Developing Possible Solutions

by ReadWorks

For any given problem, there is often more than one solution. In some cases, there are very few solutions. In others, a countless array of perfectly good solutions can be introduced. Without a system for testing each solution to figure out which is best, we'd have no quantifiable way of figuring out which one to choose.

Once a hypothesis, or potential solution to a problem, is in place, it needs to be tested. More than one hypothesis can be tested, and results should be carefully recorded.

Some solutions are more easily identifiable as being "the best." For example: the quickest route from home to school; the gear ratio that will make it easiest and most efficient to ride your bike; the best time of year to plant tomatoes. All of these solutions address very specific, concrete problems and are highly testable. And once you've found a satisfactory solution, you may not have to do too much testing. The solution will remain satisfactory indefinitely, as long as all other variables remain constant.

Of course, there are other problems we encounter where the solution set is wide-ranging and more open-ended.

Have you ever heard the expression "to build a better mousetrap"? It's an old saying that refers to a problem-solving endeavor that invites inventors and engineers to endlessly reimagine new and better solutions. In this case, the problem is very old and famously banal-catching mice.

Most mousetraps might look like the ones we see in a hardware store. But a new, improved design is always possible. It might be something completely different. Like an electrical current rigged with mouse-charming, atonal music; a gummy surface, following the principles of flypaper, designed to trap mice humanely; or, more organically, a housecat (with no bell).

In this case, depending on the goals and constraints of the project, an unending number of different solutions are possible. Scientists use many different techniques and resources to develop solutions-these include induction, ideas from other fields and research, their own creativity, mathematical calculations, and whatever else they may have access to. The inspiration for new and elegant solutions can come from an unexpected place. Just as artists look to the world around them for creative stimulation, scientists often take cues from the environment.

Although some people believe that artists and scientists do very different work, the two groups really have a great deal in common when it comes to problem solving and creativity.

The "stages of inquiry" a scientist goes through to come up with a satisfactory or plausible solution is sometimes romanticized in the annals of history. Throughout history, scientists have reported sensations of ideation that read thrillingly. Archimedes, for example, leapt out of his bathtub in a fit of inspiration. Eureka! (This means "I have found it!" in Ancient Greek.) Lightning may not strike every time, and most researchers learn not to rest on their laurels with that expectation. Still, many people who spend lots of time pondering difficult problems are familiar with the tickling sensation of a hunch or the satisfying power of a breakthrough.

After a solution or a set of testable solutions have been developed, the next step is to test them rigorously and systematically so that no aspect goes unexamined. In a controlled experiment, different groups of testable material are subjected to testing and compared with a control group for which outcomes are known. Experiments are usually regarded with a measure of skepticism themselves and are subject to change and redesign as the testing stage continues.

If the solution follows its predicted behavior-for instance, if the flypaper mousetrap in fact traps the mouse humanely, as desired-then it's a success. Funding is sought out for mass production of the flypaper mousetraps and investors start getting dollar signs in their eyes.

But maybe the flypaper mousetrap is faulty. Perhaps the mouse overpowers the adhesive on the trap and escapes easily. Or maybe the chemicals in the adhesive poison the trapped mice, nulling the mousetrap as a humane pest control option. There are always a number of things that can go wrong.

Once researchers observe problems with the proposed solution, they must go back and tweak the solution based on observed issues. In the case of our flypaper mousetrap, they'd have to look to the chemists who formulated the toxic adhesive. If one of the crucial goals of the mousetrap project was to leave caught mice unharmed, the process must prioritize that constraint. Once a new, non-toxic adhesive has been developed, the product will go back into testing. This process will be repeated until all of the conditions and constraints of the project have been satisfied.

This order of operations can go on for a long time. Some commercial products have appeared to meet all criteria in the lab, and once released to the general public, have failed, sometimes with dangerous results. Testing commercial products for commercial distribution is just one example of how the scientific method is applied carefully and comprehensively to make sure that solutions are as safe and successful as possible on the other end.

This stage and all stages of the scientific method are what we call *iterative*, meaning they are subject to repetition with the goal of achieving a desired goal or result. Scientists will test a solution over and over again, altering it each time until the results satisfy every criterion.

Failures can be discouraging, but they can also be instructive and useful! Certain kinds of failure may lead to reevaluation of the project's original intent and even redefinition of the elements. For example, if our mousetrap flypaper continues to fail-no matter how many times it is altered-there is something fundamentally incompatible with mice and tacky paper. Each constituent part would have to be investigated more deeply, and new conclusions drawn from that second cycle of research would be used to inform a new design. This can lead to amazing new discoveries.

Often a testing scenario will be conducted by a group of scientists, even generations of testers, as individuals pass in and out of the experiment. It can be helpful to introduce a new individual's perspective to the research-it's a creative collaboration that benefits from many minds at work, rather than just one.

A classical model of scientific inquiry was established a long time ago by Aristotle, who broke down reasoning into three categories: abductive, deductive and inductive inference. The distinctions between these three modes of problem solving have to do with how leaps in logic are made from one set of information to the next. Abduction has been defined as *guessing*, meaning it involves making certain assumptions that are only based on known results and not yet proven. Abduction relies more heavily on creative projection than deductive or inductive inference.

Inductive inference relies upon a degree of anecdotal support from past testing. Scientists take into account specific examples of how materials or organisms are known to behave and apply that information to make predictions about how situations involving similar materials or organisms will play out. Inductive reasoning is regarded as probable, meaning that it is not foolproof. It is only more *likely.*

Deductive reasoning is the inverse. Broad principles, rather than specific examples, are applied to specific materials, organisms or situations, and results are predicted based on those ideas.

All of these strategies are called into play in a testing scenario. As more information is pulled, testing scenarios can change and evolve. There is no satisfying a truly rigorous team of scientists. In designing solutions that meet every project constraint and push research to instructive new territory, it's necessary to keep asking questions and keep redesigning experimentation, even after a seemingly satisfactory solution has been achieved. This may seem like a frustrating burden to bear, but the results have led humankind to amazing progress. Patience with the testing process is ultimately rewarded not just with advanced, reliable solutions to everyday problems, but with new information that can be applied and reapplied to other scenarios as well.

Biochar

by ReadWorks

When researchers at the Virginia Polytechnic Institute Agriculture Program, also known as Virginia Tech, started work on a soil enhancement research project, they kept their minds open. The project was focused on the possible uses of biochar, charcoal used specifically for agricultural and other environmental applications.

Biochar has been in use for centuries. Pre-Columbian Amazonians used it as a means to revive nutrient-depleted soil. They burned agricultural waste under a cover of soil in order to create a layer of biochar in the ground. The resulting product is called "terra preta", or dark earth. Applying terra preta to this soil increased the agricultural yield of the land and enriched previously poor tribes and communities.

These Native Americans had discovered the benefits of using biochar as a soil amendment. When used in this way it doesn't only improve crop yield. It also improves water quality and reduces soil emissions of greenhouse gases, nutrients leaching, soil acidity, and irrigation and fertilizer requirements.

Biochar is still in use in South America. Scientists have learned that it is particularly good as a soil enhancement in areas with acidic clay soils and sandy soils. Biochar increases the soil's ability to attract and retain water. As a result, nutrients, phosphorus and agrochemicals are retained for the plant's benefit. Plants are therefore healthier and fertilizers leach less into surface or groundwater. Biochar is a useful carbon sequestration tool. The hope is that rural farmers in Brazil will switch from traditional slash and burn farming to slash and char.

So what does an ancient agricultural technology have to do with the scientists at Virginia Tech?

The researchers at Virginia Tech work in environmental science. Many of them also live in central Appalachia. Central Appalachia is mining country. For generations, the area has been mined for coal. More recently, mining companies have been using a technique called mountaintop removal. This means they take layers of rock and mineral off the top of the mountain in order to get access to the coal seams inside. The removed mountaintop, called overburden, is replaced on the ridge and compacted to replicate the original mountain shape. Energy and environmental industry officials call these areas post-mined land.

Post-mining sites are difficult to reclaim. The resulting soil is highly acidic and infertile. The post-mined compacted soil proves more difficult to seed. The soil needs to be loose and open in order for seed to get into the soil. In post-mined land, the ground is too compact. Post-mining sites, therefore, typically look very different from the surrounding area. These sites are more likely to be home to invasive botanical species. Residents and environmental activists complain the landscape is ruined, that the mountain terrain is scarred.

Even if no new permits for mountaintop removal mines are issued, the problem of how to reclaim the post-mined sites remains. Researchers at Virginia Tech decided to try using biochar to help reforest the post-mining site soil. They got permission to apply a layer of biochar to a post-mining site before it was reseeded and replanted. What the team found was that the biochar worked, but not as well as they had hoped. Soil samples showed the biochar had improved the chemistry of the soil. But not enough biochar had been added to make a serious difference. Researchers learned they would have to seriously up the amount of biochar they applied to the site. The kind of biochar the team used, however, was expensive. It cost about $1,000 a ton. Ten tons per acre, the amount the researchers applied, wasn't enough biochar to make a significant improvement to the soil conditions across the site.

The research project had a practical constraint. The team was looking for a solution to the problem of post-mining land. If the biochar was going to cost a small fortune, it would not be feasible for local government or nonprofit groups to use in such large amounts.

The team went back to the drawing board. They redesigned the biochar tests by increasing the concentration of biochar in specific locations. In other words, the team created "planting cells" of biochar-enhanced soil on the post-mining site. Within these "cells" the soil recomposed itself quickly and well. The team had created healthy soil in which saplings could grow. Many trees die on post-mining sites, so improving the chances for individual trees to survive was a good result.

The team would have rather seen the same results with a small amount of biochar spread across the post-mining site. But getting some improvements, given the financial constraint, was better than nothing.

Happily, researchers working with biochar learned that its physical properties would make it ideal for working with other environmental problems. They hypothesized that the material would be useful in treating the biosolids that come from municipal waste, in other words, the sewage of urban areas. Urban waste is, in many areas, dumped into fields outside the municipality, creating zones that smell bad and can't be used for other purposes. The municipal waste is very wet and the biochar is very dry. Researchers hypothesized that biochar can be added to coat the waste to create a product that can be spread as fertilizer. In the process, the biochar reduces the smell of the waste and helps reduce greenhouse gases. Early studies show they are correct; biochar can be used in this way.

Name: ___________________________________ **Date:** _______________

Use the article "Developing Possible Solutions" to answer questions 1 to 2.

1. According to the article, what does any given problem often have?

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Answers will vary.

2. Summarize the process a scientist goes through to come up with a satisfactory solution.

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Answers will vary.

Use the article "Biochar" to answer questions 3 to 4.

3. What did researchers at Virginia Tech try using to help reforest post-mining site soil?

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Answers will vary.

4. Summarize what the researchers did to improve the quality of post-mining site soil.

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Answers will vary.

Use the articles "Developing Possible Solutions" and "Biochar" to answer question 5.

5. Think about the process for coming up with a solution described by "Developing Possible Solutions." How closely did the researchers at Virginia Tech follow that process? Support your answer with evidence from both articles.

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Answers will vary.