RES.TLL-004 STEM Concept Videos, Fall 2013

Transcript – Problem Solving Process

How do you design, test, and build a small and completely edible boat that propels itself through your cocktail? This is a complicated problem, but it – and many other problems like it – can be solved systematically, by breaking the problem down into several key phases. In this video, we'll explore how two MIT graduate students created these Cocktail Cruisers.

This video is part of the Problem Solving video series.
Problem-solving skills, in combination with an understanding of the natural and human-made world, are critical to the design and optimization of systems and processes.

Hi, my name is Lisa Burton and I am Nadia Cheng. We are graduate students in Peko Hosoi's lab in the Department of Mechanical Engineering at MIT.

Today, we're going to tell you about a class project that we worked on that turned into a product called cocktail cruisers.

After watching this video, you should be able to identify the steps of the problem solving process and recognize that the problem solving process is iterative.

Chapter 1
Take a moment to think about your approach to problem solving. What steps do you generally go through? [PAUSE]

Please pause the video and take a moment to think about it. Then continue playing the video to hear about one approach. [PAUSE]
While different people might approach a problem in different ways, using an explicit strategy for problem solving can be very helpful. You can find different problem solving strategies in the literature. The strategy that we will present in this video is adapted from Don Woods and Philip Wankat.
The first step is to define the problem. What are the criteria? What are the constraints?
After defining the problem, you need to gather information. What are the knowns and unknowns? What content knowledge is needed to solve the problem? Have others worked on a similar problem before?
The next step is to explore. Look at the problem in different ways. Brainstorm different approaches to meeting the criteria given the constraints.
After exploring, you need to pick one approach to solving your problem and plan your strategy. Determine the resources needed to carryout your plan. A flowchart, outline, or schematic might be

useful.

After the planning phase, it is time to act. In this step, you follow your plan to create your solution.

Once you have a solution, you need to check it. Does it make sense? Does it meet the criteria? Where does it fall short? Is any troubleshooting required? If the solution isn't satisfactory, it might be necessary to explore some more and create a new plan.

Once you have your final solution, what have you learned that you can generalize to other contexts?

Finally, disseminate your results so that others can learn from your solution. This could be through a class discussion, a formal presentation, or a scientific paper.

Chapter 2

Now that you are familiar with the problem solving process, see if you can identify where I used these steps as I worked on a class project.

This project began in my Fluid Dynamics class, which focused on interfacial phenomena and was taught by my other advisor, Professor John Bush. The main criterion, or requirement, for the project was to conduct an experiment, perform a simulation, or design a product fundamentally based on a topic covered in class. There were also some constraints placed on the project. We only had three months to work on it and a limited budget. Other than that, it was very open-ended.

It was really up to me to define the problem from there.

Learning about the Marangoni effect inspired my design. The Marangoni effect arises from a gradient, or difference, in surface tension.

We can see the Marangoni effect by adding a drop of soap solution to a container of water. The soap solution reduces the surface tension of the water locally, causing flow. Using black pepper flakes as a tracer, we can visualize the flow away from the area of low surface tension.

Surface tension is simply a property of liquid that results from intermolecular forces. In the bulk of a uniform liquid, each molecule experiences a zero net force because molecules that exert equivalent force on each other surround it. At the surface of a liquid, molecules from the liquid experience a non-zero net force pulling them toward the bulk of the liquid because they are not completely surrounded by like molecules. This causes the surface to minimize its area.

The high surface tension of water allows objects denser than water, such as a paper clip or a water strider, to float on the surface.

If an object has a high surface tension liquid on one side of it and a low surface tension liquid on the other side, the difference in surface tension will cause the object to move toward the high surface tension liquid.

We can see that happen in this demonstration of a toothpick floating on water. If we add a few drops of soapy water to one side of the toothpick, the toothpick moves away.

I decided that I wanted to make a miniature boat that would be propelled by a surface tension gradient. I wanted to propel the boat in a water-based environment, with the ultimate goal of using it in a food setting. This required that the second liquid be safe to eat since it would mix with the water. At this point, I wasn't concerned with making the boat edible, because it could simply be removed by hand from the food.

Therefore, the problem we needed to solve was how to design a boat that could be propelled by the Marangoni effect. This included the identification of a liquid that was edible and had the appropriate

surface tension for use as the propellant.
I started gathering information about different fluids that had a lower surface tension than water. I also looked at the existing designs of other boats, noting what propellants they used and their method for releasing the propellant into the surrounding water.
To identify important physical features of the boat, I did some calculations, starting with a simple force balance diagram. We can represent the boat as a rectangular prism for now. Viewing the boat from the side, we see just a rectangle.

In the vertical direction, the forces acting on the boat are the force due to gravity, or the weight of the boat, and the buoyancy force, which is equivalent to the weight of the water displaced by the boat and the meniscus. You've probably noticed that water in your drinking glass slightly climbs up the wall of the glass. This is the meniscus and it depends on the material of the object (for instance, the boat or the glass), the liquid, and the gas (in our case air).
Therefore, to make the boat float, we must ensure that the weight of the water displaced balances the weight of the boat. This is Archimedes' principle.

In the horizontal direction, we have the force of surface tension of the "fuel" on the left side and the force of surface tension of the surrounding fluid, which we will assume is water. If these forces aren't equal, the boat must accelerate, according to Newton's Laws. Therefore, to make the boat move faster, we want the difference in surface tension to be as great as possible.
Once the boat is moving, drag becomes important. Drag opposes the direction of motion and increases with velocity and the cross sectional area of the boat. A smaller cross-sectional area will allow the boat to move faster.

To ensure that the boat remains stable, the center of mass must be below the center of buoyancy. Otherwise, the boat will tip over and sink.
As I explored different ideas, it became clear that I needed to do some testing.

To find an edible, low surface tension liquid to act as the boat's fuel, I tested different liquids I found in my kitchen, from hot sauce to sugar water to vinegar. From these tests, I decided that I needed a low surface tension liquid that was also volatile, or evaporative. This is necessary for the boat to continue to move; otherwise, the fuel surrounds the boat equally on all sides so that no surface tension gradient exists and therefore the boat does not move.

The best fuel I found was liquor. The alcohol content of the liquor and the surface tension are inversely related. Therefore, using a very high alcohol content liquor will result in a faster boat.
I started sketching ideas for what the boats might look like. Drawing on previous research, the initial design had an open fuel reservoir in the middle of the boat with a small slit that allows the liquid to leave the reservoir. The overall shape was a very simple boat shape.
After testing materials for a while, it was time to come up with a plan. I decided that I needed to create a prototype so I enlisted the help of my lab mate Nadia. She suggested using a 3D printer to create the boat in the Edgerton Center student shop.

The only way we were really going to know if the boat design was going to work was to actually try it. It was time to act, and having rapid prototyping technologies—such as 3D printers—available significantly expedites the testing and iteration process. The 3D printer requires that we develop 3D representations of our boat design in CAD. There are various types of 3D printing technologies; the one we used utilizes fused-deposition modeling, or FDM. The way it works is that there is a spool of a thin plastic "thread" that is fed through a nozzle. The nozzle heats the plastic to soften it so that the plastic can be laid out to build a 3D object. Basically, it is like piling a piece of string on top of itself to make a 3D shape. Because the boats needed to be less dense than the liquids they were to float on, we specified that the boats were to be printed "sparsely", such that the plastic thread was to be laid out loosely whenever possible in the interior of the boats.

Once we had our boat, it was time to check and see if it did want we wanted it to. Of course, our very first boat wasn't the ideal solution. The reservoir was too small and the boat was too large; it didn't hold enough fuel and moved slowly because of the mass.

But it gave us insight into what we needed to change. We modified our plan, created a new design, and tested it again. After some troubleshooting, we went through several design iterations. We examined many different boat designs and liquors to use as fuel until we had a design we were happy with.

I presented my project to the class at the end of course. I successfully stayed within the design and project constraints. I created a boat that used edible materials for propulsion through the Marangoni effect.

After completing the course project, we continued to pursue this idea. We wanted to improve our design and also make the boat out of edible material so that they could be used as a fun garnish for drinks. This required us to generalize our solution to a new situation. We constructed soft, flexible molds out of silicone by 3D printing rigid plastic molds that the silicone molds could be made from. After creating the molds, we tried several edible materials for the boat including candy, chocolate and marshmallows. We quickly discovered that the density of the material was a common limiting factor. After further testing, we found two materials that worked: edible wax and gelatin, which we foam as it sets to reduce the density of the boat.

We've since disseminated our product. I won a design award at a competition at MIT and we're currently working with Chef Jose Andres to incorporate our design into his restaurant. Additionally, an article in the American Society for Engineering Education PRISM magazine helped spread our ideas and product to a broader audience.

To recap, in order to solve this problem, we had to

- define the problem
- gather information
- explore
- plan
- act
- and then check our solution

We were able to generalize our solution to a new context and then disseminated our results.

The problem solving process really helped us approach this problem and break it down. By consciously using a problem solving process, you will find that you will become a more confident and better problem solver. Best of luck!

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