On the transmission dynamics of knowledge

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Much has been written about the analogy between the spread of knowledge and that of diseases [1,2]. But analogies only carry one so far. Even within the epidemiological literature [3,4] it has been necessary to highlight the differences between the transmission dynamics of communicable and sexually transmitted diseases. Within this perspective we have studied the successful invasion of Feynman diagrams (a technique for calculation in physics) throughout the US/UK, Soviet and Japanese scientific communities, during the 1940s-50s. Remarkably, as has often been the case in the ecological literature [5], simple models can capture the dynamics and provide a quantitative basis for comparison.

Detailed historical analysis [6] confirms that the diagrams spread as a contact process between individuals. Borrowing from epidemiology, we model this process in terms of a susceptible population undergoing contacts with a few “infectious” individuals at a rate β. Physicists require an apprenticeship time, akin to incubation, before mastering the new technique. They can then spread the idea as long as they are actively “infectious”, for a time $1/(\mu+\delta)$.

However, disease acquisition is a haphazard process, while learning is at root intentional. This distinction leads to important differences. While disease prevention relies on limiting contacts, ideas spread by deliberately increasing them. For example the spread of Feynman diagrams was greatly enhanced in the US by the rapid expansion of postdoctoral fellowships at the Institute for Advanced Study in Princeton. Under the influence of Feynman’s protégé Freeman Dyson, postdocs practiced using the diagrams in intense collaborations, fanned out to take jobs throughout the US and UK, and began teaching their own students. In Tokyo Tomonaga’s close-knit group was especially receptive to the new techniques, having developed similar ones on their own. Under postwar occupation the Japanese University system expanded tenfold, with members of Tomonaga’s group placed around the country, leading to a very efficient spread akin to that by Princeton’s postdocs [6].

Also unlike diseases, for which most individuals are susceptible at birth, new ideas require work to “catch”. Susceptible communities must be built through extensive training, and even more work is required to develop proficiency with new techniques. Intentional structures facilitate and accelerate the maturation of knowledge, such as formalized doctoral training and postdoctoral apprenticeship that unfold over significant periods of time. Moreover publishing and archiving create reservoirs that maintain ideas endemic, even after founding communities disappear. The combination of long periods of infectiousness and high contact rates, despite long incubation, leads to extremely high reproductive numbers R_0, much larger than those for communicable diseases [7].

Most unlike diseases, ideas often encounter active resistance and competition. For example, highly influential physicists like Schwinger (Harvard) and Landau (Moscow) were skeptical of Feynman diagrams and encouraged young scientists to use their methods instead, thus reducing the size of the susceptible population. Therefore stiflers must often be included [8]. The incorporation of these features results in a simple mean field model that captures the diagrams' patterns of spread in the US/UK, Japan and the USSR [9].

The empirical validation of this approach for the case of Feynman diagrams shows that mean-field epidemic models can contribute to the quantitative understanding of the transmission dynamics of knowledge.

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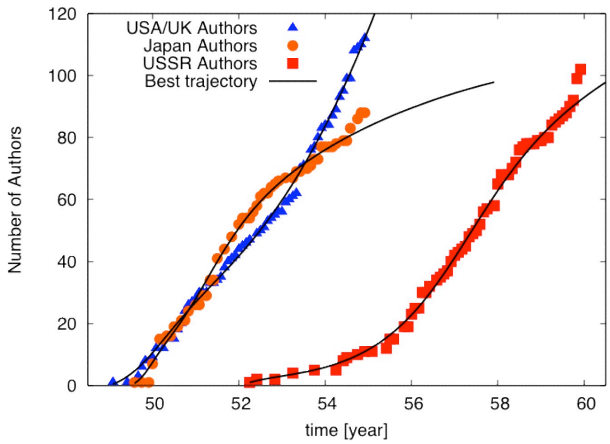
(a)

$$
\begin{cases}
\dot{S} = & \Lambda - \beta S \dfrac{I}{N} - bS\dfrac{Z}{N} - \mu S \\
\dot{E} = & (1-p)\beta S \dfrac{I}{N} + (1-l)bS\dfrac{Z}{N} - \rho E \dfrac{I}{N} - \varepsilon E - \mu E \\
\dot{I} = & p\beta S \dfrac{I}{N} + \rho E \dfrac{I}{N} + \varepsilon E - \delta I - \mu I \\
\dot{Z} = & lbS\dfrac{Z}{N} - \mu Z \\
R = & N - (S + E + I + Z)
\end{cases}
$$

(b)



(c)

$S(t)$	Susceptible
$E(t)$	Incubators
$I(t)$	Adopters
$Z(t)$	Stiflers
$R(t)$	Retired
Λ	Recruitment rate
$1/\mu$	Scientific life expectancy
ε	Natural progression rate
$1/(\mu+\delta)$	"Infectious" period
β	Transmission rate
ρ	Transmission rate
b	Transmission rate
l	effectiveness
p	effectiveness

Figure 1 - The initial growth dynamics of Feynman diagram use, model equations and table with state variables and parameter definitions. (a) Model equations with nonlinear transition rates from the susceptible (S) to the incubator (E), "infectious" (I) and stifler (Z) classes, as well as from the incubator (E) to the "infectious"(I) class. (b) Symbols show the number of authors (without repetition) who published articles using Feynman diagrams in the USA/UK, Japan and the former Soviet Union, respectively. Continuous lines show the model's solutions that best fit the data. Multiple parameters are simultaneously estimated, including the initial susceptible populations (103, 9 and 1) and the basic reproductive numbers, R_0 (13.21, 11.61 and 15.26) for the USA/UK, Japan and the Soviet Union, respectively. (c) Table showing state variables and parameter definitions.