

Fighting a Fire versus Waiting for the Wave: Useful and Not-So-Useful Analogies in Times of SARS-CoV-2

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As SARS-CoV-2 has swept the planet, intermittent lockdowns have become a regular feature to control transmission. References to so-called recurring waves of infections remain pervasive among news headlines, political messaging, and public health sources. We explore the power of analogies to facilitate understanding of biological models and processes by reviewing strengths and limitations of analogies used throughout the COVID-19 pandemic. We consider how, when analogies fall short, their ability to persuade can mislead public perception, even if unintentionally. Although waves can convey patterns of disease outbreak, we suggest process-based analogies might be more effective communication tools, given that they can be easily mapped to underlying epidemiological concepts and extended to include complex dynamics. Although no single analogy perfectly captures disease dynamics, fire is particularly suitable for visualizing epidemiological models, underscoring the importance and reasoning behind control strategies and potentially conveying a sense of urgency that can galvanize individual and collective action.

Keywords: epidemics, disease dynamics, second wave, risk communication

“Separate the fuel from the flames, and the fire stops.”

—William H. Foege, key strategist for global smallpox eradication (and former volunteer firefighter)

Speech and the perception of speech are merely models for reality, as Plato elegantly described in his Allegory of the Cave. Much in the same way that speech allows us to structure our own experiences of the world and communicate our conceptual understanding of it, scientific reasoning and discourse are rooted in the use of models as conceptual representations of reality (Taylor and Dewsbury 2018). Such representations can take many forms of varying complexity, from physical constructs (e.g., 3D models or diagrams) and simple verbal descriptions to complex statistical and mathematical models aimed at evaluating the properties of dynamic systems by synthesizing information on the processes shaping these dynamics (e.g., epidemiological models estimating future infections from current transmission, recovery, and mortality rates). Despite their varying modes and uses, all models share a common feature in that they facilitate connections between abstract concepts and more familiar domains.

The role of scientific models in understanding complex biological phenomena has been brought into sharp public focus by the 2019 novel coronavirus disease (COVID-19)

pandemic. From the outset, existing epidemiological models and knowledge gained from previous epidemics have formed the basis of efforts to understand and predict the trajectory of the spread of COVID-19's causative virus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). Mathematical models have been continually updated and extended to synthesize newly acquired information and more detailed knowledge as the pandemic has progressed. Although such models have been crucial to developing scientific understanding and informing pandemic management, their inner workings and predicted dynamics can be difficult to convey to nonexperts (Arroliga et al. 2002). This is particularly problematic in the context of public health responses, where highly dynamic situations are coupled with an urgent need for rapid communication and transparent decision-making (Casarett et al. 2010). Analogies (i.e., conveying an unfamiliar concept by likening it to a different, more familiar concept) offer a compelling means of framing unfamiliar epidemiological concepts to effectively communicate with and inform policymakers, as well as the wider public. Indeed, given that even the most complex mathematical model is only an abstract representation of reality, the process of modeling can be thought of as akin to building a sophisticated quantitative analogy of the world.

Through establishing a similarity and allowing the audience to arrive at the intended meaning by themselves, the

strength of analogies lies in harnessing existing knowledge of one system to understand another. Beyond their role in structuring how we communicate, analogies and metaphors can also play a role in how we conceptualize our experience of the world, whereby complex or abstract experiences can be systematically mapped to more accessible or familiar experiences—termed *target* and *source* domains, respectively, in conceptual metaphor theory (Lakoff and Johnson 1980). Moreover, the use of analogy to frame novel concepts can influence how we perceive and respond to information via framing effects (Robins and Mayer 2000, Scheufele 2004, Tierney et al. 2006), which have been demonstrated empirically (Thibodeau and Boroditsky 2013, Thibodeau et al. 2017). In the context of communicating scientific concepts, it follows that the ability of analogies to convince means that, when misused, analogies may perpetuate misunderstanding (Taylor and Dewsbury 2018) and, with reference to epidemics, even impede effective disease control.

Given the central role of models in developing our understanding of SARS-CoV-2 dynamics, a closer examination of how analogies can be used to clearly map from models to more familiar situations could be of benefit in devising more effective and accurate public messaging and for conveying epidemiological concepts that are central to public health responses (in effect, creating more accessible models of the models). In the present article, we consider how analogies can be employed as a heuristic tool to support conceptualization of models by nonexpert audiences by exploring the direct relationship between analogies and mathematical models in the context of the COVID-19 pandemic. We highlight how intuitive analogies that are more closely related to scientific evidence can improve understanding, promote action, and limit misinformation. We focus in the present article on analogies related to SARS-CoV-2 but emphasize that the same overarching principles (the use of simple, intuitive, and clearly mapped representations) are relevant when analogizing scientific concepts in general.

Models as the basis for analogy

To successfully map from models to analogies, it can be helpful to first consider the role of models (and their support by empirical evidence) in framing how we think about the world as scientists.

Biological processes can often be dynamic and hard to intuit. Difficulty arises because there is no omnipotent biological understanding (there are always parts of a system that are unknown or unobserved), and we often lack *a priori* knowledge of how to conceptualize an unfamiliar system or process. To this end, models offer a means to describe what we know, simplify what we don't know, and analyze the dynamic consequences of how different components in a system interact. By creating a simplified representation, models may aim to summarize, understand, and infer properties of a system; predict future states of the system or outcomes of interventions; and identify parts of the system that are unknown or uncertain (Haefner 2005). An effective

analogy could achieve these same objectives for nonspecialists as the underlying models do for biologists. For example, in the context of SARS-CoV-2, the public and policymakers may be familiar with the concept of a virus and transmissible disease, but the mechanisms that govern disease dynamics are less easy to discern. Given the epidemiology of the virus is understood by scientists through mathematical models, analyzing which analogies best capture the biological processes underlying disease dynamics (as represented to the best of our available knowledge by epidemiological models) could improve public and policymaker perception of the target domain (in this case, the dynamics of SARS-CoV-2 and its ensuing disease, COVID-19) and thus guide responses in terms of proactive measures and prevention.

Despite their many uses as idealizations of reality, a single correct model does not exist. Whether a model is useful or not (*sensu* statistician George Box: “All models are wrong, but some are useful”) largely depends on the user's objective, be it simply describing a phenomenon to disentangling complex mechanisms or forecasting the future. Models concerned with the former can be classified as *pattern based*, in which the mathematical terms have no biological significance beyond representing the pattern or form of the phenomenon (e.g., polynomial regressions). Models that attempt to address the latter objective (i.e., to understand underlying mechanisms) are often referred to as *process based*, where the terms in the model have some meaningful biological interpretation. A strength of process-based models is the ability to infer dynamics beyond observed conditions, providing guidance about the state of a system under future conditions or in response to a hypothetical intervention.

Process-based epidemiological models have been fundamental to our understanding and prediction of the COVID-19 pandemic trajectory (Hao et al. 2020). The most common approaches to modeling SARS-CoV-2 dynamics (Adam 2020) have been extensions or variants of a basic SIR (*Susceptible, Infected, Removed*) modeling framework (Cooper et al. 2020, Dehning et al. 2020, Giordano et al. 2020) that describes the progression of a novel disease in a closed population:

$$\frac{dS}{dt} = -\beta IS$$

$$\frac{dI}{dt} = \beta IS - \gamma I$$

$$\frac{dR}{dt} = \gamma I$$

The SIR model (Ross 1916, Ross and Hudson 1917, Kermack et al. 1927) captures the outbreak of an epidemic, from the introduction of a single infected individual, subsequent exponential growth, followed by a slowing of transmission as the population progresses toward herd immunity (Keeling and Rohani 2007). The progression of

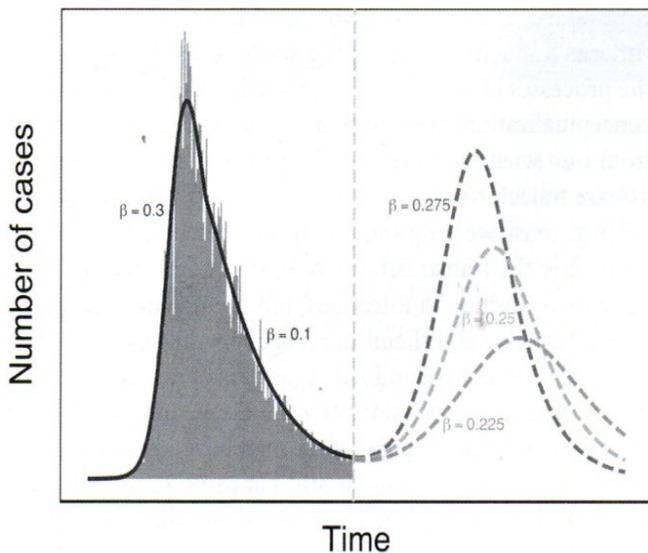


Figure 1. Schematic showing relationship between simulated SIR model output (solid line) and a typical epidemic curve (bars) that depicts observed daily incidence of disease. In this example scenario, a novel pathogen with transmission rate $\beta = 0.3$ per day causes infections to grow exponentially until a decline in β means case numbers peak and then decline. Changes in the value of β could be due to behavioral changes, interventions, or properties of the pathogen (e.g., temperature-dependent transmissibility). The dashed curves illustrate how a subsequent increase in transmission rate β to different levels can change the shape of potential future trajectories. Note that incidence data and SIR curves are for illustrative purposes only and do not represent real data or disease incidence (case numbers and SIR curves are based on simulations).

the epidemic is shaped by the transmission rate, β , which scales both with the number of contacts between people over a given period and with the probability that a contact results in infection, and by the removal rate, γ . Together, these parameters determine the basic reproductive ratio R_0 and, thus, the rate of infections, the height and breath of the peak, and the number of people required to reach herd immunity. Within a population in which all members are susceptible ($S/N = 1$), an epidemic occurs if an infected individual on average infects more than one person—that is, if $R_0 = \beta/\gamma > 1$. Because β depends in part on our behavior, and in part on properties of the pathogen, it is intuitive that changes in either of these could influence the course of an epidemic (figure 1). A changing β , for example, could be due to a reduced number and duration of close human contacts via physical distancing (also known as *flattening the curve*) or changing environmental conditions that directly affect the pathogen's ability to transmit effectively (e.g., the influenza virus transmitting more effectively in colder and less humid weather; Lowen et al. 2007). The same is true for γ , which may, for example, depend on properties of the pathogen determining duration of illness, as well as on the level of care provided.

A key simplifying assumption to highlight in the basic SIR model is homogeneity of mixing (Anderson and May 1992), whereby every individual is assumed to have equal contact rates with all others, implying that disease-causing interactions are random and homogenous across the population. However, real populations are often structured in space (e.g., separated by geographic distance) to form subpopulations, which themselves can be subject to other forms of stratification (e.g., age-based or social stratification) that further shape interactions among individuals, with implications for contact and transmission rates. Incorporating population structuring into epidemiological models has most often been achieved using metapopulation models i.e., splitting the population into subpopulations and accounting for contact rates between these subunits (Hess 1996), and network models, which represent individuals as nodes in a network and explicitly characterize individual variation in interactions (potential disease-transmitting contacts) as diverse connections between nodes (Bansal et al. 2007). At the population level, disease dynamics and patterns of infection can be profoundly affected by structuring, meaning it can be a critical concept to grasp for understanding infection spread.

Although the SIR framework and its more complex extensions are widely used in epidemiology (Kleczkowski et al. 2019), the model in mathematical form is not a particularly intuitive tool for communicating with nonspecialist audiences. Nonetheless, given that much of our existing understanding of COVID-19 dynamics is based on the SIR modeling paradigm (although not without limitations; see Gnanvi et al. 2021), mapping the model's components, implications, and extensions into more broadly accessible analogous forms can bridge the gap between scientific knowledge and public understanding, facilitating transparent communication of information and heightened perception of risk and risk mitigation.

Analogies and their relationship to models during COVID-19

Analogies to represent COVID-19 have spanned virtually every natural and crisis-related phenomenon to some degree. Throughout the pandemic, militaristic analogies that invoke being at war with, battling or fighting the virus as an embodied enemy have been particularly frequent (Semino 2021). For example, an analysis of COVID-19 discourse on Twitter showed war-related language to be the most common framing, featuring in approximately 5% of tweets (Wicke and Bolognesi 2020). Rather than conveying scientific information, war rhetoric can have a multitude of other functions in public discourse on disease (Flusberg et al. 2018), including magnifying the perception of threat, boosting public morale, and justifying extraordinary state measures (e.g., emergency legislation or funding, nationalizing businesses, and economic shutdowns). Militaristic metaphors can also shift the perception of responsibility from individuals to the state (Burnette et al. 2022, Schnepf

and Christmann 2022). Such purposes are outside the scope of our primary focus: nuanced communication of scientific concepts to inform day-to-day choices by the public and to support rapid decision-making capabilities that are needed from policymakers in dynamic situations. As such, we do not consider war-based analogies any further in the present article and, instead, focus on analogies of SARS-CoV-2 in terms of how they relate to key epidemiological concepts (but see Bates 2020, Wicke and Bolognesi 2020, Castro Seixas 2021, and Semino 2021 on the use of war rhetoric in the context of COVID-19).

The wave analogy

One of the most pervasive analogies used in epidemiological communications is that of a wave (Biggerstaff et al. 2014, Leung et al. 2020), as is evidenced throughout the COVID-19 pandemic in both public health communications (e.g., Looi 2020, Xu and Li 2020) and public discourse (e.g., on Twitter; Wicke and Bolognesi 2020). Its ubiquity in disease biology can be attributed to the similarities between the shape of a wave and the graphical form of infection progression through a population during an epidemic. Although the wave can aid in conceptualizing patterns and forms of infections, it is also crucial to recognize where the analogy can break down in terms of conveying biological processes, potentially leading to counterproductive public perceptions.

The appeal of the wave analogy is ostensibly self-evident: Wave-like patterns of infection, starting with low numbers that rise to a peak before falling, are a typical characteristic of most epidemics and, indeed, typically emerge from the SIR model outlined above. Wave-like patterns are even more striking when infectious diseases display multiple peaks of cases over time. Repeated peaks can emerge through a variety of factors, but all rely on some level of susceptibility remaining present in the population after previous peaks—for example, through previously unexposed individuals, waning immunity (Saad-Roy et al. 2020, 2021), or the introduction of immunologically naive hosts e.g., via births (Anderson and May 1992). Provided that susceptible hosts are available, new surges of cases can occur when behavior changes (e.g., relaxed physical distancing, increased contact), when the probability of a contact resulting in infection changes (e.g., if the pathogen's transmissibility changes seasonally), or a combination thereof.

Superficially, a wave therefore seems a compelling analogy to describe patterns of disease outbreak, given it is simple to grasp and is effective in capturing the visual form of the initial progression of an epidemic. However, its efficacy as a means of communication is dependent on both its purpose and the context in which it is used—that is, whether the user seeks to describe patterns in infections or convey an understanding of the underlying processes. The critical limitation of the wave analogy (and wave-related imagery—e.g., floods, ripples, and tsunamis; Johnson 2020) is a limitation associated with pattern-based models in general—although suitable for describing patterns in hindsight, no information

is provided as to the mechanisms that contribute to these patterns. Little in the image of a wave can be traced back to the processes of the SIR model, meaning that the simplified conceptualization presented to the public is disconnected from our scientific understanding of the factors governing disease trajectories. For example, changes in human behavior (e.g., mask wearing and physical distancing) can dramatically alter the transmission rate β , thus contributing to the increase or decline in infections, but the dynamic influence of our behavior is difficult to reconcile with images of real-life waves, which rise and fall regardless of our actions. The lack of mechanistic considerations not only makes it difficult to discern whether a population may have already entered a wave while the epidemic is still happening but also complicates discussions of whether, and if so, when subsequent waves might be expected.

Perhaps most importantly from a risk communication perspective, the reliance on a wave analogy fails to convey to politicians, health officials, and the public about the mechanisms driving disease spread and the tools at our disposal for preventing transmission. Although the use of wave terminology, such as *breakwater*, *wave breaker* (Moulson 2021), and *breaking the wave* may communicate reductions in case numbers (i.e., flattening the curve), the mapping is relatively abstract between the concept of a breakwater or wave breaker—a physical structure that reduces acceleration of aquatic waves—to the wide variety of proactive and preventative measures that can be taken to reduce risk and prevent wave formation. A literal image of a wave implies waiting for a physical force to arrive and managing its impact as well as possible without being able to do anything to prevent the force from washing over. As such, the analogy may have also contributed to impressions that being in a “trough” may be the time “to make the most of... summer” (Thiessen 2020), such as “take [a] holiday now to prepare... for a second wave” (Donald 2020), and may have even fueled suggestions to enjoy “some respite [and] a meaningful” holiday period once the wave has passed and restrictions lifted (Department of An Taoiseach 2020, Carroll 2021). However, viruses do not behave like aquatic waves at all, and although calls for broad relaxation of restrictions during periods of lower incidence may be well intentioned and provide some psychological and economic benefits, these very actions could also contribute to a new surge of cases.

As such, the reliance on wave analogies to guide public understanding of epidemiology could potentially lead to a defeatist mindset or even become a self-fulfilling prophecy. “Response fatigue” to warnings of recurring waves might also emerge in the general population, hindering control efforts (WHO 2020). In the case of SARS-CoV-2, beyond capturing the initial disease outbreak, the wave analogy may also serve to illustrate the workings of a panic-neglect cycle at the societal level: high mortalities leading to physical distancing and other control measures to bring case numbers down, followed by a relaxing of measures when case numbers are low and the threat does not seem as imminent,

Box 1. Campfire as an analogy for the SIR model of disease outbreak.

Picture a campsite in the woods. Dry pieces of wood lie stacked ready to be lit for a campfire (each piece representing one susceptible individual in a population). A first match is lit, but the pile doesn't catch fire (threat from pathogens spilling over from the environment—flames from a match). A second match sparks, again, no success. The third attempt seems more effective: A twig catches fire, then a second and a third, but then the flames fizzle out before the rest of the pile starts to burn. Ultimately, it takes several matches before the campfire takes off: One twig catches fire (the so-called patient zero) and lights another three (transmission rate, $\beta = 3$ per min); after a minute, the first twig fizzes out (recovery or removal rate, $\gamma = 1$ per min), but by now, the other three have already lit several more, before going out themselves (recovered individuals). At this point, the prospect of cold and fireless night has receded, and indeed, after another minute, another 27 twigs (infected individuals) are on fire. Remembering the basics of exponential growth, we now realize that, with each burning twig on average lighting three more twigs each minute ($R_0 = 3$), the fire could burn through thousands of twigs in minutes (e.g., 59,049 twigs could theoretically catch fire in 10 minutes). Of course, that's many more twigs than have been piled up. Instead, based on our experience with fire, we are sure that what will happen is a fire that initially grows bigger and hotter rapidly, then reaches a peak in the number of twigs that are burning, and finally begins to die down before ultimately going out (herd immunity is reached), probably well before every single piece of wood has burned.

resulting in a new infection peak. Thus, even while useful for characterizing patterns in hindsight or for demonstrating possible outcomes of nonintervention scenarios, overreliance on the wave analogy may become counterproductive in other contexts.

Beyond waves, epidemics are often analogized in a similar manner in terms of natural forces or disaster imagery (Semino 2021). Storm and floods are regularly evoked when describing initial increases in case numbers, revealing little of the underlying mechanisms driving the disease and, therefore, no information on ways available to change course. Despite their lack of mechanistic-model underpinnings, storm analogies are similar to waves in providing a simple visualization capturing the pattern of an outbreak reasonably well. The first few raindrops felt in advance of an oncoming downpour resemble the initial exponential growth rising to a peak in infections, followed by a subsequent decline as the storm passes over, conveying the message that infection numbers can increase rapidly from small beginnings. However, storms also suffer from the same limitation as waves: By implying a physical force coming at us regardless of what we do, we are left powerless to take any action except to endure the onslaught and weather the storm.

Fire as an analogy for COVID-19

Although waves and storms provide examples of the strengths and weaknesses of a pattern-based analogy, fire offers an alternative process-based analogy to effectively convey the establishment, spread, and (crucially) the control of SARS-CoV-2. Despite its potential to map to multiple aspects of disease transmission and control (Semino 2021), fire as a framing for COVID-19 is less evident. For example, fire lexicon features fewer times than wave lexicon in UK media coverage of the pandemic (Charteris-Black 2021).

As a simple example, a campfire analogy (box 1) can be an intuitive and reasonably accurate representation for the processes described in the SIR model that drive disease outbreak in a closed population. Of note in this analogy is the

clear mapping to the modeling framework, meaning mechanisms that are key to controlling disease trajectory can be more easily identified and targeted for action. Susceptible individuals (S ; pieces of wood or fuel) live together in a population (N ; a pile of wood) and are at risk from pathogens spilling over from the environment (an initial spark), eventually making some unlucky patient zero sick (lighting the first twig on fire). Some outbreaks may quickly die out and possibly go undetected (because of stochastic processes, or akin a low β with only a few twigs catching fire but then fizzling out). Others may result in an epidemic that spreads through a population (a roaring campfire). How quickly the virus (fire) spreads depends on how many individuals (twigs) each infected individual (burning twig) infects (lights) on average during the time it is infectious (sufficiently aflame to set another twig alight)—that is, the R_0 . In our example in box 1, just after lighting the fire, each twig was burning an average of 1 minute ($\gamma = 1$ per min) and lighting three other twigs ($\beta = 3$ per min) during that time, resulting in a growth rate of three new burning twigs during the lifetime of a twig—equivalent to a disease with a basic reproductive ratio of $R_0 = 3$. As the epidemic (fire) progresses, each infected person (burning twig) retains the potential to infect (light) three other people (twigs) on average; however, because some of these contacts may already have had the disease and become immune or died (burnt), the effective reproductive ratio, known as the R_e value, decreases. The epidemic (fire) eventually peaks, and then starts dying out once R_e falls below one. By the time the epidemic ends (the fire has burnt down), typically less than $1 - \exp(-R_0)$ percent of the population will have had the disease (been on fire), with the remainder of the population protected by herd immunity (Keeling and Rohani 2007, Britton et al. 2020)—unburnt fuel is separated by sufficient numbers of burnt wood such that any flames cannot move between and reignitions fizzle out quickly.

The analogy can be spun further, and this is where its use as a communication tool for mitigation strategies becomes

Disease spread through
heterogeneous network

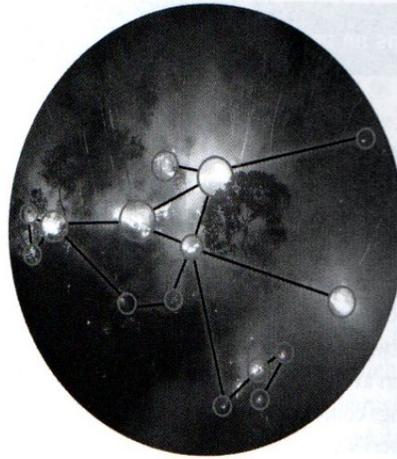
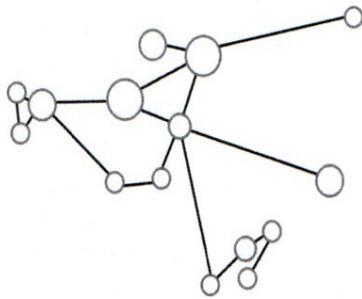


Figure 2. Schematic of disease transmission as determined by spatial structuring in a heterogeneous network of contacts. Disease spread is analogous to the progression of a forest fire (shown in inset) in that wildfire burns through patches of connected trees or forest, which are heterogeneously distributed in space (analogous to nodes in a network). Image: (right panel) Bruno Kelly, *Amazônia Real, Manaus Amazonas, Brazil (Desmatamento e Queimadas 2020)*, used under CC-BY 2.0 (cropped and with network overlaid).

apparent. For the public, thinking in terms fires and fuel can help to both visualize the progression of an epidemic, while also placing emphasis on the impacts that individual actions (e.g., movement and physical distancing) can have on transmission. For example, limiting the risk of burning pieces of wood (infected individuals) spreading fire to dry fuel (susceptible individuals) can be achieved by increasing the distance between pieces of wood (physical distancing), dismantling piles of wood or removing vegetation (limiting large gatherings), or throwing a fire blanket on a burning pile (lockdowns in response to outbreaks). Moreover, the analogy can be extended to consider vaccinations. For example, using water to douse flammable vegetation and tree litter immediately around campfire sites is a similar preventative tactic to targeted vaccine campaigns in infection hotspots (e.g., high-density urban centers).

For policymakers focused on population-level control of the disease, forest fires may be a helpful analogy because these more accurately capture the role of spatial structure in the spread of a transmissible disease through a heterogeneous network of human contacts (Hanage 2020, Osterholm and Olshaker 2020; figure 2). For example, forest fire spread can be mitigated by removing connections between patches of burning forest and at-risk areas through tree felling (i.e., removing links between nodes in a network model). In fact, it was the recognition of similarities to fire that inspired the application of nuanced firefighting strategies in the fight against smallpox, the only human disease to be eradicated to date (Foege 2011). Techniques such as hot spotting (identifying, and focusing on, larger outbreaks and superspreading events early) and constructing firebreaks, whether at the individual (physical distancing, masks, or isolation) or local or regional level (e.g., temporary restrictions on affected districts, health monitoring at borders or testing or quarantine

protocols for travel) can be valuable tools for curbing spread (analogous to reducing β in the SIR model or reducing contact rates or network connections in metapopulation and network models, respectively). Nuanced application and communication of these tools is key, however, and, again, the fire analogy can be of help. Although repeated peaks are frequently characterized using the wave analogy, the reoccurrence of infections is primarily a consequence of the large numbers of susceptible individuals (i.e., fuel for the fire) remaining in populations in which exposure (and subsequent immunity) was curbed by control measures or in areas in which fire (infection outbreaks) have yet to occur. The established public perception of fire and wildfires as serious hazards (Dombeck et al. 2004, Semino 2021) and the existing culture of fire safety can also contribute

to sustained risk awareness. Once a fire is extinguished, we don't dismantle fire defense strategies (from fire alarms and hydrants to fire departments on call 24 hours). Instead, we learn from experience how to minimize risk, strengthen our defenses, and educate people on how to respond in the event of a future fire e.g., fire drills or safety courses (Nuzzo 2021). These same concepts can be harnessed to generate a similar sense of vigilance toward the threat of rapid disease reemergence and the importance of proactive countermeasures.

Incorporating more complex dynamics

The forest fire analogy conveys the basic SIR processes, while also highlighting a key modification to the general epidemiological framework: the role of spatial heterogeneity in driving complex disease dynamics. Communicating these concepts is essential to understanding the importance of sustained and coordinated management strategies at various geographic scales, from local and regional SARS-CoV-2 suppression to disease control and eradication at the national and global level.

After the initial rise and fall in case numbers that characterized the outset of the COVID-19 pandemic, analogies involving electricity have been employed to justify control measures combatting subsequent infection outbreaks (Bergen 2021). In response to clusters of rising infection numbers, short-term measures—including fixed-period closures, lockdowns, and shelter-in-place orders—have been described as “circuit-breakers” (Gallagher 2020, Bergen 2021, Office of the Premier of British Columbia 2021) to counteract a “surge” in cases. In the context of metapopulation dynamics and network models, the simple image of breakers in an electrical circuit emphasizes the role of intervention measures targeting a drop in the movement or contact rate between infected and uninfected subpopulations

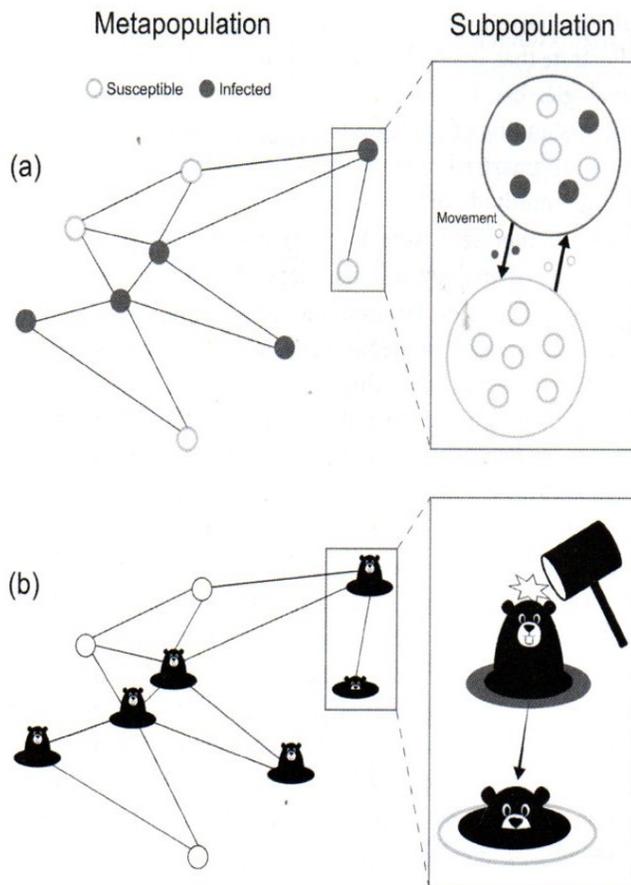


Figure 3. (a) Spatial heterogeneity in disease dynamics represented as a networked metapopulation, where filled nodes indicate subpopulations with active infections and unfilled nodes indicate infection-free subpopulations. Disease is transmitted between subpopulation via movement between nodes (top inset), which leads to reoccurring outbreaks across the metapopulation in a manner that resembles (b) the popular Whac-a-Mole game. Once whacked (bottom inset), a mole can pop up elsewhere in the network because of connectedness between mole burrows—that is, like network connections between subpopulations in panel (a).

(or a breaking of network connectedness), which can reduce overall infections and curb disease spread in a similar manner to that conveyed by the concept of fire breakers (Welsh Government 2020).

The superficially similar attributes of shutting down an electrical circuit and shutting down economies to constrain transmission draws attention to a further implication of the circuit-breaker analogy: Once the circuit is reconnected (restrictions lifted), the transmission of electricity—and of the virus—can resume as before, ultimately leading to recurring outbreaks and intermittent restrictions. Concepts of metapopulations, contact networks, and the role of spatiotemporal dynamics in enabling infections to reappear or persist locally and globally, can be further explained using analogies to games such as Whac-a-Mole, ping-pong, and tennis. Within larger metapopulations (e.g., entire countries) infection-free subpopulations (cities or towns) can

exist where the disease has either not been established or has been successfully suppressed. However, subpopulations of susceptible individuals remain at risk of recurring outbreaks via movement and contact with adjacent subpopulations (areas within the larger metapopulation with active infections). These metapopulation dynamics are reflected in the popular Whac-a-Mole game (figure 3), in which moles repeatedly pop up across the play area while a player counteracts by whacking each mole once it appears locally. Similar ideas are invoked by other game-based analogies—if the ball (virus) is left in play, it can continually move around the playing field or be returned across the net until the ball is taken out of play and the game ends—that is, the disease can continually reappear locally until eliminated from the overall population. Following the game analogy to its logical conclusion, we can deduce that the short-term approach of sequentially whacking moles or balls (i.e., infection outbreaks) only once they pop up (suppressing local outbreaks but ignoring widescale, long-term suppression measures) does not remove the risk of a mole or ball reappearing. A core concept of metapopulations (and of networks) is thus highlighted: Local populations do not exist in isolation of one another. If infection persists among subpopulations (or, in global terms, among countries), we could be subject to recurring outbreaks and an endless game of disease Whac-a-Mole. The same concept can also be applied to vaccination efforts, where coordinated global rollout of vaccines is the most promising means for both eliminating SARS-CoV-2 morbidity (Wouters et al. 2021) in local populations and reducing the threat of COVID-19 at broader scales (therefore, also limiting the opportunities for emergence of new variants and vaccine escape; Krause et al. 2021).

Game analogies serve to illustrate the dynamics that could arise if the roles of spatial structuring and contact networks are not explicitly considered. Geographic disparities in COVID-19 dynamics globally have provided some examples of the Whac-a-Mole game in action. Although some countries (e.g., New Zealand) have successfully suppressed disease outbreaks, others, including Canada (Pelley 2021), Ireland (Carroll 2021), India (Asrani et al. 2021), South Africa (Burke 2021), the United States (Walters 2021), and the United Kingdom (Bryant 2021), have seen recurring and large infection peaks stemming from the relaxation of large-scale population-level restrictions or the rise of more transmissible viral variants. At times, the use of a Whac-a-Mole analogy has been muddled—for example, when measures to support localized restrictions (tracking and tracing; e.g., Mueller 2020)—are insufficient to detect and curb outbreaks before clusters spread (a weak attempt at mole whacking). The concept of metapopulations and associated persistent risk of disease reemergence can also be underplayed through declaring certain subpopulations (regions or countries with low case numbers) as “safe” or, conversely, as hotspots (with associated implications for travel and free movement; Nasser 2021). Such messaging could even potentially undermine disease control efforts at broad geographic scales by

misrepresenting the very behaviors—abandonment of preventative measures (e.g., masks), more disease-transmitting contacts—that can lead to the reemergence of infection in infection-free areas (or indeed, emergence of new variants; Lancet 2021) and ultimately contribute to the persistence of the disease in the wider population or metapopulation. Moreover, we also note that the term *game* can have generally positive connotations—as measured by valence (i.e., the pleasantness of a stimulus; Warriner et al. 2013)—that may hinder the perception of risk or threat.

Invoking additional analogies

It is important to note that as simple abstractions, no one analogy can claim perfect representation, and there are limits to how far a single analogy can be taken (Taylor and Dewsbury 2018). For example, asymptomatic transmission may be less easy to reconcile with fire. Depending on the context and the purpose, switching between a range of alternative analogies could become useful to capture different attributes or reach new audiences. Moreover, because both our scientific understanding and the public's perception of COVID-19 develops, more focused analogical reasoning can be invoked for precisely conveying a specific aspect of pandemic management or disease control.

A striking example of an analogy that has homed in explicitly on mechanisms to control transmission rates is the Swiss cheese respiratory virus pandemic defense infographic (https://figureshare.com/articles/figure/The_Swiss_Cheese_Respiratory_Virus_Defence/13082618). The eye-catching visual of Swiss cheese, with its layers of overlapping porous cheese, has been used to underscore the roles of complementary intervention measures that scale from individuals to populations (Reason 1990, Roberts 2020). Targeting a single component of the SIR model (transmission rate β) the image of Swiss cheese is a simple and effective means of communicating the function of combined actions in reducing transmission, ranging from the individual (facemasks, hand-washing, distancing) to the population level (testing protocols, quarantines, vaccination). No single measure is sufficient to halt transmission entirely (the holes in the cheese), but the combination of controls (slices of overlapping cheese) can effectively reduce overall transmission rate. As the vaccine rollout progresses, the Swiss cheese analogy could become of particular use in conveying the role of continued preventative measures in reducing transmission and controlling infection spread until widespread vaccine coverage is achieved (Giordano et al. 2021). Of note in this analogy is also the presence of the misinformation mouse, who nibbles through the layers of cheesy protection (weakening control measures), underscoring how misinformation or misleading communication can undermine intervention efforts.

Analogies as nuanced communication tools

Broadly, the use of analogy in relation to the COVID-19 pandemic has often focused on describing phenomenological patterns of infections as waves (Wicke and Bolognesi

2020, Charteris-Black 2021). The examples we outline above illustrate that, depending on topic and context, various other analogies can be used as effective tools to support public understanding of epidemiological information (table 1). We have summarized in the present article only a small number of the multitude of analogies and metaphors that could be used to represent aspects of SARS-CoV-2. The effective mapping of analogy will also depend on cultural and contextual differences. For example, invoking wildfire or forest fire may transmit a greater sense of risk in regions where wildfires pose an acute threat (e.g., Brazil, the west coast of North America, or Australia, where wildfire framing was used as early as February 2020 in reference to the emerging pandemic; Mannix et al. 2020). Nonetheless, we suggest that to reflect complex or nuanced aspects of the ongoing pandemic, analogies that are more directly linked to models and mechanisms underpinning these patterns could be a powerful way to reframe public dialogue. To this effect, we highlight that process-based analogies, particularly those related to fire, can be highly useful communication tools, given that they are easily mapped to underlying epidemiological concepts, can be extended to include more complex spatial processes, and can convey a sense of urgency to motivate individual and collective action.

The most crucial consideration is the intended message to be transmitted via analogy in a given context. Is the objective to capture a particular pattern or process, convey complex dynamics, or to highlight risks and potential outcomes of interventions? Attention should be paid to the ways in which analogy can enhance (or conversely, mislead) these aims. For example, a wave can be a simple and effective tool to describe or even learn from patterns retrospectively (it is hard to know whether you are in a wave or not until the wave has passed). Perhaps even more importantly, a wave can be compelling example of what might happen if no control measures are implemented (expect a rise or flood of infections). However, continuing to describe the pandemic as a series of successive waves may contribute to this becoming a self-fulfilling prophecy by furthering a sense of inevitability, and, ironically, the type of behavior that can drive the wave of increased case numbers. Alternatively, to boost understanding of the processes that lead to infection outbreaks, visualizing the pandemic in terms of fire can be an effective means to convey risk while empowering the public with an awareness of our ability to mitigate recurring peaks and take proactive measures. Alongside forest fires, the term *circuit breakers* conveys the basis for targeting spatially structured spread through rapid reduction of contact rates, whereas the image of Swiss cheese highlights the effects of multiple layers of protection scaling from individuals to populations, and the role of synchronous control measures to support mass vaccination.

Incorporating analogies that describe more nuanced spatiotemporal dynamics (e.g., forest fires and games) could offer a tool to communicate metapopulation dynamics, convey the basis for coordinated action on equitable vaccine

Table 1. A sample of analogies and metaphors used to represent aspects of the SARS-CoV-2 pandemic and their relationship (subjectively classified) to aims of epidemiological modeling.

Analogy	Example of use	Frequency	Type	Complexity	Purpose	Link to model aims
Wave	First, second, or third waves, ripples, floods, surge, tsunami	Most common	Pattern based	Simple (only focuses on the number of infections, sick, or mortalities)	Describe patterns, illustrate nonintervention scenario	Summarize
Fire	Raging, wildfire, blazing, “quench the virus,” “hotspots.”	Less common	Process based	Can be complex (captures heterogeneity or spatial structure)	Communicate mechanisms, predict future dynamics, motivate actions, predict intervention outcomes, create intuition for consequences of actions	Summarize Understand properties Predict future states or interventions
Games	Whac-a-Mole, ping-pong, tennis, chess	Less common	Mostly process based	Complex (captures spatiotemporal dynamics)	Communicate mechanisms, Predict future dynamics, Predict intervention outcomes	Summarize Understand properties Predict future states and interventions
Electricity	Circuit breaker, dimmer switch, surge	Common	Mostly pattern based	Simple (targets transmission or movement rate)	Communicate mechanism	Understand single property
Disasters	Weathering the storm, meltdown, avalanche of cases	Common	Pattern based	Simple (only focuses on the number of infected)	Describe patterns, illustrate nonintervention scenario	Summarize
Swiss cheese	Swiss cheese model of pandemic defense Misinformation mouse	Less common	Slightly process based	Simple (targets individual to population-level scaling of controls)	Communicate mechanisms (focusing on β)	Understand single property
War	Battling the virus, on the frontlines, heroes, onslaught	Common	Evocative or motivational	–	Motivate collective action, convey threat	–

Note: This is not an exhaustive list.

distribution, and justify continued societal-level control measures to protect the vulnerable. The “trough” stage post infection peak can be a crucial moment to shift from the ubiquitous wave comparison and instead highlight the importance of the broader metapopulation in long-term pandemic management. At local scales, a combination of extensive vaccination and sustained preventative measures (Giordano et al. 2021, Krause et al. 2021) (facilitated by sufficient societal support systems) can effectively extinguish remnant low-level infection incidence, whereas consideration of the wider metapopulation—and the challenges of devising policies to reduce transmission and subsequent waves at larger (global) scales—is ultimately required to break out of intermittent lockdown–reopen cycles and reduce COVID-19 morbidity worldwide (Oliu-Barton et al. 2021). To revisit the fire analogy, successful firefighters don’t leave a housefire with the kitchen still burning. Leaving even one small fire left unchecked (an area with active infections or low vaccine coverage) can allow embers to jump and outbreaks to reemerge. Persistence of infection is of particular concern in a global context, when such sparking “embers” might be in the form of novel variants of concern (Gilmore 2021; as seen in the emergence of more transmissible variants of SARS-CoV-2), conveying the roles of both continued

control measures and global equity in vaccine coverage (Fontanet et al. 2021, Kim et al. 2021).

A valuable next step to further identify and develop effective epidemiological communications would be to quantify the diversity, relative frequencies, and spatiotemporal characteristics of metaphors and analogy use in the context of COVID-19 (e.g., through topic modeling of COVID-19 discourses on news media and social media; Wicke and Bolognesi 2020). Assessing how analogy use relates to observed infection dynamics through time would also be informative. For example, are certain analogies more prevalent after an increase in case numbers and absent when cases are low? Importantly, in the present article, we primarily review which analogies most accurately represent epidemiological concepts and do not consider the extent to which an analogy is believed or understood by target audiences or used in decision-making. Further work could directly measure audience response to different metaphorical framings across a variety of cultural and contextual settings via empirical linguistic or framing studies (Steen et al. 2014, Thibodeau et al. 2017, Schnepf and Christmann 2022). For example, *wildfire* and *wave* can evoke different responses, with the former provoking a greater intensity of emotion (Warriner et al. 2013)—measured by the valence

and arousal evoked by a word, but see Warriner and colleagues (2013) and Scott and colleagues (2019) for information on linguistic dimensions.

Conclusions

“[Models are] like having a flashlight. If you see a cliff, you don’t just necessarily walk over it because the flashlight showed you it was there. You do something. You don’t walk over the cliff.”

—Caroline Colijn (Grant and Howlett 2020).

An important aspect of scientific modeling is the concept of uncertainty. Models are tools to help illuminate the path ahead and identify likely outcomes or uncertainties; we can then use this knowledge and make strategic choices to either follow a given path (regardless of potential risks or uncertainties) or take action and change course (Grant and Howlett 2020). Analogies are an indispensable means of communicating these same concepts of informed risk assessment and tools for proactive mitigation to a broad audience. While the risk from SARS-CoV-2 remains high in most countries and vaccination efforts race against new variants (Fontanet et al. 2021), there continues to be an urgent need to communicate the underlying epidemiology effectively to policymakers and the public. Emphasizing the tools available to us, and their relation to controlling transmission, has the potential to empower the public to understand that management of this pandemic—and, dare we say it, prevention of the next one—can be achieved and is within our existing control, even as emerging variants pose additional challenges for public health management. Although many people’s hopes rest on effective treatment and sufficient vaccine coverage, process-based analogies can demonstrate that in the meantime, by aligning individual and collective actions with sufficient societal support, we have mechanisms at our disposal to limit transmission and reduce cases. The successes of hot spotting and other firefighting strategies, both in the past and in the present, have shown that case resurgences are not inevitable and can be managed with the right tools and mindset.

We hope that thinking of ourselves as firefighters, in the middle of a global blaze, allows us to remain vigilant and can help galvanize collective action, in a way that waiting for so-called and seemingly inevitable recurring waves cannot.

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