Environmental Detectives: An Environmental Science Curriculum for Middle Schools Year 3 Evaluation

Prepared for the Montshire Museum of Science

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Environmental Detectives (ED) is a new environmental science curriculum for middle schools, being developed by the Montshire Museum of Science in Norwich, Vermont. With funding from the National Institute of Environmental Health Sciences (NIEHS), the five-year project began in Spring 2000. During Year 2, a first round of field testing of the ED curriculum materials with two science teachers was carried out during the 2001-02 school year, with an independent evaluation assessing this initial pilot work (Char, 2003).

Year 3 (July 2002 – June 2003) formally began with a week-long summer teacher institute and a week-long camp with students held in July 2002. During the week-long Summer 2002 teacher institute, five middle school teachers worked to familiarize themselves with the ED curriculum that had been piloted during Year 2, heard a series of Dartmouth science faculty present their research, and came up with a series of ED activities that would be used with students during the five-morning lab camp held the following week at the Montshire Museum. During the lab camp, students had the opportunity to observe in the lab animals and plants collected from a nearby pond, to conduct hands-on experiments investigating fate and transport in groundwater, do a dose response investigation of their own design, and to embark on a field trip to the nearby copper mines in Strafford, Vermont. The student camp served as a classroom lab to further specify the ED curriculums lessons that would piloted during the upcoming school year.

A total of four science teachers from Vermont and New Hampshire, new participants to the *Environmental Detectives* project this year, were involved in the field testing of the new version of ED curriculum units during Year 3. The teachers taught the ED curriculum in four different schools in Thetford, Sharon and Hartford, Vermont, and Orford, New Hampshire. A fifth teacher from Orford took part in the Summer Institute, but ended up not trying out the ED curriculum during the spring, as she had initially planned.

All four teachers were present during the 2003 Summer Institute, and attended several project meetings held with Montshire staff and Dartmouth faculty over the course of the school year. Teachers were free to choose when, and in what way, they wished to incorporate the ED curriculum into their regular year-long curriculum. All teachers chose to use the ED curriculum with multiple class sections of their students. The year culminated with a student symposium held at the Montshire Museum.

Independent evaluator, Dr. Cynthia Char of Char Associates, continued to follow project activities in Year 3. The main foci of this year's evaluation work with classrooms was to learn how teachers chose to incorporate the ED curriculum into their different science curriculum and classroom practices, and to assess the kind of student learning that is afforded by the ED curriculum. Research activities included review of curriculum documents, observations of the teacher institute and student camp held in July 2002 and of regular teacher meetings with project staff, and interviews with, and observations of, field test teachers during their implementation of the ED curriculum during the 2002-03 school year. A pre-program and post-program student survey featuring a variety of student learning tasks was also administered to students in the four participating field test schools.

Description of Year 3 ED Curriculum Materials

The Year 3 field test curriculum consisted of six different kinds of activity components that provided a range of different scientific experiences in *Environmental Detectives*:

- *Ground water unit* (activities included: water cycle, personal water usage calculations; soda bottle challenges; porosity and permeability activities; ground water/aquifier model designs; clean the water challenges using different substrates, filters)

- *Case Studies* (activities included: scientific articles, readings, and interviews)

- *Experimental Design* (teacher-designed introduction of experimental model)

- *Concentrations* (activities included: demonstrations and activities with dilutions and % solutions)

- *Student-Designed Investigations* (activities included: question, design, implementation, reports, poster presentation)

- *Scientist Visits* (scientists described his/her research pertaining to chemicals in the environment and fate and transport.).

A unique component of ED was the scientist visits involving faculty, research scientists and graduate students from Dartmouth College. Teachers had the option of requesting that particular faculty or graduate students come to their class on a certain week, and present their research and how it addressed the question of fate and transport of chemicals in the environment. Scientists also could discuss and critique students' ongoing ED investigations, methods and procedures with individual groups of students. During Year 3, a select group of Dartmouth faculty and graduate students made visits to ED classrooms in three of the four participating schools.

For the field test, teachers were free to pick and choose which ED activities and lessons best fit with their instructional needs, and decide how they wished to integrate the activities into their regular science classes.

Field Test Findings

I. Study of Classroom Implementation

General Description of ED Classroom Implementation: All four science teachers taught multiple sections of 7th and/or 8th graders, and chose to use ED in two or three class sections.

School	**Description of ED classes**
School A	7th graders; 3 class sections
School B	8th graders; 3 class sections
School C	7th & 8th graders; 2 class sections
School D	8th graders; 2 sections

Each teacher chose to incorporate the materials into their curriculum in a somewhat different way. One teacher (School D), relatively new to teaching, chose to use ED in her fall term, in a comprehensive, intensive fashion. Students used the materials on a daily basis, for approximately 8 weeks. Another teacher (School A), a veteran science teacher, also chose to use the curriculum in a comprehensive, intensive fashion, but beginning in the winter and running into the spring term. In both cases, the ED curriculum activities could be easily identified as forming a quite distinct unit in their students' classroom experience.

The remaining two teachers tended to fold the ED activities into the broader flow of their on-going science curricula. One teacher (School C), with a moderate amount of science teaching experience, taught at a school utilizing Sizer's Essential Questions. She primarily used ED as part of her fall term's study of plants. While planning to utilize ED again during the spring, when her class focused on the study of animals and the human body, she ended up not being able to return to ED as initially planned.

The fourth teacher (School B) taught at a school that had as part of its core mission a focus on environmental studies. A veteran science teacher, she had students working independently on a number of environmentally-oriented activities throughout the school year. She chose to utilize the ED activities primarily in the spring term, forming some of the final science experiments students engaged in during the year.

The year culminated with a student symposium held at the Montshire Museum in May 2003, an idea generated by the teachers during an early spring ED project meeting. Teachers expressed the importance of organizing an event that recognized and celebrated students' ED work, and offered the opportunity to share their scientific research with other schools participating in the field tests, Dartmouth faculty, and Montshire staff.

Teachers' Use of and Perspectives on Specific ED Components: As shown in Figure 1, all four teachers elected to use ED's centerpiece activity, student investigations. This constituted the component to which they devoted the most class time, involving approximately three to four weeks of class sessions. They also recognize the ED's core concept of dose response, with all conducting activities dealing with concentrations prior to students' design of their own experiments.

Two other distinctive components of ED – scientist visits from Dartmouth faculty and graduate students, and case study materials – also appeared valued by teachers, and used by three of the four teachers. For the case study component, several teachers came up with their own readings and articles that they assigned to students as homework, or classroom reading. A number of teachers also had students use the Internet to gather background information on particular plants and animals that they were considering for their own student investigations.

The two program components addressing possible pre-requisite context and information for ED – concerning groundwater transport, and experimental design – were used by two of the four teachers.

Figure 1: Classroom Implementation of Various ED Activities

School	Ground water	Case Studies	Experimental Design	Concentra-tions	Investiga-tions	Scientist visits
School A	Yes	Yes	Yes	Yes	Yes	Yes
School B	Yes	Used own	No	Yes	Yes	Yes
School C	No	No	No	Yes	Yes	Yes
School D	No	Yes	Yes	Yes	Yes	No

In teacher interviews conducted during the spring, teachers spoke about the different ways in which they viewed the ED curriculum as fitting into various aspects of their science curriculum in life science and chemistry. ED was seen as providing their students with engaging, new opportunities for multi-session hands-on investigations highlighting the nature of investigable questions. The focus on dose response was seen as valuable not only in terms of chemical concepts and effects in the environment, but as also offering opportunities for students to be involved in engaging activities dealing with concentrations and dilutions of solutions, gathering data, and mathematical concepts and representations of percentages, decimals, and graphing.

Teachers regarded contact with the Dartmouth scientist researchers and exposure to the ED curriculum as primarily valuable in enhancing teachers' and students' understanding of scientific questions, hypothesis, and design of experiments, rather than necessarily in terms of the links between scientific research and real world issues in the environment, or the connections between chemistry and life sciences. Utilization of case study materials was relatively modest and treated more as an optional than core component of the ED curriculum. Teachers tended to seek out materials that were more easily readable for middle school students, and incorporated them into more structured in-class or homework assignments, accompanied by class discussion and comprehension questions.

Students' preparation of written reports, posters, and oral presentations formed an important culminating event of the ED curriculum. Presentation of their own, original research in their schools was well-received by both student presenters and audiences, giving rise to teachers' request that a project-wide student symposium be offered at the Montshire Museum in late spring. The student symposium was well-attended by student teams representing all four participating Year 3 schools, and offered a valuable exchange between students from different schools, and between students, Dartmouth faculty and Montshire staff.

In summary, the primary educational value of the ED curriculum was largely defined by teachers in terms of offering students important hands-on experiences with formulating research questions, and designing and conducting scientific experiments of their own design. Teachers greatly appreciated the contact with Dartmouth faculty, feeling like it expanded their own, and their students' understanding of scientific experimentation.

II. Study of Student Learning and Engagement

<u>Description of Student Survey Instruments</u>: Given the evaluation's foci on student learning and engagement, pre-program and post-program student surveys were designed to gauge students' initial background knowledge about various aspects of environmental science at the beginning of the ED curriculum use, and level of knowledge after using the ED curriculum. The survey instrument was adapted from one created for the previous, Year Two evaluation of *Environmental Detectives*. Pre-program surveys were administered in the fall prior to when teachers began using the ED curriculum; the post-program survey was administered at a time coinciding with the end of the ED curriculum use.

Both the pre- and post-program surveys featured a common set of different open-ended problems. One problem type posed a scenario in which two fictional characters posited different points of view about the harmfulness of chemicals in the environment. Students were asked which person they most agreed with, and to provide explanations that included facts, information, experience, and other evidence for their explanations.

A second problem posed an environmental mystery to students. It asked students to design an investigation that would help them determine what might have caused an incident in the mystery. Students were asked to outline and investigation that addressed some aspect of the problem described, and were encouraged to incorporate a range of different components of a scientific experiment (e.g., question, hypothesis, method or procedure, control, replicates)

A third problem type was a "question-formulation" task, and asked students to think about any concerns or questions they might have about the harmful effect of things in the environment on people or animals, and to pose these concerns as two questions they would like answered. This problem type was designed to assess students' concerns and awareness about the environment and the general kinds of orientation for question-posing they possessed.

The post-program survey also included a set of survey items to solicit student feedback on the various activities done in Environmental Detectives. Students were presented with a table featuring the six different ED components by name and descriptions. They were asked to identify two activities they liked best and one activity that they liked least, and to provide reasons for their choices. Students were also asked to provide any suggestions they might have for improving the activities and unit.

A short series of survey items also assessed students' reactions to the Dartmouth scientist visits. These items asked students for their rating of how interesting they found the visits, what they found most interesting about it, and whether prior to this visit, they had ever heard a research scientist do a live presentation about his or her research.

Survey Sample: The student survey sample consisted of all students who completed both pre-program and post-program surveys. The sample consisted of both seventh and eighth graders drawn from the four participating schools, with a total of 140 students. Both boys and girls were represented in generally comparable numbers in each school. (See Figure 2 for more detailed breakdown of student sample.)

Figure 2: Student Sample for Year Three Evaluation

School	Description	Number of students
School A	7th graders; 3 class sections (21 girls; 21boys total)	42 students
School B	8th graders; 3 class sections (16 girls; 22 boys total)	38 students
School C	7th & 8th graders; 2 class sections (13 girls. 14 boys total)	27 students
School D	8th graders; 2 sections (17 girls; 16 boys total)	33 students
Total		140 students

Findings

Appeal and Engagement of ED Activities for Students

Student responses to the post-test survey indicated several ED activity components which were generally quite appealing to students, and others that were somewhat less appealing

(Figure 3.) Solid conclusions concerning students' overall ratings of activities they liked best and least are somewhat tempered by the fact that not all four teachers used all six activity components. Thus, the total number of students using any one activity component varied by component, making firm cross-comparisons across activity components difficult. However, there were some general trends that seem worth noting, regarding which of the five activity components were favored by students, and reasons for those choices. Specific findings concerning a sixth, "experimental design" teacher-led activity component is not reported, since survey responses indicated that students confused this activity with the broader student investigation component.

Figure 3: Appeal of Different ED Activity Components

	Number of teachers using component (4 total)	% of students identifying activity as one of two liked best	% of students identifying activity as one liked least
Investigations	4	51%	13%
Groundwater Unit	2	38%	13%
Scientist Visits	3	35%	8%
Concentrations	4	27%	4%
Case Studies	3	11%	26%

(n = 140)

Student Investigations: Students indicated that the ED's centerpiece -- the student investigations -- was the most popular activity component. Investigations were chosen by about half (51%) of students as one of the two activities they liked the most. The reasons that students gave for liking this activity pertained to the active, hands-on nature of the activity and the enjoyment of working with their organisms. Students also said that they liked the fact they were able to design their own activity, receive interesting results, and produce posters and reports they felt proud of. Some students offered the following kinds of reasons for enjoying the investigations:

> *I liked experimenting with the daphnia because I had never done anything like that before.*
>
> *The experiments were fun to set up and see the results.*
>
> *I liked the investigations because I was actually doing something and seeing the results. I got to see how many daphnia died and make conclusions for myself.*
>
> *We got to make a poster and we got to design our own experiment.*
>
> *I liked the investigations because it told me how to write a good report.*

Only 13% said that they liked the student investigations the least. The primary reason given for not liking this activity was the amount of writing or effort that was involved.

Groundwater Unit: The next most favored component was the *Groundwater* unit. While only two teachers had used this component, 38% of all students had chosen this as one of their favorite activities, while only 13% of all students indicated the Groundwater unit as their least favorite. For one of the two teachers who used this unit, it was an extremely popular set of activities for her students, with 78% of the students choosing this activity as one of their favorites. For the second teacher, 33% of students indicated Groundwater activities as their top choice. The reasons students gave for liking the groundwater unit focused both on the problem-solving and hands-on nature of the activity.

> *I liked the soda bottle filtration experiment, because you really had to use your mind to figure out the layers that you would use.*

> *I liked the clean the water challenges – because I was able to go through and solve problems and a lot of hands-on stuff.*

Scientist Visits: Scientist visits were conducted with three of the four field test teachers. The scientist visits were also quite popular with students, chosen as one of their favorite activities by 35% of the students. Students also indicated that they found the visits interesting, with about two thirds of the students (63%) expressing that they found the visits "interesting" (42%) or "very interesting" (21%) (Figure 4).

Figure 4: Students' Interest Ratings of the Scientist Visits

	Not at all interesting	**Somewhat interesting**	**Interesting**	**Very interesting**
Total (n = 102)	5% (5)	30% (31)	42% (43)	21% (23)

(n= 102; NR/other = 7)

The scientist visits offered a quite novel experience for most students (Figure 5). 41% of all students indicated that they had never previously heard a research scientist do a live presentation about his or her research, and an additional 29% indicating that they had experienced only one such visit before.

Figure 5: Students' Prior Experience with a Live Presentation by a Research Scientist

School	**Never**	**Once**	**Twice**	**Three times or more**
Total	41% (43)	29% (30)	15% (16)	15% (16)

(n = 105; NR = 2)

Students offered a wide variety of reasons they enjoyed the scientist visits. Some students reported liking the connections between what they were doing in their own experiments and with what real scientists do, and the feeling that they were engaged in interesting, authentic science experiences:

I liked to see what professionals are doing; when they gave us suggestions on our projects.

I liked it when the scientists came in because it was interesting to hear about the same kind of experiments we were doing from a real scientist.

I liked the presentations because we got to ask real questions.

Others were impressed by the breadth of knowledge of the scientists, as well as how much they clearly enjoyed their work:

I liked how they knew all the little details about those experiments.

I liked hearing about what people do and how much they love it.

I liked their enthusiasm.

Some students focused more on the content of the presentations and what they learned about chemicals and their local environment:

I found most interesting how chemicals can help us and kill us.

Learning things that are happening right here in Vermont.

I liked learning about what goes on in my environment.

Of note, the scientist visits received a much higher appeal rating than previously in Year 2, in which circumstances of the main scientist visit (class schedules requiring that a long presentation be given spanning two class periods to a large group of combined classrooms) seemed to have hindered some of the positive response to the event that year.

This year, the scientist visits were chosen as least favorite by only 8% of students. The primary reasons given were that students did not want to sit and listen to a lecture, and preferred more active, hands-on activities. Students, however, did respond favorably to presentations that had interesting visual elements, in the case of several presenters who had interesting PowerPoint presentations:

We got to learn visually instead of orally and homework. They brought interesting slide shows and neat diagrams to portray the topic.

I liked some of the info on our land being different (VT and NH), and the pictures from the air.

Concentrations: The activity component involving concentrations received a satisfactory appeal rating, with about a fourth (27%) of students indicating it as one of their favorites, and only 4% indicated it as least favorite. Most students enjoyed the activity in that it was not only a hands-on activity, but it allowed them to use real scientific equipment:

> *I liked the dilutions because it was fun and because we used real tools.*
>
> *Because I liked using the pipet.*
>
> *I liked measuring doses in (10) (10) (100) %.*

Some students also talked about enjoying the activity given the results they were able to produce in their experiment:

> *My favorite part of the dilutions was when in class we diluted koolaid to 100%, 10%, 1%, .1%, .01% and .001% and tasted the Koolaid to see the difference.*
>
> *I liked doing the (concentrations and dilutions (because it was fun seeing how much or how little amounts of chemicals had effects on living organisms.*

One student did mention that he enjoyed the connection to mathematics, saying, "I learned a lot. I learned things that we were doing in math."

Case Study: As in the Year 2 evaluation, the Case study component was the least popular one for students, chosen by only 11% of students as their favorite, and 26% of students as their least favorite. Students' reasons for not liking the activity was that they felt it was boring, too hard, or that they preferred learning in ways other than "reading information."

Of note, however, 21% of students in one particular class said that they liked it the best. Some of these students expressed the value of the case studies' connection to reading:

> *I like it because I like to read.*
>
> *I liked it because I did not know anything about the frogs and I found out and learned about it. I find it interesting to read articles that involved comprehension skills, something that I really lack.*

In summary, students rated as most appealing the student investigations, the ED centerpiece component, followed by the groundwater unit activities. Students cited liking these activities for their hands-on and problem-solving nature, and the opportunity to design their own experiment or groundwater design. The scientist visits were also positively received, with students enjoying the direct contact with the research scientists, a new experience for many students. The case study activity, with its focus on reading, continued to be less appealing, with students preferring more active, hands-on activities. These findings are generally quite similar to student responses in our Year 2 evaluation

What was perhaps noticeably absent in students' reasons for enjoying an activity were connections between the activity and its relevance and applicability to the real world.

With the exception of several student comments about what they enjoyed about the Dartmouth scientist visits, the ED activities appeared to have been primarily received as fairly discrete "lab-based" experimental experiences. Stronger connections between the ED activities and the broader context of chemical impact in the environment might possibly have been enhanced through field-based activities, more extensive use of appropriate case study materials and Internet research, or greater teacher emphasis in student reports and presentations on the connections between students' experimental results and understanding.

Student Learning

Point of View Debate Task: As we had found in our Year 2 evaluation, performance on the pre-tests revealed that the middle school students began the ED program with some basic level of awareness of chemicals and the environment. Even in the pre-program survey, students were not naïve enough to think that "Almost all chemicals found in our environment are bad for living things." Rather, students almost always sided with the more tempered view of "Most chemicals found in our environment can be both good and bad for living things. It depends." This attitude was sustained in the post-program surveys, in which the vast majority of students agreed with the statement "Chemicals can be good and bad. It just depends." rather than the statement "Chemicals are bad for the environment. They are not natural and cause harm to living things."

Pre-Test Debate Task

What do you think? Consider this dialogue:

Tessa: Almost all chemicals found in our environment are bad for living things.
Tom: Most chemicals found in our environment can be both good and bad for living things. It depends.

Whom do you agree with – Tessa or Tom? Explain why you agree with this person. Try to include some facts, information, experiences you've had, or other evidence in your explanation.

Post-Test Debate Task

What do you think? Consider this dialogue:

Mike: Chemicals are bad for the environment. They are not natural and cause harm to living things.
Morgan: Chemicals can be good and bad. It just depends.

Whom do you agree with – Mike or Morgan? Explain why you agree with this person. Try to include some facts, information, experiences you've had, or other evidence in your explanation.

A clear shift, however, was evidenced in the reasons they gave to selecting these points of view. After experiencing *Environmental Detectives*, students increasingly called upon their knowledge of dose response as a reason to understand the relative nature of chemicals being considered harmful. As shown in Figure 6, while only 12% of all students applied knowledge of dose response in the pre-test point-of view task, 37% of students demonstrated such knowledge on the post-test. Of note, students across all four schools demonstrated an increase in their demonstrated understanding of dose response on this task.

Figure 6: Students' Use of Dose Response Rationale on Debate Task

Schools	**Pre-test: % of students with dose response rationale**	**Post-test: % of students with dose response rationale**
School A (n = 42)	5% (2)	29% (12)
School B (n = 38)	34% (13)	66% (25)
School C (n = 27)	4% (1)	37% (10)
School D (n = 33)	3% (1)	15% (5)
Total (n = 140)	12% (17)	37% (52)

Students expressed their understanding of dose response in the following ways:

> *I strongly agree with Morgan because everything is toxic at a certain dose. Some chemicals can be good. But that same chemical can be toxic at a higher dose. Then some chemicals can be bad at a very small dose.*
>
> *Morgan is more true. I think this because I now know about dose. When I say this I mean that no chemicals are always bad, it just depends on the amount. The chemicals that we think are bad are the ones we can not have very much of. You are only hurt by a chemical if you have too much or too little of it.*
>
> *Everything is toxic and even the good things for you if you have too much of it then it can cause harm. I heard if you have way too much water then you could die.*
>
> *Chemicals are good and bad. For example, chemicals such as iron is good for you. But on the other hand, everything is harmful at high levels.*
>
> *There are some chemicals that are very bad like arsenic and mercury and then there are some that are bad when they reach a high dose like salt and iron, but these things don't do anything at a small dose.*
>
> *All chemicals can be lethal at a certain dose, but some are good at the right dose.*

Furthermore, some students' rationale for dose response explicitly referred to their Environmental Detectives experiments:

> *Everything is toxic, it just depends on the dosage. Even sugar can be harmful if taken in large doses. While performing our dose response labs, we found out that*

Round-up which claims to be environmentally safe, was harmful to daphnia (a small organism at the base of the food chain.)

Some chemicals help plants, but can also harm them with too much of the chemical. I found this out in my experiment with radish seeds.

In my experience with road salt, a small amount of a chemical usually doesn't harm the environment.

Contrasting with the observed increase in students' dose response rationale, the main decrease in response type from pre-test to post-test was students' tendency to simply restate aspects of the problem, or to offer vague statements that did not contain any new information in the rationale (21% of students in pre-test, 8% of students in post-test.)

A predominant type of reasoning that held fairly steady across pre-tests to post-tests was the view that there are both good chemicals and there are bad chemicals (e.g., oxygen and iron are good chemicals, whereas mercury and arsenic are bad chemicals). Similarly, students referred to chemicals that had "good effects" and chemicals that had "bad effects." In the pre-tests, 43% of students expressed this type of reasoning, while 39% did so in the post-tests. This primary form of student reasoning of "good chemicals versus bad chemicals" was also observed as in our Year 2 evaluation.

There appeared to be a number of variants of this type of reasoning, with students defining "good" in a variety of ways. Some students described chemicals that were beneficial to, and needed by, the human body, such as iron, salt, and calcium. Others described "good" in more utilitarian terms as chemicals that were put to good, practical use for people's benefit. For example, students mentioned such things as chemicals used in medicines, mercury used in thermometers and gold used for coins, bleach for cleaning laundry and chlorine for killing bacteria in swimming pools, Miracle Gro to grow plants, and herbicides to kill plants one doesn't want. A few students seemed to define "good" simply as lack of harm, such as the student who said "Some chemicals are also good. Potassium which you find in bananas aren't bad for you or the environment."

A number of students drew upon their *Environmental Detectives* experiences to provide examples of specific chemicals that have positive and negative effects on different plants and animals:

In our experiment, we diluted some seed with the chemical, Miracle Gro, and it helped our seeds grow.

Just a little acetone could kill hundreds of brine shrimp or plants.

All chemicals are not bad. Some chemicals are used to help animals and plants. Most of the chemicals we used in our dose response experiments were harmful to daphnia, such as acetone.

There was no increase in students' reasoning that some chemicals could be more harmful to some species than others (6% in pre-tests, and 8% in post-tests). Students' responses in their post-tests, however, clearly utilized information and experiences they had gained from their *Environmental Detective* experiments, mentioning specific chemicals and organisms that they had worked with.

Figure 7: Individual Student Rationale on Debate Task Reflecting ED Investigations Work

Individual Students' Pre-test Responses	**Same Students' Post-test Responses**
I think Tom is right because if all chemicals were bad, there would be no living things and some chemicals in the environment are needed.	*Some chemicals are good (Miracle Gro – good on plants) but could be harmful to other things like animals (Miracle Gro on brine shrimp.)*
Most chemicals found in the environment can be very deadly. Some can be good for our environment, animals and plants.	*There are many chemicals that can be good and can be bad for the environment. For example, Jessica and I used Round Up and put earthworms and they died so you think Round Up would be good, but it's not.*
I think Tom is right because some chemicals help us and other animals.	*Vinegar is good for us, but it will kill the brine shrimp.*
Some chemicals are good, and some aren't good. It does depend on the chemical, some are good for some things and bad for another.	*Chemicals can be good and bad. For example, Miracle Gro is good for growing plants, but if it somehow slid down a hill and in a creek with brine shrimp in it, it could kill them.*

In summary, analysis of students' responses to the point of view task indicates that a good number of students had acquired a notion of dose response, and were able to apply this concept and related experimental evidence they had observed to the task. Their experiments also gave them direct first-hand experience with specific chemicals and organisms that they were able to be used as concrete evidence for understanding of the positive and negative effects of chemicals on plants and organisms. At the same time, the open-ended task revealed students' varied understandings and interpretations of what might make a chemical "good", ranging from having a beneficial biological effect on the human body, to utilitarian purposes, to lack of harm.

Environmental Mystery Task: In the environmental mystery task on the post-test survey, students were presented with the following written scenario:

> Your science class has been successful at keeping an aquarium of live Daphnia for two weeks. Daphnia are small organisms that live in ponds and lakes and are food for aquatic insects and fish. Daphnia are supposed to be fed a pinch of powdered green algae every two days. After stopping by to check on the homework assignment, you noticed that all the Daphnia in the tank had died since you last observed them two days ago.
>
> While looking at the tank full of dead Daphnia, you make the following observations:
>
> 1) the tank water is now slimy and green
> 2) the tank has been moved and was now receiving direct afternoon sun
> 3) a container of disinfectant (cleaning solution) was sitting next to the tank and the surrounding counter smelled of disinfectant

Students were asked to design an investigation that would help determine what might have caused the Daphnia's mortality (death) in the tank. The directions told them to outline an investigation that used components of a scientific investigation, and were encouraged to draw upon a list that included: question, hypothesis, method or procedure, replicates and control.

Students' responses to this challenging, open-ended task were quite varied, and primarily differed along two different dimensions. First, students varied in how many of the three possible variables cited in the problem (i.e., presence of algae in the water, the tank being affected by direct sunlight, or presence of the disinfectant) they chose to address in their investigation. Second, students varied in the kind of reasoning they expressed as guiding the design of their investigation. Reasoning types were divided into six categories.

<u>Reasoning Type</u>
Level 1: Largely cites information presented in problem; "educated guess"
Level 2a: "Test" the water or organism
Level 2b: Replicate circumstances and see what happens
Level 3: Sets up experimental treatment with two conditions/values: one condition "with" a certain variable and one condition "without" a certain variable (control)
Level 4: Sets up experimental treatment with three conditions/values: conditions with three different values (e.g., "none", "some" "a lot")
Level 5: Sets up experimental treatment with more than three conditions/values, resembling concentrations or dose response

__Figure 8: Sample Responses for Different Reasoning Types__

Reasoning Type	Sample Student Response
Level 1 (Educated guess)	Someone could have tried to clean under the aquarium and moved it into the sunlight and never moved it back to where it was. Then the algae grew because the sun helped it grow and the algae strangled the daphnia because there wasn't enough air to breathe.
Level 2a ("Test" water or organisms)	I predict that the cleaning solution might have poisoned the daphnia. First I would look on the bottle to see if it was poisonous. Next I would test the water for any signs of chemicals and finally I would clean and refill the tank.
Level 2b (Replicate circumstances)	Someone might have accidentally sprayed the tank with disinfectant and the daphnia died from the chemical. Get some that are still alive and experiment them with the cleaner.
Level 3 (Experiment with two conditions/values)	Does sunlight affect Daphnia's mortality? Place a tank of daphnia in a place that receives daily sunlight. Place another in a place that receives little sunlight throughout the day. Keep the tanks in the same place through the experiment. No control is needed because the changing variable is with and without sunlight. Have 2 replicates of each one. My hypothesis is that the sunlight doesn't affect the daphnia.
Level 4 (Experiment with three conditions/values)	Question: Does too much sun kill Daphnia? Hypothesis: Too much sunlight kills daphnia. Materials: daphnia, sun; window; food; water; 3 tanks. Procedure: collect materials Put 5 daphnia in each (3) tanks. Put one by window, one in dark corner, and one in between window and corner. We will have 3 replicates. Watch over next few days and see how daphnia die in each location.
Level 5 (Experiment with four or more conditions/values; dose response)	Question: Does a lot of algae kill daphnia? Hypothesis: A lot of algae does kill daphnia. Experiment: First I would put 8 daphnia in 8 different dilutions of algae from a lot to the normal amount given every two days. I would test this for a week, checking the daphnia every 3 hours.

As shown in Figure 9, student responses were amazingly varied. When formulating the problem task for the survey, we had anticipated that most students would focus on a particular observation or factor, such as the algae, the cleanser, or the sunlight, and attempt to design an investigation focusing on that single factor. We, in fact, found that only about half of the students (51%), focused on a single factor, while 44% attempted to address two or three of the factors in their investigation (The remaining 5% (8 students) produced responses that were sufficiently vague as to be uncodable.)

We had envisioned that the problem's directions encouraging students to include a "question" and "hypothesis" in their investigation design might have sharpened their focus on a single factor. For example, we thought students might offer as a question, "Did the direct sunlight kill the daphnia", with a hypothesis of, "Strong direct sunlight will cause daphnia to die."

However, what we found was that many students listed as a question something much broader as, "What caused the daphnia to die?" Accordingly, students' typical hypotheses might be, "I think both the cleanser and the sunlight caused the daphnia to die," or "They died from being overfed, the sun overheated them, and some of the cleaner entered the daphnia's water." They then proceeded to attempt to outline an investigation or series of steps that addressed two or three factors.

Figure 9: Students' Formulation of an Investigation, Breakdown by Number of Variables and Reasoning Type

Reasoning Type	**One Variable**	**Two Variables**	**Three Variables**	**Total by reasoning type**
1 Guess based on information in problem	9% (13)	5% (7)	7% (10)	21% (30)
2a Test water/organism	8% (11)	1% (2)	3% (5)	13% (18)
2b: Replicate circumstances	10% (14)	6% (8)	9% (13)	25% (35)
3 Experiment with two conditions/values	10% (14)	5% (7)	3% (5)	19% (26)
4: Experiment with three conditions/values	4% (6)	3% (4)	0	7% (10)
5 Experiment with four or more conditions/values	10% (14)	0	1% (1)	11% (15)
Totals by variables	51% (72)	20% (28)	24% (34)	

(n = 140)

The second dimension along which student responses varied considerably concerned the type of reasoning they employed to guide their investigation. At the most basic level, about a 1/5 of the students (21%) offered views mainly based on information presented in the problem, rather than attempt to design an investigation of some kind.

> *Question: How did it happen and when?*
> *Hypothesis: That the cleaning solution could of fallen into it. (Student from School A)*
>
> *How did the daphnia all die? I think they died because of the sun and the disinfectant. I think this because considering daphnia live in lakes and ponds, they don't get direct sunlight and having them sitting in the sun will fry them. Also, the disinfectant issue. I think that if someone was cleaning and spraying around them, then it probably got into their water and poisoned them. That's why I think they died. (Student from School D)*
>
> *I think that the daphnia died of the sunlight. Daphnia only live up to 7 days. Going from cool shade to direct sunlight is a big change for the tiny creatures. They could have died from heat exhaustion. It was their time to die, the rays of the sun. There is the possibility of them dying from too much food. Maybe*

someone put in too much and they died. The water could have absorbed the cleaning solution. All three of these could have done it. (Student from School B)

About 2/5's of students (38%) offered beginning notions of experimentation, either expressing the need to test the water in the tank or to test the daphnia (such as for the presence of cleanser) (13%), or to replicate some circumstances of the original scenario and to observe what happens (25%).

I think the disinfectant killed all the daphnia. How I would test it I would filter the water and see how much disinfectant was in the water and then test on some live daphnia and see if the same amount of disinfectant would kill the daphnia. (Student from School A)

The question to solve is what killed the daphnia? The procedure would test the water in the tank. Then you would want to get more daphnia and test them with the cleaning solution. You would want to keep track of the movement and heart beats. By all the time this has happened you should know what killed them. You should test the cleaning solution and see if that's able to kill daphnia. (Student from School B)

Take nine cups of water. Put clean water in 3 of them. Put a pinch of disinfectant in one, and fill another 3 with algae. 3 daphnia to each container and record which group lives longer. (Student from School C)

To figure out which one of the three observations you could put 2 or 3 daphnia in 3 different dishes. For the first observation you could make the dish slimy and green and let it sit for 2 to 3 days and see what happens. For the second observation you could put the daphnia and dish in the sunlight for 2 to 3 days and see what happens. For the third observation you could leave the cleaning solution out next to it for 2 to 3 days and see what happens. That will determine which observation killed the daphnias. (Student from School D.)

About a fifth (19%) of the students offered an experimental design of more traditional form with two conditions: one "with" a certain variable, and one "without" (or less of) that variable. Thus, there was often either an explicit or implicit sense of a control group, and the isolating of a single factor or variable.

We could take two clean tanks of water and put 20 daphnia in each. In one of the tanks I could put 1/2 cup of disinfectant. Then I could see if the disinfectant effects the daphnia. (Student from School C)

Question: What caused the daphnia to die?
Hypothesis: I predict that because the tank had been moved and the sun was directly on the daphnia, and they must of overheated.
Method: 1) Fill 2 of the exact same tanks with 100 daphnia in each one.
2.Feed daphnia.

3. Place one tank near the window so that it will receive direct afternoon sunlight.
4. Place the second tank where no sunlight can interact with the daphnia.
5. Wait 2 days and take some observations.
Replicates – Repeat this same procedure 5 times.
Control – The amount of brine shrimp in each tank, the temperature of the water, and the amount of food each tank is fed. (Student from School A.)

Question: What killed the daphnia in the tank?
Hypothesis: I think it was a combination of it being moved into direct sunlight and having the disinfectant next to it.
Procedure: Have 3 tanks all filled with water and with daphnia in them. Put one in the sun, one next to a container of disinfectant, and put one on a table in normal light. Check on them and record your observations.
Replicates: Have 2 replicates of each tank.
Control: the tanks in the plain light (not direct sunlight) is the control. (Student from School C)

A little less than a fifth (18%) proposed an investigation that had at least three different levels or "concentrations" of one variable. Only 11% offered investigations that had four or more levels or concentration of a variable, indicating most strongly some type of concept of dose response.

Question: Was it the cleaning solution that killed the daphnia and if so, how much does it take to kill it?
Hypothesis: The daphnia were killed by the cleaning solution.
Method/procedure: Put 6 daphnia in 8 different jars. Make concentrations of cleaning solutions (ex: (100%; 10, 1, 0.1, 0.01 0.001, 0.00001%)
Add 1 concentration to each jar, leaving the last jar with just water. Everyday, check and see how many daphnia have died.
Replicates: put 6 daphnia in all 8 jars. Do this 3 times, so that you have 3 jars with 6 daphnia in each for each percent (make drawing with 3 jars with 100%, 10%, 1%, etc.
Controls: Make sure to control how much solution goes in each jar. Make sure jars are same.
Variables – all have same light, etc. (Student from School A)

Question: Does feeding daphnia more than a pinch of green algae every couple of days affect the death rate of daphnia?
Put 12 daphnia in a 32 ounce bottle. Have 10 replicates, making 120 daphnia. Have 2 bottles as the control group. Put 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 pinches as the doses. Wait a week and record how many from each group survived their dose.
Hypothesis: I think that at 3 pinches 75% of the daphnia will die. (Student from School C)

Question: Does a tank with more slimy green stuff have an affect on the death rate of daphnia over a week.

Hypothesis: I believe it will have no affect.
Method/procedure: Put 24 daphnia in 6 containers with four in each container. Then put 1, 2, and 3 pounds in the amount of green slimy stuff in 3 of them than 4, 5, and 6 pounds in the other 3. then have another with 4 daphnia in it, but no green slimy stuff.
Check everyday at noon to see how many are dead in each amount of green slimy. (Student from School C)

I would test the daphnia on doses of disinfectant because sunlight and algae are in their natural environment. I would test them in doses of 100%, 10%, 1%, and .1%. This would tell me how much of the disinfectant is needed for them to die. (Student from School D)

I would test all the problems on other healthy daphnia. The first thing I would do is I would take the cleaning solution and water it down. I would have my stock that wasn't watered down at al (100%). I would water it down to 10., 1, and .1 and put them in each in two different containers, making sure I have at least two different containers for the replicates. Then I would catch the daphnia and put two daphnia in each container.
1) Check daphnia.
2)Make solutions
3)Put daphnia in solution
4)Watch effects. (Student from School B)

These investigations using "Level 5" reasoning also generally tended to be much more detailed, and included information pertaining to the number of organisms (daphnia), measurable outcomes (death), use of replicates, and attention to controlling certain variables.

Analysis was also conducted on whether or not students' descriptions of their proposed investigation included a variety of features characteristic of well-designed dose response experiments: replicates and controls (both listed in the task's directions), reference to amounts, dilutions or concentrations (reflecting dose response concepts), and specification of the number of organisms used in the sample, specific measurable results they would be observing, and reference to a time period utilized for data collection.

Figure 10: Students' Inclusion of Experimental Features

	Range across 4 Schools	**Total Student Sample**
Number of organisms	12% - 44%	24% (34)
Replicates	0% - 44%	21% (30)
Controls	6% - 30%	17% (24)
Measurable Results	3% - 30%	17% (24)
Dilutions or Concentration	7% - 21%	14% (20)
Time for data collection	3% - 19%	12% (17)

As shown in Figure 10, roughly one fifth (17%-24%) of all students incorporated mention of the number of organisms, replicates, controls and measurable results. While this level of frequency appears somewhat modest, it should be kept in mind that only 36% (51 students) of students offered descriptions of investigations that resembled experiments with two or more conditions (Levels 3-5). Thus, of those students who did outline experiments, a reasonably high proportion of them elected to include experimental features regarding sample size, controls, replicates and measurable results.

Students' identification of certain features was fairly clear and direct, while inclusion of other features reflected more varied levels of understanding and interpretation. Students' inclusion of the number of organisms used in the experiment was fairly straightforward, ranging anywhere from 2 to 100 daphnia in a given container or tank. Similarly, students who included reference to measurable results typically indicated that they would observe whether the daphnia died, or survived. Students in one class that had previously conducted more involved ED investigations on daphnia behavior in their classrooms also indicated that they would observe daphnia appearance, movement and heart rate.

Students also clearly made reference to the amount of time involved in the data collection period. Given the problem scenario's focus on "two days" (both the frequency be which the daphnia are supposed to be fed, and the fact that two days had elapsed since you observed the daphnia to be alive), most students referred to observing the daphnia for several days, or "after two days." A few students offered more discrete time periods, such as "checked every half hour for 3 hours," "every hour for the next 3 days," or "test them for a week, checking the daphnia every three hours."

When referring to controls, students either indicated that they would set up conditions that featured the presence or absence of a certain variable (similar to the reasoning employed in Reasoning Level 3, above), or that there were certain variables that they would be sure to hold constant, or keep the same, such as the amount of water, use of clean containers for each tank, number of daphnia in each container, etc.

Students had various interpretations of the term, "replicates." Some students correctly used the term to refer to the use of more than one container for a given condition or concentration. For example, rather than having a single test tube with daphnia exposed to 10% disinfectant solution, students would use two different test tubes with that solution. Others thought replicates referred to the number of different daphnia in a given container, and the use of more than one daphnia per container. Yet others used "replicates" as more of a repeated trial, saying that they would run the experiment once, and then do another replicate by running the experiment several other times. A few students used "replicate" similar to "repeat", such as "fill a test tube with water and replicate this 8 more times."

Regarding dilutions or concentrations, students either referred to varying the amount of cleanser, algae, or sunlight (i.e., one pinch of algae food vs. two pinches of algae food), or specifically represented concentrations in terms of percentages. Half of the 14% of students (10 of the 20 students) who referred to dilutions or concentration in their investigations specifically used percentages to represent varying concentration levels of their variable (typically the amount of cleanser in solution, but sometimes also the amount of algae, or sunlight.)

Some of the students offered quite detailed descriptions of their investigations, such as the following:

> *Question: Was it the cleaning solution that killed the daphnia and if so, how much does it take to kill it?*
> *Hypothesis: The daphnia were killed by the cleaning solution.*
> *Method/procedure: Put 6 daphnia in 8 different jars. Make concentrations of cleaning solutions (ex: (100%; 10, 1, 0.1, 0.01 0.001, 0.00001%)*
> *Add 1 concentration to each jar, leaving the last jar with just water. Everyday, check and see how many daphnia have died.*
> *Replicates: put 6 daphnia in all 8 jars. Do this 3 times, so that you have 3 jars with 6 daphnia in each for each percent (Has drawing with 3 jars with 100%, 10%, 1%, etc.)*
> *Controls: Make sure to control how much solution goes in each jar. Make sure jars are same.*
> *Variables – all have same light, etc. (Student in School A)*
>
> *Question: What is the death toll of daphnia in disinfectant?*
> *Hypothesis: All daphnia will die except for the control jar.*
> *Purpose: The purpose of this experiment is to find out what the lethal dose of disinfectant is for daphnia.*
> *Procedure: 1. gather materials.*
> *2. prepare dilutions*
> *3. supply daphnia*
> *4.observe at appropriate intervals.*
>
> *Materials: 16 jars.*
> *Water – amounts may vary*
> *Disinfectant*
> *1 10 ml pipette*
> *1 disposable pipette*
> *1 graduated cylinder*
> *64 daphnia*
>
> *The controlled variable will be the amount of daphnia, in each jar.*
> *Replicates: There will be 2 replicates of all 8 jars. The levels will be 100% (disinfectant); 10%, 1%, 0.1%, .01%, .001%, a.0001% and control. There will also be 4 daphnia in each jar. (Student from School A)*
>
> *Question: At what dosages can cleaning solution be lethal? And how do cleaning solutions affect the environment?*
> *Hypothesis – at 10% the threshold dose will be apparent.*
> *At 50% the LD 50 will be apparent*

When 10% of the solution is exposed the organism will die over a long period of time with low doses.
When 50% the organism will die quickly.
Method and procedure – gather materials – organisms (daphnia) 48, containers (16), pipettes, water, bubbler, chemical.
Replicates – 4 containers of beakers (500 ml)
1 container of 12 daphnia.
Dosages: 1%, 10%, 50%, 100%.
Controls – chemicals, same organism (daphnia), some light, same temperature, same food, same water. (Student from School B)

In summary, the complexity of the problem scenario, with any one of three factors (e.g., algae, sunlight and disinfectant) possibly contributing to the death of the daphnia, appeared to have encouraged students to be tempted to embrace the full scope of the problem. Only about half the students chose to design an investigation that focused primarily on one factor. The investigations that students designed reflected a variety of levels of reasoning about experimentation, ranging from simply "educated guesses" based on details of the problem, to initial attempts at a test of some kind (e.g., testing the water, replicating the same circumstances and seeing what happens), to a more formal experiment of some kind. Of the more formal experiments, students ranged in whether they conceptualized the experiment as having primarily two conditions, "with" and "without" a certain variable (e.g., disinfectant), versus experiments that had three or more "levels" or concentrations of a certain variable. Only a little more than a tenth (11%) of students proposed investigations that had three or more "concentrations" of a certain variable, resembling a dose response experiment.

At the same time, roughly a fifth of the students were able to offer experiments that included a variety of specific detailed experimental features, such as the number of organisms they would test, the use of replicates, controls, and what would constitute measurable results.

Students' Posing of Environmental Questions Task: The broadest open-ended task for the surveys was one in which students were asked to think about any concerns or questions that they might have about the harmful effect of things in the environment on people or other living things, and to pose these concerns as questions they would like to have answered. This problem type was designed to assess students' concerns and awareness about the environment and the general kinds of orientation for question-posing they possessed.

Previously, findings from our Year 2 evaluation involving students from the one participating field test school (n=49) had shown a slight increase in the level of specificity of terms and mention of dose response that students used in the post-test, compared with their pre-test surveys. For example, a small number of students (10% - 16%) offered post-program responses that mentioned specific chemicals by name, reference to amounts or doses of certain chemicals, and to local environmental locations in Vermont or New Hampshire, whereas almost none (0%-6%) had done so in their pre-test surveys.

Comparison of student responses on the pre-program and post-program in Year 3 showed no increase in students' mentioning of dose, specific chemicals or local environmental locations. As the final item of a rather challenging post-test, there was a fairly high non-response rate on this item, with 38% (54) students not responding to this item on the post-test versus 15% (21) students not responding to this item on the pre-test. However, even when adjusting for the smaller number of actual respondents to this item on the post-test, versus pre-test, no increase in these more specific terms or mention of doses were observed.

Figure 11: Content Analysis of Environmental Questions Posed by Students

Terms Mentioned	**% of students on Pre-test (out of total respondents to item; n = 119*)**	**% of students on Post-test (out of total respondents to item; n = 86*)**
"Chemicals"	11% (13)	13% (11)
Specific chemicals by name (e.g., arsenic, mercury, copper)	20% (24)	21% (18)
"Road salt" or "Round-up" or "Miracle Gro"	6% (7)	2% (2)
Local environmental locations or VT/NH	7% (8)	5% (4)
Reference to amount of a certain chemical/dose	0% (0)	2% (2)
"Toxins" or "toxic"	3% (3)	1% (1)

*(*original n = 140 for matched sample of pre-tests and post-tests, minus number of students with no response to this specific survey item (21 for pre-tests, 54 for post-tests)*

This lack of increase in Year 3 may be due to a variety of factors. First, several of the participating classrooms chose to fold the ED activities into a longer sequence of science curricular activities over a longer span of time, as opposed to a more concentrated focus of ED, as had been the case in Year 2. Thus, the post-test was not always administered immediately following a more intensive focus on a 'chemicals in the environment" series of activities. Second, teachers in Year 3 conducted the ED activities on their own, as opposed to being co-taught by the Montshire staff member, as in Year 2. The use of the case study materials was more optional in Year 3, and teachers often substituted more isolated readings that they felt were more appropriate in reading level to their students, and generally did not couple the ED curriculum with any field-based work involving field trips to local sites, as had been the case in Year 2. Thus, this subtle survey item may be detecting a more modest emphasis on specific dose response issues and connections to the local environment that occurred with Year 3 teachers.

At the same time, some students did reflect specific changes in the kinds of environmental questions they posed before and after their use of Environmental Detectives, as shown in Figure 12. For example, these students tended to more frequently mention arsenic as a specific chemical, and make references to effects of dose response.

Figure 12: Changes in how Individual Students Posed Environmental Questions, before and after Environmental Detectives

Individual Students' Pre-Test Responses	**Same Students' Post-Test Responses**
Are there harmful chemicals in potato chips?	*Is the arsenic ever going to really effect the people in NH?*
Milfoil in Lake Morey *Mercury in Lake Morey.*	*What is the average lethal dose of mercury?* *What is the average lethal dose of arsenic?*
Global warming – how are they making the world unhealthy? *Landfills – what's going to happen in the future?*	*What will happen to roadside plants when they are diluted with salt?* *What will happen to animals when they are introduced to fertilizers*
Are pesticides harmful and/or helpful? *Are pesticides everywhere?*	*How much arsenic is in our water and how much does it take to make us ill or die?* *Are any chemicals that aren't harmful to us (humans) harmful to wildlife? Are any chemicals that aren't harmful to wildlife harmful to us (humans)?*
Is global warming a real issue? *Are pesticides damaging my food sources?*	*Arsenic – is the situation getting worse?* *What happens to the Elizabeth Cooper mines now?*
What are some chemicals that can help the environment? *Is mercury a use for anything in the environment?*	*How does salt water effect daphnia?*

Student Discussion from Spring Symposium: Finally, some additional insights regarding students' perspectives and learning from ED are gained from student discussions that occurred during the final spring student symposium. As noted earlier, the symposium was held at the Montshire as a culminating event for students drawn from the four participating field test schools. Following a morning of presentations by Dartmouth faculty, and science poster sessions by students sharing their work with each other, students were divided into four discussion groups. Each group was asked to reflect back upon their experiences with Environmental Detectives, and to discuss how they had felt, and what they thought they had learned. Each group was moderated by one of the field test teachers.

As shown in Figure 13, students were highly positive about the ways they had felt using *Environmental Detectives*. Students spoke about feeling smart, interested, excited. They appreciated learning things more "first hand" rather than reading it in a book, and enjoyed seeing projects from other schools, hearing how college students were doing similar kinds of investigations, and coming to the Montshire Museum. Negative sentiments were few, and mainly concerned feeling confused or frustrated at times, reflecting the ambitious scope of the student investigations, and feeling nervous or flustered about having to give presentations at the Montshire symposium.

Figure 13: Student Responses of "How We Felt", Response type by Group and Comment

	Group #1	Group #2	Group #3	Group #4
Positive Affect	Fun Interested Excited Confidence Honored Special Better Informed SMART! Relieved	A lot better than book. Interested in results Excited when experiments went "right" (didn't go the way you expected) Intrigued.	Fun Presentation shorter than expected. Exciting. More fun to do first hand then read it Nice to see other schools' projects College students doing same thing. Liked coming to Montshire	Good Powerful Happy Smart Interested Helpful Educated Intelligent
Negative Affect	Confused Overwhelmed Frustrated	Frustrating when it didn't go right	Using live organisms/sad Nervous Presentations – boring	Nervous Flustered

When discussing what they had thought they had learned, the discussion focused primarily on aspects of experimentation – experimental design and procedure, experimental techniques, and the process of doing science (Figure 14). Students also mentioned learning about dose response, environmental issues and the particular plants and organisms that they had worked with in their investigations.

Figure 14: Student Responses of "What We Learned", Response type by Group and Comment

Types of Responses of What Learned	**Student Comments**
Dose Response	**Group 1**: Effects of chemicals. Even sugar was toxic **Group 2:** Everything's toxic at a certain dose. Poison is related to dose. Ingestions, inhalation, absorbtion are 3 ways to get poisoned. **Group 3**: Repel x doesn't effect the immediate death toll of brine shrimp. All doses are lethal at certain levels. **Group 4:** Everything can be toxic at a certain dose
Environment	**Group 1**: Environmental issues **Group 2**: 1/4 children in US live within 1 mile of a leaking Superfund site. 3 synthetic chemicals produced a day and only 30 per 5 years on EPA watch list. **Group 3**: How chemicals in the environment affect things in the food change (sic). **Group 4**: What effects the environment Small issues can have a big effect
Experimental	**Group 1**: Designing experiments

Design and procedure	Setting up experiments Run an experiment **Group 2**: Before experimenting on an organism you must learn about it. Run experiments more than once. Need lots of replicates to get reliable data. Before testing on an organism, need healthy organisms. Need controls. **Group 3**: Do experiments slowly. Setting up experiment, replicates, concentrations Variables + controls. **Group 4**: How to set up an organism experiment.
Experimental Procedure and Techniques	**Group 1:** Make concentrations **Group 3**: Measuring with pipettes. Grease pencils rub off petri dishes easily. Breaking down percentages of liquids.
Process of doing science	**Group 2:** What we did is same as real scientists. **Group 4**: To be patient
Organisms/content	**Group 1:** Catch daphnia **Group 3**: Arapidopsis seeds are small. **Group 4**: About brine shrimp About daphnia About copper sulfate About acetone About organisms
Miscellaneous	Group 1: Terms Graphs

Design Recommendations

The Year 3 field test of *Environmental Detectives* found that middle school teachers and students found the curriculum materials to be engaging and worthwhile, and offering interesting new opportunities for students to be engaged in sustained, experimental investigations concerning chemicals in the environment and dose response. Classroom observations, teacher interviews and student surveys also indicated several areas of the materials' curriculum design that could be enhanced and improved, as outlined below.

• Continue the ED focus on experimental design and dose response investigations. Build from students' initial notions of "good" versus "bad" chemicals and non-experimental approaches to assessing situations. Introduce them to the advantages of experimental designs that adopt more than two values of a given variable, while still maintaining controlled variables.

• Strengthen the connections between ED activities and the broader context of chemical impact in the environment. This could be achieved through more extensive use of appropriate case study materials and discussion points, and teachers encouraging greater emphasis in student reports and presentations on the connections between students' experimental designs and results, and their understanding of environmental issues and situations in the real world.

• Further clarify and convey concepts and terms relating to investigable questions, hypothesis, controls, replicates, and measurable outcomes. This could be done through teacher-led presentations, classroom discussions, original student investigations, and critiquing of hypothetical and real student investigation designs.

• Continue offering opportunities for students and teachers to meet with research scientists, and other professionals dealing with chemicals in the environment. Utilize such opportunities to enhance student's understanding of applied research related to real world issues, problems and situations, the challenges and rewards of doing scientific research, the process of formulating research questions and studies, and the type of reasoning and interpretation that's involved in making sense of research data and findings.

• Continue to provide structured student handouts outlining aspects of defining investigable questions, designing experiments, collecting data, analyzing and interpreting data, and presenting and discussing results.

• Offer improved case study materials that are interesting and easily readable by middle school students, and other information sources (both print and on-line) that connect and inform research investigations with real world situations.

• Include more structured student materials and assignments that foster students' more in-depth processing and understanding of case study materials and experimental activities.

• Provide student assessment materials, including rubrics for scoring student investigations, reports, and presentations, that both students and teachers can use to guide and assess student work.

• Encourage opportunities for students to share and present their research to classmates, parents, community members, and research professionals, and to students in other schools.

References

Char, C. (2003) *Environmental Detectives: An Environmental Science Curriculum for Middle Schools, Year 2 Evaluation.* A report prepared for the Montshire Museum of Science. Montpelier, VT: Char Associates.