again be emptied onto newspaper and the worms removed charting weight and total body count. *It is expected that as the concentration of the copper sulfate increases, so will the mortality rate of the worms. Consequently, the 0.500mg/g concentration may have a 100% death rate.* Again, all information should be recorded in the data table.

10. Surviving worms can be placed back into a natural environment , such as a garden or flower-bed. Dead worms should be discarded along with the contaminated soil. It is safe to place the soil/newspaper in a bag and discard it in a trash container.

11. Student data should be plotted on a line graph so that a relationship between concentration and mortality can be established.

Class Discussion

Once the data has been analyzed, students should be able to discuss the impact that metals have on organisms living in a contaminated environment. Although red worms were used as the model, the implication that survivability is dependent on the concentration of the toxin is evident.

It is critical that the students understand that toxicity to a small organism (whose existence is necessary for the rest of life, in this case keeping the soil healthy) indicates the possibility of toxicity to higher order organisms through bioaccumulation. Also, key to the discussion is that a lethal dose does not always have the greatest impact on a population. Slow growth rates or decreased reproductive ability also affect a population, which in turn can have a greater impact than loss of individuals.

Further discussion of the laboratory techniques could include remediation techniques that may inhibit the metals impact on the worm population, such as plant cover or the increase of available space so that the impact of the toxins is diminished. Additionally, because each organism responds to a toxin in a different manner, the experiment could be changed to test different populations or types of toxic substances, such as yard fertilizer.

Appendix L: Bioaccumulation Activity

BIOACCUMULATION ACTIVITY

The purpose of this activity is to demonstrate, using the students, the theory of bioaccumulation. Although books are used as the model for toxins in the environment, it gives the students an idea of the "density" that occurs when contaminants build in an area.

Procedure:

- Each student will hold a book that is approximately equal in weight. Their textbooks are a good idea.
- Standing in a circle (if space permits) or outlining the room, one student begins the "building" by passing their book to the person next to them.
- The second person adds their book to the pile and passes both books to the next person.
- This progression continues until the person who has been passed the "collective books" can no longer hold onto them without dropping them – just like bioaccumulation of contaminants that build in an environment until they can no longer be tolerated and ultimately cause the break down of the system! *This number will differ according to the number of books and the muscle ability of the person who is holding the books – a good model for a contaminant being benign in one environment and toxic in another!*
- The "environment" can be altered by moving the students around the circle according to size (smallest student to largest student or vice versa). In this case the model shows that smaller organisms (e.g. fresh water crustaceans) struggle with less toxic concentrations, just as larger organisms (e.g. wildlife/humans) struggle with larger concentrations of contaminants. In this step of the demonstration it is important to point out that the larger organisms are carrying a larger contaminant load – an indicator of tolerance.

Class Discussion

This demonstration gives a physical model of an event that occurs in nature all of the time. The books represented a substance (zinc, for instance) that in small amounts is necessary for life, but when put into an environment where the substance builds, can be devastating. As the books (toxins) were passed from one student (organism) to another, the effect that they had on the bearer (student holding the book/toxin) became greater and greater, until eventually the organism couldn't tolerate the load.

Bioaccumulation occurs in the same manner. What starts out as a tolerated substance can potentially become a lethal toxin. As the substance moves from one area to another – copper sulfate (for instance) from a home septic system to a river, the contaminant is exposed to changing environmental conditions which can alter the chemical structure. This in turn can cause the contaminant to be taken up by organisms that normally wouldn't be harmed or exposed (due to the change in the pathway), which pass the contaminant on to other organisms either through the food web or by the nature of their existence – contaminated water at a soil interface.

The students will be asked about proactive choices. They should be able to generate ideas about markers in the environment that indicate accumulation is occurring. For instance, if there is a fish kill in the local stream, it can be an indication of toxicity – and if it is happening to the fish, what has happened to the microscopic organisms inhabiting the water, as well as the plants? Questions the students might come up with are "where did the toxin come from, how long will it remain there, how is the toxin transported from one area to another and where does it go when it settles to the sediment layer of the river"?

Assessment

Each student will be given 2-3 minutes to think about their answer to the following question, and responses that reflect an understanding of the accumulative effects of a substance will indicate success of activity.

"Give an example of a situation or event that starts out not harmful, but through a series of events, "accumulates" into a problem or toxic situation"

Appendices M: Now You See It, Now You Don't

M-1: Student Sheet Acid/Base Experiment

Now You See It, Now You Don't!!

Copper Sulfate Precipitate Lab

Purpose: The intent of this lab is to demonstrate that when a metal is exposed to changing pH ranges, it has the ability to move in and out of soluble forms.

Material:

- 20 ml of 0.1 M $CuSO_4$
- 2 – plastic pipettes
- 0.1 gm $CaCO_3$ - buffer
- 2 ml 0.1M NaOH (sodium hydroxide)
- 2ml 0.1M HNO_3 or HCl (nitric acid or hydrochloric acid)
- 2 – 25 ml beakers
- 1 strip pH paper
- 2 medium test tube
- Goggles
- Rubber stopper to fit test tube
- Graduated cylinder

Procedure:

1. Put on safety goggles. Label each beaker – one with NaOH and the other with HNO_3. Using the graduated cylinder measure 2 ml of NaOH, carefully pouring into proper beaker. Repeat process with HNO_3 (or HCl).

   Trial One

2. Measure 20 ml of $CuSO_4$ into a clean graduated cylinder. Pour into the test tube. Place in test tube rack. Record your observations of color and clearness of copper sulfate in your lab book.

3. Using a pipette, fill barrel with NaOH (sodium hydroxide). Counting, add 10 drops of sodium hydroxide to the copper sulfate test tube, carefully observing the changes. Write down your observations in your lab book. Using a stopper, invert the tube to mix the base (NaOH) with the copper.

4. Once you have recorded your observations, using the other pipette, fill the barrel with HCl (hydrochloric acid). Counting, add 10 drops of

hydrochloric acid to the test tube of copper sulfate/sodium hydroxide, carefully observing the changes. Record observations in lab book.

5. Place test tube in rack.

Trial Two

6. Repeat step 2 using a new test tube, adding 20 ml of copper sulfate and 0.1 mg of calcium carbonate. Put stopper on tube and invert to mix. It may take 2-3 minutes for calcium carbonate to dissolve.

7. Using your memory and written observations, begin adding NaOH to test tube, count each drop added until you have achieved the same color/clearness of the *original copper sulfate* that you had in trial one. Record total NaOH drops added, as well as your visual observations.

8. Repeat the process using HNO_3, counting drops and recording your observations.

9. When completed, place test tube in rack.

Lab Questions – Place in lab book

1. Describe what the copper sulfate looked like when you began to add the base (NaOH)?

2. Describe what happened to the cloudiness when you added the acid (HNO_3)? Give an explanation as to *why* you think this happened.

3. In an acidic environment, metals such as copper become more soluble (which means the copper won't separate from the solvent when filtered). How did you know that the copper had been exposed to an acid? Describe what you saw.

4. When you added the calcium carbonate to the test tube in trial two, describe how it affected the number of drops of base and acid that had to be added to the test tube, to match trial one.

5. Calcium carbonate is a buffer, which means that it keeps the pH of a solution or an environment (your yard) from moving too acidic or too basic. If there was a metal contaminant that you were trying to get to be taken up by plants, and the pH needed to be below 6 (acidic), how could you accomplish this?

Now You See It, Now You Don't
Teachers Edition

This lab is a good quick way to help students gain a greater understanding of acid/base reactions and the impact of buffers. It isn't necessary to do qualitative work, but rather to help the students create a visual model of metal precipitation due to exposure to a basic solution.

It can be applied to many types of classes because it doesn't require a great deal of measurement for the students, but does help them to improve their ability with simple lab equipment. It is helpful to explain that an acidic solution will release a hydrogen (proton) and that a basic solution will accept a proton. In this lab the exchanging of hydrogen results in a copper precipitate. Applied to a natural environment, the exchange of a proton and the amount of acid in a solution is also a measure of pH. Regarding soil, a neutral pH is in a range of 6.5-7.5, above that is basic, below 6.5 is considered acidic.

As an environmental model, the manipulation of soil/water pH is beneficial when dealing with a metal contaminant. Especially in the case of plant - assisted remediation, the metal must be soluble (available for uptake) which dictates that the metal be in an acidic environment. This can sometimes be accomplished by acidifying the soil through the application of acidic acid.

Moreover, this lab directly shows that when a metal (copper sulfate) is put in the presence of a 'basic' environment the metal will become less soluble, and in the case of remediation, stick to the soil or sludge, hindering removal.

Solution "Recipes"
All Solutions Are 0.1 M - Each student pair requires 40 ml

Copper Sulfate
15 grams per 600 ml of distilled H_2O – swirl to mix
Each student pair requires 40 ml
This amount gives enough for 15 - paired students

Nitric Acid or Hydrochloric Acid
Nitric Acid
0.06 grams per 100 ml of distilled water
Each student pair requires 2 ml

Hydrochloric Acid
0.16 grams per 100 ml of distilled water
Each student pair requires 2 ml

Sodium Hydroxide
0.24 grams per 100 ml of distilled water

Appendix N: Soil Percolation Demonstration

BOTTLED WATER – WHAT IS GOING ON WITH THE GROUND?

For this exercise, you will be working in groups of six – 2 people per team/bottle. You will be using your fine observation skills to determine the process of water filtering, through a model that you will build in class. So it's really important that you work together and stay focused – there's a lot of learning to do!

Materials:

Per 2 person team

- 1 – 2 liter bottle
- 1 – graduated cylinder
- 1 – 600 ml or 1000 ml beaker
- 500 ml of sand or potting soil or a mix of both
- 500 ml of water – placed in an ehrlenmyer flask
- 1 timer or a good view of a clock

The construction of the bottles is the hardest part of this lab.

Procedure:

1. *Place a 2 liter bottle flat on the table and locate the "hip" near the bottom (the area that starts to round down to the base of the bottle). Using the point of the scissors, carefully puncture a hole in the bottle so that you can insert the scissor blade. Cut a straight line around the circumference of the bottle, removing the base.*

2. *Flip the bottle over so that the cap is on the table. As one team member measures 100 ml of water in the graduated cylinder, the other team member locates a permanent marker. Supporting the bottle, pour the 100 ml of water into the opening and make a mark on the outside level with the water line.*

3. *Repeat the process of adding 100 ml increments of water and marking the outside of the bottle until you have reached the 1000 ml mark.*

4. *From the group of six, each team of 2 members will be assigned a different soil type: sand, potting soil or a 50/50 mix of both. Once your instructor has given your team its soil type, fill your over turned bottle to the 500 ml mark with that soil.*

5. *Obtain a 600 ml or 1000 ml beaker. Place your inverted bottle into the beaker. Your bottle cap* should not *touch the beaker bottom. Fill a flask with 500 ml of water, measuring the amount with a graduated cylinder if needed.*

6. *Your team should now have three bottles with three different soil types in them. On your lab sheet place your 'guess" as to which one of the bottles will move 500 ml of water through it the fastest (question #1).*

7. *In the data table you will record the time it takes 100 ml, 200 ml, 300 ml, 400 ml and 500 ml of water to move through your soil column. As one member of the team watches the clock or sets the timer, the other team member pours 500 ml of water into the over turned bottle. Begin timing as soon as the water is poured onto the soil, and record the seconds/minutes per 100 ml.*

8. *Once the 500 ml of water has moved through the soil column, record the numbers of your other team members in your data table, and discuss your findings. What were the differences in time, what factors contributed to the speed, why has one type of soil held onto the water, etc.? Be prepared to discuss your findings with the entire class.*

9. *Empty and rinse the beaker that has the collected water in it – only if your soil column is still dripping should your leave your bottle on top of the beaker. Discuss as a class and answer lab questions.*

Data Table for Porosity/Permeability Lab

Water Amount		***Time***	
	Sand	*Potting Soil*	*50/50 Mix*
100 ml H_20			
200 ml H_20			
300 ml H_20			
400 ml H_20			
500 ml H_20			

Post Lab Questions

1. Which soil column (which bottle/type of soil) will the water move through the fastest?

____

____

2. According to the actual experiment, which soil type allowed the water to move through the fastest? Which soil type was the slowest?

____

____

3. Looking at the soil in the bottle, which type has the largest grain or biggest pieces? How do you think this affects how fast the water moves through the column?

____

____

____

____

4. Comparing your data to the rest of your classmates, is there a general statement that can be made about soil types? If so, what could you say? " When you compare sand, potting soil or a mix of both, it has been found that"........................

____
____
____

Extension Question

5. You learn that there has been a hazardous waste spill at a construction site. Applying what you know, what type of soil would you hope that the spill occurred on so that you would have enough time to clean the area (what kind of soil would you want to be there to "hold" the contaminants so that they don't move into the water table)? Explain your answer.

____
____
____
____
____

Appendix O: Remediation Unit Evaluation

REMEDIATION UNIT EVALUATION

Read the following questions and answer them with an honest opinion.

1. Did you learn anything about how toxins in the environment can harm living organisms?

   Yes No

2. Are there natural systems in the environment that can clean toxins out of the soil and water?

   Yes No

3. List three things that you learned from this unit
   a.

   b.

   c.

4. Did your opinion of the impact of humans on the environment change after this unit? If yes, how?

   Yes No

5. Did you know before the unit that plants have the ability to clean up contaminants from the environment?

   Yes No

6. If you had to decide if an area was contaminated, what part of the environment/habitat would you look at first and why?

7. What activities that you were involved in helped you learn the most? Why?
   a. Bullfrog Pond

   b. Red worm Lab

   c. Wetland Tanks

   d. Soil Column Demo.

   e. Precipitation Lab

   f. Research Paper

8. What was the best part of this unit and why?

9. What was the worst part of this unit and why?

10. Give one suggestion to make this unit better when it is taught again.

Thanks for your input. Your opinion is valuable and important.

Appendices P: Rubrics

P-1: Maintaining a Journal

MAINTAINING A JOURNAL

In science class it is often easy to get lost in the middle of learning, caught up in the excitement of the lesson. Then your instructor asks you a question, and you stare blankly at him or her, hoping that no one knows that you are there. I know this, I have been there.

One of the best things that I have learned is that if I keep a written record of the steps in a lab, my results, how I felt about a project, etc., it was a lot easier to hold on to the information. With that, you will be required to keep a lab journal throughout the unit on contamination and remediation. You will be rewarded for your hard work by having gained a greater sense of organization, a deeper base of knowledge, and most importantly, a substantial grade.

The requirements for the journal are simple: any lab that is done in class will be recorded (the procedures in your own words) including the results of the experiment, any observations that are the result of a demonstration, class notes, and any thoughts or feelings that you hold about a lesson.

Your journal will be worth 270 points, a documentation of all that you have learned. Include in your entries: calculations, data, class and personal observations, outcomes of experiments. Each experiment has an expected outcome, but your opinion is your own, one of the things that cannot be degraded or criticized.

This journal is an opportunity to say what you mean and mean what you say!

GUIDELINES FOR EXPERIMENTS AND JOURNAL WRITING

Experiments

- Lab reports will be placed in the second half of the book and will be numbered and titled.
- Lab information will be placed on the right side and calculations/personal observations will be placed on the left.
- All entries are written in ink, not pencil. Mistakes are not erased – a line is drawn through them, and the entry is rewritten.
- All lab reports will include the following:
    - Name of the lab
    - Your name and the members of your group

- Purpose of the lab – what are we trying to figure out
- Hypothesis
- Material used
- Procedure (may be written in your own words)
- Data and results
- Conclusion – what did you learn, how did you feel about it?

Journal Writing

- Journal entries placed in the front half of the book
- Date of entry – left hand column
- State what you are referring to – a lab, an observation, etc.
- Questions you need answered
- Anything you don't understand
- Suggestions on how the lab/demo/lesson can be improved

P-2: Remediation Unit Grading Rubric

Rubric for Remediation Unit

Journal	*Daily entries, all projects, labs included	50 points
	*Followed guidelines	30 points
	*Neat, orderly, easy to read	20 points
Bull Frog Pond Questions		10 points
	*Analysis questions	15 points
Now you see it Lab (includes observation)		5 points
Self Sustaining Mechanisms Handout		10 points
Redworm Lab	1st data table	20 points
	Avg. mass table	5 points
	Graph	15 points
	Questions	20 points
Heavy Metal Wetland tanks	Copper charts	10 points
	Plant chart	5 points
	Questions	30 points
	Question #11	5 points
Notes	*plant/animal micronutrients	5 points
	* Glaciation	5 points
	* Phytoremediation	10 points
Total Possible		**270 points**

P- 3: Pre and Post Test Grading Rubric

Pre and Post Test Grading Rubric – 20 Total Points

1. What is meant by "heavy metals"? How do they differ from other metals?

- Heavy metals have a higher density and tend to accumulate in the environment, include living organisms, at a higher rate than other metals.
- This question was worth **2 points**, partial credit of **1 point** given if they answered part of the question correctly.

2. Define toxic

- "Toxic" refers to any substance that can cause harm or death when it reaches a critical concentration, a level that is not tolerated by the organism
- This question was worth **1 point** if answered correctly, no partial credit given.
-

3. Describe how a substance can become toxic.

- Any substance can become toxic if it accumulates, either in the environment or within an organ system, and can not be disposed or removed from the system.
- This question was worth **2 points**, partial credit of **1 point** given if students answered only with "the substance accumulates".

4. Name three different ways that heavy metals are known to enter the environment?

- Heavy metals occur naturally in the environment, where they are generally tolerated. Other contributing pathways include: industrial waste (liquid, solid, gaseous), human activity private life (car exhaust, lawn application of fertilizer, septic chemicals, etc.) break down of natural containment areas, pollution.
- This question was worth **3 points**, partial credit of **1 point** given per stated example.

5. Explain why lower organisms, such as plants and invertebrates are the first
living things to be affected by toxic contamination.

- Toxicity is dependent on concentration of substance and the organism's ability to remove the toxin from its system. Lower organisms are generally smaller in size, their vascular systems are smaller and they live directly in (contact) with the source of the contamination. Due to their inability to move away from the source of toxicity, they are affected first and most often harmed in the greatest way, when contamination occurs.

- This question was worth **2 points**, partial credit of **1 point** given if student stated that the organism lived in the soil but could not explain why it would be poisoned first.

6. Describe the difference in soil types and explain why soil composition affects
   the toxicity of a contaminant.

- There are three main soil types – sand, peat, loam and a mix of all three. Depending on the area of the world (geographically), soil types are different, due to environmental factors such as water exposure, glacial activity, slat concentration, etc, The larger the particle size, the larger the air space between particles. This air space also allows for solid/liquid contaminants to move and be stored in one area. The sandier the soil, the greater the "holding ability" of the soil.
- This question was worth **2 points** given for stating soil types and **1 point** given for explanation of compaction.

7. Define remediation and explain why it is important.

- Remediation is the process of containing and cleaning an area that has been contaminated by a toxic substance. This can be accomplished a number of ways, and it benefits the environment because it stops the contamination from spreading to other habitats, and harming other organisms.
- This question was worth **2 points** for a full definition and statement of importance, partial credit of **1 point** given if a definition or the importance was stated, but not both.

8. Define phytoremediation and explain how plants are able to "take up" metals
   through their roots into the shoots, stems and leaves.

- Phytoremediation is the use of plants to contain a toxin in a contaminated area by sequestering the toxin, in this case, heavy metals, through their root systems. Once the metal has entered the root system, it is taken up into the plant through the vascular system and is either contained or volatilized by the plant.
- This question was worth **2 points** if the definition and explanation of removal of metals was provided, **1 point** partial credit was given if only a definition was provided.

9. Give an example of a natural remediation site that can be found in nature.

- A wetland is a natural remediation site. Contaminants are removed and/or contained by the roots/shoots of the plant and the water is cleaned by the respiration of the plant. Other examples of natural remediators include poplar trees, weeping willow, cat tails and duckweed.

- This question was worth **2 points** if an example was given and an explanation of how the site removed toxins, **1 point** partial credit given for only stating the example.

10. Can plants used for phytoremediation be recycled? How?

- Plants that contain metals and other contaminants that have been sequestered can be recycled. Burning the organic material and collecting the ore is one example. Plants can also be removed from the contaminated area and buried in a landfill, adding to the organic structure of the soil.
- This question was worth **2 points** if the student stated that plants could be recycled and explained how that was accomplished, **1 point** partial credit given if there was no explanation as to how the plant was recycled.

Appendix Q: Permission for Use of Copyrighted Song

Subj:	**Re: inquiry**
Date:	8/18/2004 8:20:31 AM Eastern Standard Time
From:	admin@dunkeld.co.uk
To:	Ruledbylove@aol.com

Dear Karen,
You have our permission with great pleasure....it's great to hear of Dougie's lyrics and music being used in such a way...the 11th graders are our future!
Good luck with the unit
Kind Regards,
Jennifer

Jennifer MacLean
(Manager for Dougie MacLean
Director of Dunkeld Records Ltd: Partner Limetree Arts and Music Publishing)
Tel: 01350 724281
Mobile: 07739 414169
www.dougiemaclean.com

On 3 Aug 2004, at 12:24, Ruledbylove@aol.com wrote:

> Mr. Maclean,
> I am an environmental teacher in the United States who will be
> teaching hazardous waste to a group of 11th grade students. I am
> interested in playing your song "Rescue Me" as an introduction to the
> unit. It will not be published or used in an manner for money making
> - it is my intent to raise the awareness of the students, broaden
> their idea that not everyone is ok with poisioning the ground.
> I am not sure to the requirements or your permission to using this
> work in this manner, can you help me out?
> Thanks for the consideration and help.
> Sincerely,
> Karen Gould

Appendix R: UCRIHS Letter of Approval

MICHIGAN STATE
UNIVERSITY

July 23, 2004

TO: Merle HEIDEMANN
118 North Kedzie Hall
MSU

RE: **IRB# 04-582** CATEGORY: EXEMPT 1

APPROVAL DATE: July 22, 2004
EXPIRATION DATEJuly 22, 2005

TITLE: A Study of the Removal of Heavy Metals in the Environment through Phytoremediation

The University Committee on Research Involving Human Subjects' (UCRIHS) review of this project is complete and I am pleased to advise that the rights and welfare of the human subjects appear to be adequately protected and methods to obtain informed consent are appropriate. Therefore, the **UCRIHS approved this project.**

RENEWALS: UCRIHS approval is valid until the expiration date listed above. Projects continuing beyond this date must be renewed with the renewal form. A maximum of four such expedited renewals are possible. Investigators wishing to continue a project beyond that time need to submit a 5-year application for a complete review.

REVISIONS: UCRIHS must review any changes in procedures involving human subjects, prior to initiation of the change. If this is done at the time of renewal, please include a revision form with the renewal. To revise an approved protocol at any other time during the year, send your written request with an attached revision cover sheet to the UCRIHS Chair, requesting revised approval and referencing the project's IRB# and title. Include in your request a description of the change and any revised instruments, consent forms or advertisements that are applicable.

PROBLEMS/CHANGES: Should either of the following arise during the course of the work, notify UCRIHS promptly: 1) problems (unexpected side effects, complaints, etc.) involving human subjects or 2) changes in the research environment or new information indicating greater risk to the human subjects than existed when the protocol was previously reviewed and approved.

If we can be of further assistance, please contact us at (517) 355-2180 or via email: UCRIHS@msu.edu. Please note that all UCRIHS forms are located on the web: http://www.humanresearch.msu.edu

Sincerely,

Peter Vasilenko, Ph.D.
UCRIHS Chair

PV: kj

cc: Karen Gould
224 E. Court St. #106

OFFICE OF
RESEARCH ETHICS AND STANDARDS

University Committee on Research Involving Human Subjects

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