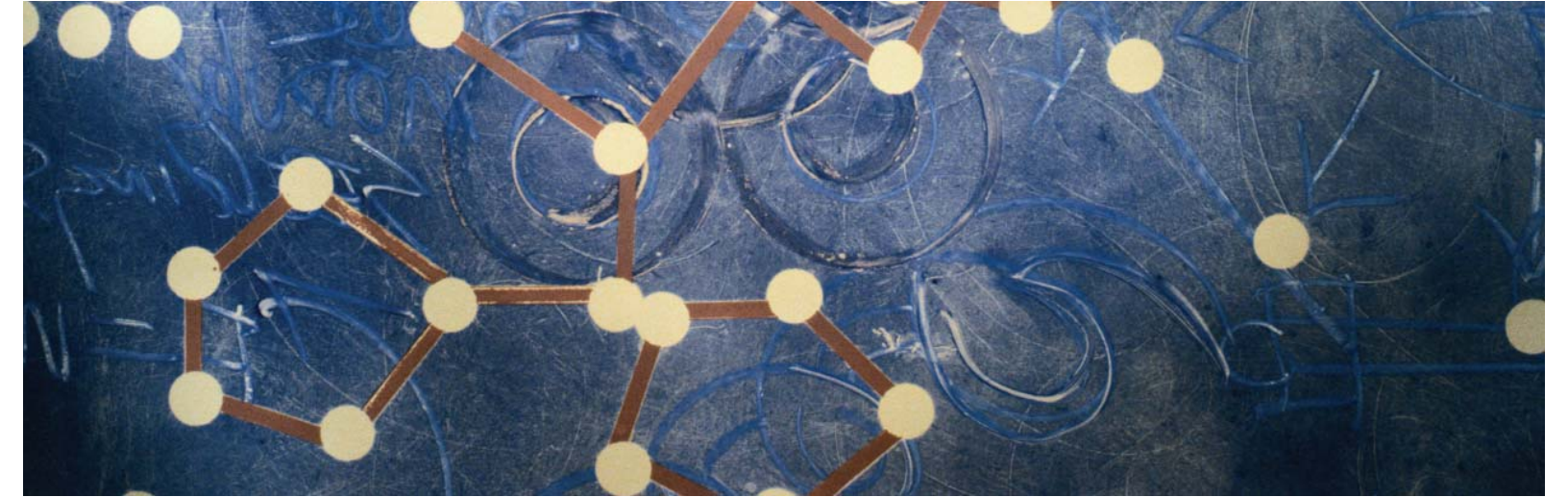




PCBs in the Last Frontier

A Case Study on the Scientific Method

By Michael Tessmer



This interrupted case study is based on current research involving the global transport of polychlorinated biphenyls (PCBs). Students are asked to propose several hypotheses and experiments in an attempt to determine how PCBs are transferred globally. As the case unfolds, it becomes clear that the transport mechanism is more complicated than scientists first thought. The case requires minimal background knowledge and is suitable for major and nonmajor courses in biology, chemistry, and environmental science.

The case

Part I — PCBs

Polychlorinated biphenyls (PCBs) are compounds that were once used as insulators in electrical transmission lines and in the production of polymers. Each PCB differs by the quantity and location of the chlorine atoms. An example of one of the many different PCBs is shown in Figure 1.

PCB production was halted in 1977 due to their potential toxicity,

but the chemicals are still found in the environment due to their stability. Studies in remote areas of Alaska have shown that PCBs can even be found in lakes untouched by humans. There is no known natural process that produces PCBs, so all of the PCBs in existence are presumed to have been produced by humans.

Questions

- ♦ What scientific observation about PCB distribution is described above?
- ♦ Propose a hypothesis or “explanatory story” to explain the global movement of pollutants such as PCBs. Specifically, how could they end up in the most remote Alaskan lakes?
- ♦ Propose a method, either through observations or direct experimentation, that would test your hypothesis from the question above. (Note: Your approach may be on a local scale despite examining a global phenomenon.)

Part II — Global transport

Later studies showed that the global circulation of PCBs was due at least in part to atmospheric transport. PCBs enter the atmosphere by several mechanisms including the burning of organic material and evaporation in warmer climates followed by condensation at higher latitudes. This explains how chemicals made by humans could be found in areas untouched by humans.

Questions

- ♦ Come up with a hypothesis or “explanatory story” to answer the following question:
- ♦ Should PCB levels differ significantly in Alaskan lakes that are near each other and at the same altitude? (Keep in mind that a hypothesis is an educated guess,

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so it requires a reason why you think your answer is correct.)

- ♦ Propose a method, either through observations or direct experimentation, that would test your hypothesis from the question above.

Part III — Significant difference?

Recent observations of PCB levels in arctic lakes have shown that the levels of PCBs are not the same in all lakes that are near each other and at the same altitude. In fact, lakes at the terminus (i.e., the start) of river systems had higher PCB levels than completely isolated lakes that were nearby.

Questions

- ♦ What possible “explanatory story” might explain the observation described above? (Hint: Think of species that leave a lake but return later in life.)
- ♦ How would you test your hypothesis from the question above?

Part IV — Riddle solved

Recent scientific studies have shown that sockeye salmon returning from the ocean to spawn in Alaskan lakes contain elevated levels of PCBs. After spawning, the salmon die and their contents become part of the lake sediment and/or enter the food chain. The salmon are responsible for adding approximately six times as many PCBs to remote lakes as atmospheric circulation. The types of PCBs in the salmon also match those found in the ocean.

Question

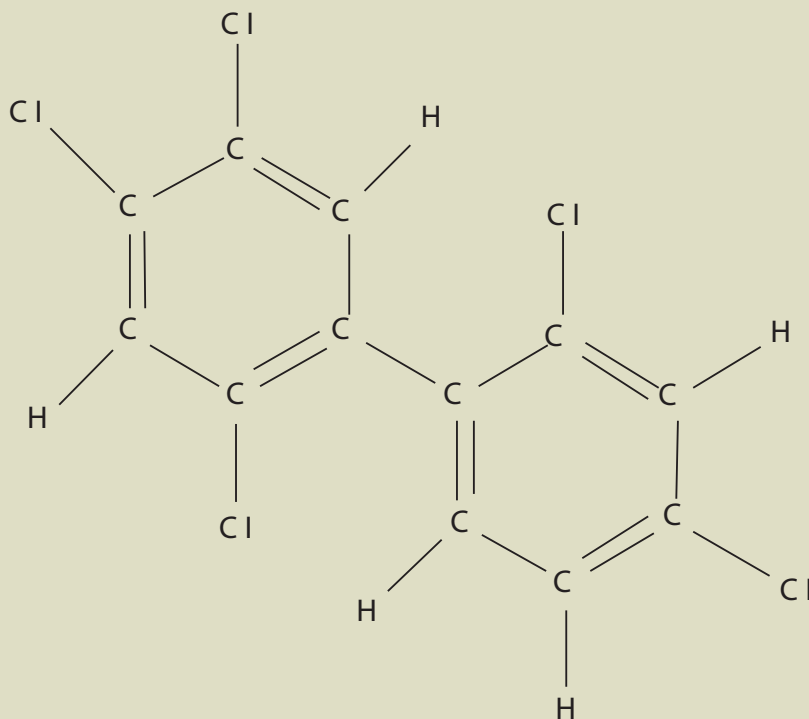
- ♦ Imagine yourself as a scientist working on this issue. What would you want to look at next?

Teaching notes

This case study was developed after reading an article in the journal *Nature* concerning the bioaccumulation and transport of PCBs by sockeye salmon from the Pacific Ocean to Alaskan lakes (Krümmel et al. 2003). It involves students reading basic background informa-

FIGURE 1

2,2',4,4',5'- Pentachlorobiphenyl.



tion before proposing hypotheses to explain the information. The emphasis is on making predictions and explaining the reasoning behind a prediction.

PCBs are a good example of a persistent pollutant that has a global distribution. The example shown in the case study is one of 209 possible congeners. The precise mixture of congeners depends upon the original source and is quite variable. The compounds are excellent insulators and were used mainly in heavy electrical equipment. Examples of other uses include polymer manufacturing and carbonless copy paper production. The persistence of PCBs in the environment is related to their thermal stability and general resistance to biodegradation.

The acute toxicity of PCBs was first recognized on a large scale in the 1960s from an accidental contamination of cooking oil in Japan (Spiro and Stigliani 2003). Several thousand people suffered a variety

of illnesses ranging from skin discoloration to higher mortality for infants born to exposed mothers. The long-term health effects have been harder to identify, but it is suspected that PCBs cause endocrine disruption by binding to the Ah (aryl hydrocarbon) receptor (Spiro and Stigliani 2003) and can affect thyroid function in the hydroxylated form (Cheek et al. 1999).

This case was designed to be used early in a course such as general or introductory chemistry, general biology, or environmental science. Because little background knowledge is needed, it can be used with either science majors or nonmajors. The case could also be extended for use in a course such as analytical chemistry where it could involve reading and discussing the original paper from *Nature* and subsequent published research.

Objectives

- ♦ To help students review the scientific method.

- ♦ To teach students how to better state hypotheses.
- ♦ To encourage students to design experiments that test a hypothesis.
- ♦ To introduce students to the scientific literature with a relatively easy-to-read article.

Classroom management

I have used this case in a general chemistry class of 40 students working in groups of three. As written, the case can be completed in a 50-minute lecture session or in a lab setting.

The case is broken up into four parts, which the instructor distributes one part at a time with discussion after each part. (In large classes this may be less practical and the instructor may want to pass out the entire case and instruct students not to look ahead.) Students read each part and then spend about five minutes discussing the questions as a group. After each part there is a short class discussion with a summary of the best answers. After completing the case, I provide copies of the *Nature* article that the case is based on to any students who are interested in reading more. The content of the article is accessible to most students and can serve as a good introduction to the primary literature.

Before beginning the case, I run a short class discussion on the steps of the scientific method. With input from the class, I draw a diagram showing the steps as a refresher. Most students have seen the steps to the scientific method enough times that the basics can be discussed as a class. Added discussion can also occur on the difference between an experiment where a variable is manipulated and making observations to answer a question. This more subtle distinction can be emphasized while students are discussing ways to test hypotheses. The case presents several opportunities for students to propose experiments, and the discussion from the early part of the case will likely lead to

improved answers later on.

When asked to explain how PCBs could end up in remote Alaskan lakes, students often suggest that they were transported by air, either via evaporation or emission from industrial plants. This is a good starting point and turns out to be one of the transport mechanisms for PCBs. A common alternative hypothesis is that the PCBs were transported by birds. While not the correct answer in this case, it is nonetheless an excellent first idea and should be included in the class discussion as a plausible explanation. It is important at this point for instructors to nurture creativity and consider multiple possibilities.

In terms of proposing a method for testing their hypotheses in Part I, student suggestions have included releasing some radioactive PCBs and then testing lakes north and south of the original lake to see if the PCBs move; releasing a large amount of a safe dye to see if the color moves north or south over several months; and catching and testing birds that migrate to Alaska to see if they contain the same types of PCBs found in the lakes.

The first time this case was used students had trouble connecting animals to the movement of chemicals and a common answer to the questions in Part III were that the PCBs were drifting up rivers. The inclusion of the hint in the question puts most groups on the right path. Instructors may choose, however, to not include the hint as part of the question, but rather to reveal it after the students have grappled with the question for a few minutes. To test their hypotheses at this stage of the case, students have suggested testing the PCB levels at different points along a river system to see if they increase going inland, as well as catching some salmon that are on their way back to spawn to see how many PCBs they contain.

A possible extension of this case comes from recent work show-

ing that organohalogenes transferred by migrating salmon end up in the resident fish of the lake where spawning occurred (Mu et al. 2004). In that work, arctic graylings residing in lakes with returning salmon showed higher levels of chlorinated fatty acids than arctic graylings in lakes with no returning salmon. The transfer mechanism is not known at this time. This touches on issues of bioaccumulation that can be covered depending on the time available. Areas related to this are lipid solubility and movement through the food chain, which are especially good topics for students in environmental science courses.

A complete answer key to this case is available on the National Center for Case Study Teaching in Science website at www.science-cases.org/last_frontier/last_frontier_notes.asp ■

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