out well because they made predictions that survived testing. Yet numerous historical examples point to how, in the absence of adequate data, elegant and compelling ideas led researchers in the wrong direction, from Ptolemy's geocentric theories of the cosmos to Lord Kelvin's 'vortex theory' of the atom and Fred Hoyle's perpetual steady-state Universe.

The consequences of overclaiming the significance of certain theories are profound — the scientific method is at stake (see go.nature.com/hh7mm6). To state that a theory is so good that its existence supplants the need for data and testing in our opinion risks misleading students and the public as to how science should be done and could open the door for pseudoscientists to claim that their ideas meet similar requirements.

What to do about it? Physicists, philosophers and other scientists should hammer out a new narrative for the scientific method that can deal with the scope of modern physics. In our view, the issue boils down to clarifying one question: what potential observational or experimental evidence is there that would persuade you that the theory is wrong and lead you to abandoning it? If there is none, it is not a scientific theory.

Such a case must be made in formal philosophical terms. A conference should be convened next year to take the first steps. People from both sides of the testability debate must be involved.

In the meantime, journal editors and publishers could assign speculative work to other research categories — such as mathematical rather than physical cosmology — according to its potential testability. And the domination of some physics departments and institutes by such activities could be rethought^{1,2}.

The imprimatur of science should be awarded only to a theory that is testable. Only then can we defend science from attack.

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Ebola survivors Zaizay Mulbah (left), a former money changer, and Mark Jerry, previously a delivery driver, are working as nurses' assistants at a Liberian Ebola centre.

Mobilizing Ebola survivors to curb the epidemic

Scaling up the recruitment of individuals who have recovered from infection deserves urgent consideration, argue Joshua M. Epstein, Lauren M. Sauer and colleagues.

ultiple governments and nongovernmental organizations have called on health-care personnel the world over to help control West Africa's Ebola outbreak; these include Médecins Sans Frontières (MSF), the World Health Organization (WHO) and United Nations children's charity UNICEF. But the

demand for labour far exceeds the supply¹. UN estimates, which may be low, suggest that approximately 5,000 international medical, training and support personnel are needed in the coming months.

While foreign assistance must continue, a nascent local strategy is a candidate for broad adoption. We call it MORE, for >



Ebola survivors are assisting in World Health Organization response efforts, which could be expanded.

MObilization of REcovered individuals. The idea is simple: those who have recovered from Ebola could be engaged to reduce transmission, helping to bring the epidemic under control.

Examples of the approach can be seen in Sierra Leone, Guinea and Liberia. For instance, the UN is training survivors to support children who have had contact with infected individuals and are within Ebola's 21-day incubation window (the time it takes to develop symptoms after being infected with the virus). MSF is similarly employing survivors to work in their Ebola treatment units in Guinea and Liberia.

There are uncertainties about the ultimate size of this cadre and, crucially, about the immunity of recovered responders to reinfection, both immediately and in the longer term (because immunity may wane). Nonetheless, the potential of MORE to shift the epidemic's dynamics makes its consideration imperative.

RECOVERED RESPONDERS

So far, Ebola has infected an estimated 16,000 individuals in Liberia, Sierra Leone and Guinea. Current estimates suggest that in West Africa, roughly 50% of people who contract Ebola will die². This would leave a substantial pool of survivors, totalling perhaps 8,000 people by the end of the year. In the longer term, this could prove to be a much larger number. Indeed, the larger the epidemic, the bigger this pool becomes.

The worst-case projections of the US Centers for Disease Control and Prevention, for Sierra Leone and Liberia only, range from 500,000 to 1.4 million cases of Ebola by January 2015 (ref.3). Owing to various methodological limitations (set forth earlier by one of us, J.M.E., see go.nature.com/86kpyw), these projections are proving to be much too high. But even if the lower of these estimates turns out to be an order of magnitude too high, there could ultimately be 50,000 cases. If 50% survive, this is a pool of 25,000. If we assume that 75% of survivors would be too young, too old, too ill or too traumatized to be recruited, the available cadre could still number in the thousands (see go.nature. com/kbx4el).

There are limited confirmatory data on protective immunity to Ebola in humans. protective immunity to Ebola in humans. Sut researchers generally agree that the evidence is pointing towards survivors being immune to reinfection. Thus far, there has not been a single reported case of a person who recovered from Zaire ebolavirus (the lineage of the current outbreak) becoming reinfected. This, and evidence from animal studies, suggests that people may have protective immunity following recovery.

RISK LEVEL

At worst, recovered responders would have the same level of risk as the general population, in which case they would need to use the same personal protective equipment (PPE) as other responders. At best, they would have high protection through conferred immunity.

In the latter event, recovered responders could operate with much less onerous PPE than current health-care workers. They would require only the training and protective equipment (medical gloves, face shield and goggles) used to minimize the transmission of more familiar blood-borne pathogens such as HIV. This would allow them to have much more extensive contact with patients than Ebola PPE normally affords. Generally, providers in full Ebola PPE work only two-hour shifts to avoid overheating (see go.nature.com/hsk4v5).

Recovered individuals can be trained to perform many important response functions (see 'Responder roles'). Some of these are beyond palliative, and may have a direct impact on disease transmission, changing the course of the epidemic itself. Such activities include isolating suspected patients from uninfected community members

EBOLA CONTROL

Reversing the epidemic

In classical epidemiology, susceptible people (S) bump into infected ones (I) as in a perfectly mixed bowl. That is, if β is the transmission probability per contact between these pools, the epidemic grows at rate βSI .

To model the impact of the MObilization of REcovered individuals (MORE) strategy, we let Z_t denote the recovered proportion of the population t days into the epidemic, and k denote the fraction of recovered people who are deployed to reduce transmission. This multiplies the classical growth rate above by $(1-kZ_t)$, which one might interpret as reducing β .

The reproductive number, R_t , is the average number of primary infections produced by a single infected individual dropped into the population on day t. If $R_t > 1$ the epidemic is growing, whereas if $R_t < 1$, it is declining. So, $R_t = 1$ is the epidemic threshold. Letting R_t^M and R_t^C denote, respectively, the reproductive numbers in the MORE and classical models (including deaths), it follows that:

$$R_t^M = R_t^C (1 - kZ_t).$$

So, if k (the mobilized fraction of the recovered) exceeds zero, MORE reduces the reproductive number. And crucially, if $R_t = 1$ or is hovering above it, mobilized survivors could tip the epidemic into fading out. More-realistic models, with social networks rather than perfect mixing, could reveal stronger effects.

RESPONDER ROLES

Many tasks that could help to bring the Ebola epidemic under control require only limited training. Recovered individuals could be screened and assigned functions on the basis of their preferences and capabilities.

IMMUNITY NOT ESSENTIAL

Low or moderate skill Emergency response management operations Family support Stigma education Contact tracing Nutrition services High skill

Hygiene education Burial education

IMMUNITY ESSENTIAL

Low or moderate skill Patient screening Waste management Burial monitoring Physical labour (moving supplies, building treatment tents, for example) Housekeeping Patient morale

High skill Patient transport Early identification of infected

and safely transporting them to treatment centres early in the course of infection, when viral loads and contagiousness are lowest. Performing simple tasks that do not require extensive training — such as giving people food and water, helping them to shower or feeding infants — would free specialized health-care workers to concentrate on more sophisticated clinical tasks. Recovered responders could also perform duties such as waste disposal and decontamination in high-risk areas ('hot zones') and ensure safe burial practices, all of which reduce the spread of the virus.

As well as reducing Ebola transmission, MORE could enhance West African health infrastructure. It will generate a form of human capital that will continue to facilitate routine health care and the early warning of Ebola recurrence when the international presence declines. Furthermore, recovered responders would be important allies in any vaccination campaign.

TIPPING POINT

Most importantly, mobilizing the recovered to reduce transmission could 'tip' the epidemic into decline. Specifically, a central idea in epidemic modelling is the reproductive number of the disease, denoted by R_t (see 'Reversing the epidemic'). This is interpreted as the average number of primary infections produced by a single infected individual dropped into the population at a particular time, *t*. If everyone is already ill there is no one to infect, R_t is effectively zero.

By contrast, the very first infectious person introduced into a dense, uninfected

population might transmit the disease to many, so the reproductive number at this time (t = 0) would be high. If R_t is greater than 1, the epidemic is growing: each infected person is converting more than one susceptible person into another infective person. If R_t is less than 1, the epidemic is shrinking. Therefore, the state at which R_t is equal to 1 can be considered a tipping point. Above this point, the disease takes off. Below it, the epidemic dies away. MORE could reduce R_t ; in countries currently close to the tipping point, such as Liberia, the strategy could bring R_t below 1 and keep it there.

The World Bank is poised to spend almost US\$500 million on foreign response for West Africa. With the economies of the most affected countries severely strained, this external support is crucial. By comparison, a small investment could establish a complementary standing cadre of local recovered responders. (Liberia's nurses, for example, are paid roughly \$10 per day.) This strategy would create local jobs paying a fair wage in places where these are in short supply.

TACKLING STIGMA

A serious concern is that Ebola survivors are stigmatized. This was true of HIV in the early stages of the AIDS epidemic. There, stigma and social marginalization were successfully reduced with intensive educational campaigns and the support of national and international leaders⁴. Similar tactics can be employed here, but much earlier, and with potentially dramatic effects. In fact, local survivor support groups and other efforts are already leading the way (see go.nature.com/t1xv4f).

MSF has begun providing 'certificates of recovery' to survivors, as a means of allaying fears. Community volunteers in Sierra Leone and Liberia are working to combat misplaced fear: by visiting the neighbours of survivors before their return home; by broadcasting on radio and television; and by physically embracing survivors themselves. Social-media campaigns are reinforcing the message that people are not defined by their disease — among these are the 'I am a Liberian, not a virus!' and the 'I survived Ebola' campaigns.

If these campaigns are effective, people infected with — or at risk of — Ebola may be particularly responsive to local survivors, who share their cultures, customs and language. In addition, recovered responders may themselves benefit from the work, improving their own psychological recovery.

High levels of illiteracy could be a concern insofar as they preclude highly specialized training. But for many of the tasks that we have highlighted, only limited training is required. People could be screened⁵ and assigned functions on the basis of their preferences, aspirations, capabilities and work experience.

Crucial to the success of the MORE strategy is implementation on a broad scale. Although several groups are sporadically using survivors, the designation of a central body to implement and manage MORE would facilitate an efficient broadening of the approach. The WHO is currently the lead organization for the international Ebola virus disease response, and it has direct relationships with local governments, ministries of health and response organizations working on the ground. An alternative lead organization, MSF, is already working in this arena. MSF has substantial experience in managing volunteers in clinical environments and has

"An urgent priority is to establish precisely which individuals indeed have protective immunity." comprehensive training programmes for various skill levels. A joint initiative of the WHO and MSF might be the best option for coordinated and effective implementation of MORE.

An urgent pri-

ority is to establish precisely which individuals indeed have protective immunity. This requires the identification of markers associated with immunity in the blood and serum of survivors⁶. Large-scale *in vivo* epidemiological studies will be important in solving this problem. Only then will we know the full potential of MORE. Meanwhile, recovered responders could perform tasks for which immunity is not essential, or use PPE where it is, as immediate steps in this promising direction.

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