3349_The Surprising World of Complex Systems_1

[00:00:00.00] [MUSIC PLAYING]

[00:00:19.38] Hello. I'm Elizabeth Hoffecker, a research scientist at the MIT D-Lab, an interdisciplinary group of educators and researchers who use participatory design and inclusive innovation to address challenges related to global poverty. Today, we're at the MIT Sloan School of Management, where over half a century ago, a group of researchers pioneered the study of complex systems.

[00:00:40.50] Our world is full of complex systems, and over lunch, I've been reading about one of those systems that's currently in crisis, our global recycling system. Did you know that right now, millions of tons of paper and plastic and other materials that we're putting in bins to be recycled are actually going straight to landfills or being burned instead? Before we take a closer look at what's going on let's clear some space and get rid of all of this.

[00:01:04.06] OK, this is paper. I'm going to put this here. This says compost, so I'll go ahead and put the food waste there. Now, I'm not sure about this remaining paper and plastic, which is dirty, but I wouldn't want to send something to the trash if it could be recycled. So I'm going to go ahead and put it here. Now, let's see if we can figure out what's going on with the global recycling system.

[00:01:27.75] Hmm, it says here that companies from China that have been buying most of the recyclable waste from the US have adopted new strict standards. They've stopped buying shipments from us because they're too mixed up and contaminated with non-recyclables and food waste. Because these buyers aren't buying from us anymore, recyclables are piling up with nowhere to go except for the landfill.

[00:01:49.62] And here it says that towns and cities across the US are finding it cheaper to just take recyclables to the landfill rather than process and clean them according to the new Chinese standards. Oh, no. Now I'm realizing that by putting as many things as I can in the bin, I'm actually contributing to the problem, because those dirty materials might cause the whole load to go straight to the landfill, even if there were lots of perfectly recyclable materials in there.

[00:02:12.61] In other words, my desire to keep materials out of the landfill might actually be causing recyclables to end up in the landfill. Exactly the opposite result of the one that I want. This kind of situation is actually pretty common when we're dealing with complex systems, where, oftentimes, a lot of individual good intentions can add up to a bad result, or an unintended consequence, that nobody wants. Let's think about a system you interact with every day, the transportation system where you live.

[00:02:40.29] The purpose of a transportation system is to move people and goods efficiently from one place to another, but like other complex systems, transportation systems can also produce results that nobody intended. And these can be both good and bad. So now, with a classmate sitting close to you, briefly discuss and see if you can identify some unintended consequences of the local transportation system where you live, focusing on consequences that you might have experienced directly. I'll see you back here in a few minutes.

[00:03:19.36] So how did your discussions go? While you were talking to each other, I was thinking about transportation systems too. Here in Cambridge, an unintended consequence of our crowded transportation system is that it has created a strong market for bicycles, because it's so much faster to get around by bike than by car, bus, or subway. All the bicycles have attracted bike thieves and a booming business and a resale of discounted stolen bikes.

[00:03:42.15] So we have this illegal economic activity as an unintended consequence of the fact that so many people here prefer to move on bicycles. You probably identified many examples that are specific to where you live, but something that all these examples have in common is that the system is producing results that its designers did not intend. So why is that?

[00:04:01.56] Both transportation systems and recycling systems are complex systems, meaning they have many different parts, some technological and some human, and that these parts interact and influence each other in dynamic ways. For example, recycling systems include individuals like myself, who may or may not recycle correctly. And technology, like machines at sorting centers that sort and organize different types of waste into bails to be sold to waste processors.

[00:04:25.93] In these kinds of systems a straightforward action can have unpredictable and surprising long-term consequences. We all participate daily in a variety of complex systems, but we rarely stop to ask ourselves how they work or why they're producing the results that they're producing. Today, in our lesson, we'll get more familiar with the basic features of complex systems by diving into the details of one system, the urban recycling system here in the US, which is currently in crisis.

[00:04:52.52] Until December 2018, recycling with a profitable activity for lots of cities and towns in the US, including Boston. In the typical urban recycling system, cities contract with a waste hauler, who collects recyclable waste at curbside from the homes of residents and delivers those recyclables to a sorting center. Sorting centers separate valuable materials from those which are trash or don't have a market and sell the valuable materials to processors, who process them into raw materials, which are then sold to manufacturers, who use these materials as inputs to produce consumer goods made from recycled paper, plastic, metal, and other materials.

[00:05:27.26] The system has many interrelated players and elements, each with different roles and motivations influencing their behavior. To explore how a system like this one functions, we're now going to do a simple role play simulation. Your teacher will pass out materials and give instructions for how to proceed. As you participate in the activity, think about what behaviors or attributes the system is exhibiting.

[00:06:00.62] Hello again. As you've just experienced, the recycling system that you modeled has some core properties that make it a system. First, it has elements, which in this case, are the different actors in the system and the materials that flow between them. Second, it has relationships or connections between the different elements. And third, it has a function or purpose, which in the case of a recycling system, is to take materials that would otherwise go into a landfill and process them so they can be used again.

[00:06:27.45] The recycling system you modeled might have looked something like this. The balls might have passed through the system in this way, but they might also have taken a different route. And if two groups of students do this activity, the route their balls take will be slightly different in each case, even though everyone is following the same instructions.

[00:06:47.85] This is because human decision making is involved, and different people make different decisions even when they're in the same situation. So in complex systems that involve human behavior, there's an element of unpredictability in the system's behavior. Another property of systems that you might have noticed is that all of the different parts of the system are connected, and the actions of one player affect the actions of the other, so there's interdependence.

[00:07:11.07] For example, I can pass the ball along until I've received it from someone else. Another thing you might have noticed is that something was flowing through the system. In this case, it was recyclable materials and money, which we represented with the balls. Let's look at the Charles River for example. The water flows down the river until it reaches a dam, where it accumulates as a stock of water. The water level rises until someone decides to open the dam and let some water flow out downstream, or until the water flows over the top.

[00:07:38.89] Complex systems operate in a similar way. There are things that flow through the system, some of which we can see, like water, and some of which we might not be able to see, like information or money. These are called flows. These flows move through the system until they reach a point where they accumulate as a stock. We can think of this like a holding tank. And they accumulate until a decision is made to let them out, in which case, they flow to another point in the system.

[00:08:04.57] We can represent this diagrammatically as follows. Here, we see an inflow of material, such as water. A place where it accumulates as a stock, represented by a box, and an outflow, represented with an arrow. We also see what looks like clouds, which represent the source of the material--perhaps, clouds or mountain snow--and the sink, or where the material ultimately ends up. Finally, we see two spigots that look like the knobs on a sink or a bathtub. And these represent the decisions or rules that control the rate of inflow into the stock and outflow to another point in the system.

[00:08:36.64] In our example of a recycling system, a place where materials accumulate in a stock is at the recycling sorting center. Here, we see recyclables flowing into the center as a rate of the amount of recyclables received per day. Once inside the sorting center, they're sorted and accumulate as a stock, or inventory of materials until they are sold to buyers and then flow out of the center again. The rate of these inflows and outflows of recyclables are controlled by policies or decisions, which we, again, see represented as spigots.

[00:09:04.99] In the case of the sorting center, these decisions have to do with space and demand for recyclable material. If space is available, the center will accept more inflows. And if space is tight, because they don't have enough buyers, they might restrict inflows, perhaps by paying less or even charging people to drop off recyclables. This illustration is just one small part of the total recycling system. As we saw in our activity, the paths of the flows from point to point in the system are much more complex than the simple line of a river.

[00:09:34.65] And some of these flows don't move straight from A to B to C, but rather get stuck going around in circles in what we call a feedback loop, in which the level of a stock and the rate of flows into or out of the stock are connected in a circular cause and effect relationship. We've all bumped into feedback loops in our everyday life, whether or not we've realized it before. A simple example of a feedback loop is the circular cause and effect relationship between motivation and performance, where my level of motivation can be thought of like a stock.

[00:10:04.21] If a student does well on her first few exams at the beginning of the year, she feels motivated to keep studying hard and staying focused on school, which then helps her to do well again on her next set of exams, which then further increases her motivation to keep doing her best, which further increases performance and so on in a reinforcing cycle. Another example of a feedback loop is the reputation of your local sports team. If the team is winning games and has a good reputation, it attracts talented players to the team, who make it more likely that the team will keep winning, which contributes to attracting more talented players and so on.

[00:10:37.60] This is called a reinforcing loop, because the dynamics of the loop reinforce each other in the same direction, so more leads to more and even more of the same. In this case, it's a direction that's desirable. So we call this a virtuous cycle. But what happens if the team is losing? Does this reinforcing loop dynamic also work in the opposite direction? Take a few minutes with your classmates to see if you can answer this question and identify some additional examples of feedback loops in your daily life.

[00:11:17.43] Welcome back. So what did you decide? Does the feedback loop of reputation work in both directions? If you think of the reputation of a sports team, or perhaps, a local restaurant, you can see that the basic dynamics of the reinforcing loop can create either a virtuous cycle or its opposite, a vicious cycle. In either case, the level of the stock, which in this case is reputation, gets either larger and larger or smaller and smaller through the self-reinforcing and circular dynamics of the loop. Now, let's take a look at how one of these feedback loops works in the context of the recycling system.

[00:11:50.87] In this case, the City wants to generate revenue through recycling. And this motivation leads it to operate with a policy that if it's making money from its program, it will try to increase the flow of recyclables through the system. For example, by making it easier for households to recycle. Let's see how this policy sets in motion a feedback loop. The City pays the hauler $5 to pick up recyclables, which gets taken to the sorting center.

[00:12:13.82] Since the sorting center has strong demand from processing plants, it can pay the city $10 for these materials. And this profit leads the city to increase incentives for recycling. Perhaps by telling households that they can just put everything in one bin to make it easier. This means that more households recycle a larger volume of material, which generates more revenue for the City and leads to even more incentives to increase recycling.

[00:12:36.61] This looks like a reinforcing loop that is a virtuous cycle. Over time, we can see that this loop dynamic causes the amount of recyclables moving through the system to increase like this. We can clearly see that this growth is not linear, rather the loop dynamic causes the rate of growth to increase exponentially. This process can keep repeating forever assuming that there is growing demand for recyclables. This is exactly the situation experienced by most major cities in the US prior to December 2018.

[00:13:06.29] But then, China introduced its National Sword policy, which requires that all incoming scrap loads be 99.5% clean and free of contaminants like foam cups, food waste, and non-recyclable garbage. That's a standard that US recycling centers can't meet, so the Chinese stopped buying. Recyclables started piling up at the centers, and they needed to find ways to slow the inflows. So many sorting centers changed their policies and started charging cities instead of paying them for deliveries of recyclables. And just like that, the reinforcing loop switched direction from a virtuous cycle to a vicious one.

[00:13:42.59] Now the City was losing money through its recycling program. So it issued new rules hoping to reduce the amount of trash in the recycling loads. But people take time to change their behavior, so some people ignored the new rules, and other people weren't aware of them, and most people just kept recycling exactly like they were before. As the City found itself losing even more money, it had to take more dramatic action, further trying to reduce the amount of trash in the loads.

[00:14:07.79] Finally, it got to a point where many cities found that it was cheaper and more efficient to simply take the recyclables directly to the landfill rather than trying to process them. So here we see another way in which the structure of a system affects its behavior. In this case, there are delays in the feedback loop, so when the city takes action, people don't respond right away.

[00:14:26.60] This causes the city to take even more dramatic action fueling the downward spiral until people stop recycling altogether. That's not a good outcome for cities or for the planet. So do you think it's possible to stop this vicious cycle and get our recycling system back on track? In small groups, discuss with your classmates: What might be one or two changes that you think you could make to help get our recycling system out of the crisis that's currently in.

[00:15:03.46] Welcome back. Were you able to identify some actions that might help get our recycling system back on track? One action you might have identified would be to create an information campaign that would educate households on how to clean their recyclables to meet the new standards. Another would be to create local sources of demand for the materials that the Chinese aren't buying anymore. For example, someone could start a local factory that can process recyclables into useful materials in the condition they're already in.

[00:15:28.72] One former student from MIT Sloan, Bilikiss Adebiyi Adiola, has implemented one of these solutions in designing a recycling system for her hometown of Lagos, Nigeria. In this system, which she set up through a social enterprise called Wecyclers, haulers on bicycles collect specific materials from households, such as plastic bottles, that can be sold to local processing plants, which use the materials to produce new products that can be sold locally. This system doesn't rely on international buyers and is designed to collect only materials that can be repurposed locally.

[00:15:59.05] Since Wecyclers started in 2011, Bilikiss and her team have successfully recycled thousands of tons of material, keeping it off the streets of Lagos. Like Bilikiss, a number of researchers and social entrepreneurs have identified effective ways to intervene into complex systems. They start from the principle we've learned today, which is that the structure of a system determines its behavior. For example, what kind of feedback loops it contains, whether or not there are delays in those feedback loops, and what rules and policies govern the flow of information, materials, money, and other elements through the system.

[00:16:31.91] Another lever for changing how a system works relates to the goal towards which the system is oriented. If a town's objective in running a recycling system is to make money, this will set up different feedback loops and behaviors in the system, as compared to a system, such as the one in Lagos, where the primary objective is to remove specific materials from the waste stream by finding new uses for them. So in thinking about the concrete actions we can take to change how a system behaves, we've now learned about a few. We can reorient the system's goals, change the rules, reduce time delays and feedback loops, or add new elements, such as new players to the system. All of which can profoundly affect how the system behaves.

[00:17:10.79] The key to remember is that in order to be able to produce effective change within a system, we first need to understand the system and why it's behaving the way that it is. Since, as we learned today, it's a system's structure that determines its behavior. When we don't understand the forces driving the system to behave the way that it does, we often find ourselves surprised to see that our actions produce negative unintended consequences, like we learned at the beginning of the lesson. So now that we know this, how might you learn more about the systems you interact with in your daily life and why they're producing the results they're producing?

[00:17:44.19] One step might be to discuss with your family and friends: what systems you interact with daily could be producing better results? You might think that your local waste management or recycling system could be improved, or you might think that your transportation system or food system has room for improvement. Once you've identified a system that you think could be working better, you can use what you've learned today to start exploring its behavior.

[00:18:06.10] What are the key stocks and flows in the system? Are there feedback loops operating? And if so, are they virtuous cycles, vicious cycles, or something else? Are there delays affecting how the feedback loops operate? This process of discovery can be your jumping off point for further exploration of the surprising and counterintuitive world of complex systems, a world we all live in and all have opportunities to influence each day in positive ways.

[00:18:39.82] Thanks for considering using this lesson with your students. This lesson offers students a basic introduction to complex systems and systems thinking, and has a few key learning objectives. One is to help students learn how to recognize systems that they might encounter in their daily life. Another is to help them understand some of the basic properties of systems and a little bit about how systems behave. And finally, the lesson helps build their ability to read and decipher basic system diagrams, which builds skills that later, they can use to actually create their own system diagrams.

[00:19:13.09] This lesson is intended as a stepping stone to prepare students to engage in subsequent project-based learning activities, which they can use to explore systems that they interact with everyday to learn about some of the basic structural components of systems and their behaviors and to also figure out how to test their assumptions about how the system is behaving and why. The main activity in this lesson is a role-play simulation where students basically get in a group and act out some of the components of a basic recycling system using balls of string.

[00:19:43.39] This gives students a chance to experience some of the basic properties and behaviors of complex systems. So we provide some detailed instructions on how to run this activity in a downloadable teacher activity guide, but I wanted to talk through kind of some tips for how to run this activity since this is the bulk of the lesson. Depending on how many students are in your class, and how much time you want to devote to this activity, it can take anywhere from 15 to 25 minutes.

[00:20:09.52] Based on personal experience implementing the activity, I do recommend planning some time to allow students to discuss and reflect on their experience after finishing the active part of the role play. This allows students to unpack and analyze their experience of kind of what they observed about the system as they were engaged in the activity. So in terms of the activity itself, here are some tips. In terms of prep materials, the main materials that you'll need to run the activity are three balls of string. It can be any kind of string, but something that the students can easily grab, and then pass to the next student. So something that's not very sticky.

[00:20:45.79] And then the students are going to each have nametags. And the nametags will look something like this. So on the front, they'll have the name of the actor. And on the back, they'll have the description of the actor and their roles. You can print these double sided, or if you have single sided printing, we've designed a separate format where you can print them single sided, and then just stapled them together like this. You'll also need safety pins or tape or something that will allow the students to attach the name tags to their bodies.

[00:21:15.46] In terms of the room setup, you'll probably want to bring all the tables to the center of the room, so that the students can spread themselves out in the space. Or you might even do this activity outside of the classroom. The idea is that the student should be able to move around freely, arrange themselves in different configurations, and be able to pass a ball of string between the different students.

[00:21:36.04] One thing to think about is that the activity is designed for 10 students to participate. So if you have fewer than 10 students or more than 10 students, there are several ways in which you can modify the activity. If you have fewer students, you might be able to take out some of the less essential roles. So instead of having two households, you could have one household. Instead of having two processing plants, you might have one.

[00:21:56.95] If you have more than 10 students, you can either have some of the extra students simply observe the activity and share their reflections in the discussion. Or if you have enough students to actually do two groups of 10, you can have two groups running the activity simultaneously. So there's a little bit of flexibility in how this activity plays out. But the idea is that all of the students are engaged either with a role or in actively watching the activity as it plays out, and then participating in the subsequent discussion.

[00:22:24.29] The remaining activities of the lesson are discussion based. And these are intended for the students to complete in pairs or groups of three, essentially, turning to the students next to them and reflecting on the questions, and then sharing back to the class. This lesson might be introducing a lot of new and unfamiliar content to students, so it will be easier for them to really take in and learn if it's followed with some kind of a homework assignment.

[00:22:47.16] At the end of the video, we suggest that students talk to their friends or family about a system they might be interested in trying to improve. And one assignment might involve having students actually do a little bit of research on that system to try to understand why it's producing the results it's producing to try to see if they can identify some potential levers for change. As part of the course materials, we provide a handout with additional information, both about running the activity and some potential follow-on assignments.

[00:23:14.73] [MUSIC PLAYING]