Teaching Epidemic and Public Health Policies through Simulation

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Abstract: - Ever since the November 2002—July 2003 SARS outbreak, epidemiologists have tried to refine the use of computer simulations to help public policy decision-makers understand the real world dynamics of epidemic transmission and to assess the potential efficacies of various public health policies. Here we describe our attempt to help novice researchers understand epidemic dynamics with the help of Huang et al.'s (2004) Cellular Automata with Social Mirror Identity Model (CASMIM), a small-world epidemiological simulation system. We designed three sets of instructional experiments to test our assumptions regarding a) simulating epidemic transmission dynamics and associated public health policies; b) assisting with understanding the properties and efficacies of various public health policies; c) constructing an effective, low-cost (in social and financial terms) and executable suite of epidemic prevention strategies; and d) reducing the difficulties and costs associated with learning epidemiological concepts. With the aid of the proposed simulation tool, novice researchers can create various scenarios for discovering epidemic dynamics and exploring applicable combinations of prevention or suppression strategies.

Key-Words: - Learning through simulation, epidemiological model, public health policy, small-world network.

1 Introduction

Complex network science and agent-based social simulation [1-2] techniques have intensified interest in using computer-based social simulations to analyze social phenomena and processes. Motivations for using computer-based social simulations include a) traditional social science research methods are insufficient for investigating the dynamics of social systems because social phenomena cannot be adequately represented by static relations and simple interaction rules [3]; b) the ability to alter computer simulation parameters allows researchers with any level of technological skill to create "what-if" experiments for examining factors that might affect social issue outcomes [4]; c) computer-based social simulations allow for faster construction of new social models [5]; and d) computer-based social simulations make it easier to create reports and to import information from CD-ROMs or the Internet [6].

Epidemiologists favor computer-based social simulations for at least four reasons: 1) observation and visualization, since they allow for slowing down or speeding up epidemic simulations to observe complete or partial spreading in a proper time scale; 2) operational training, since they reduce the dangers and costs associated with gathering and manipulating data on actual epidemics; 3) modeling, since they allow new learners to construct epidemic models to explore emerging epidemic factors and to analyze simulation processes and experimental results; and 4) understanding, since learners can observe the effects of various transmission routes and modes on epidemic dynamics and test various combinations of prevention or suppression strategies [7].

Constructed social networks based on interpersonal relationships and simple daily human contact can exert significant impacts on epidemic transmission dynamics [8-14]. For instance, interactions among individuals and contact routes are known to affect outbreaks of short-distance contagious diseases such as SARS and other enteroviruses. Due to the potential complexity of human interactions, epidemiologists and public health specialists require computer simulations that can incorporate multiple social networks to analyze and control wide ranges of possible transmission behaviors and epidemic characteristics. Furthermore, epidemic transmission speed and scope are affected by daily human activities, including the entrenched habits of modern lifestyles. For instance, the majority of adults in developed countries use identical transportation modes for daily short- and long-distance travel. The limited diversity of transportation options to regularly visited sites (e.g., workplaces and schools) creates environments for rapid disease transmission.

Since it is hard to control human movement in terms of method, timing, direction, and distance, researchers are repeatedly challenged by the task of simulating individual movement within a society—an issue referred to in the literature as the "mobile individual problem" [15-18]. After the SARS outbreak of 2003, Huang et al. [19] proposed an epidemiological model for simulating epidemic transmission dynamics and public health policies and named it the Cellular Automata with Social Mirror Identity Model, or CASMIM. They established the social mirror identity (Fig. 1) for integrating long-distance movement and geographic mobility into their model, simulating the transmission dynamics of contagious diseases, and investigating the effectiveness of various combinations of public health policies and epidemic prevention strategies [19-20]. Results from experimental simulations indicate that CASMIM is a robust epidemiological simulation system suitable for studying contagious diseases.

In this paper, we will propose three sets of instructional experiments for teaching social science researchers and inexperienced epidemiologists how to use the CASMIM simulation system. Our four primary learning goals are a) simulating epidemic transmission dynamics and public health policies associated with epidemics; b) understanding the properties and effectiveness of various public health policies, alone and in combination; c) constructing effective, inexpensive (in terms of financial and social costs), and executable suites of epidemic prevention strategies; and d) reducing learning costs associated with learning epidemiological principles.

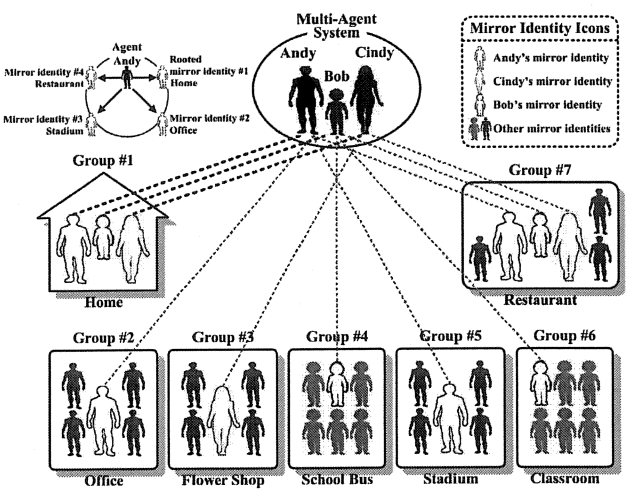

Fig. 1. An example of the social mirror identity concept.

2 Teaching through Simulation

Instruction-based education is often criticized for only providing information without teaching practical skills that learners can use to solve real-world problems. Until very recently, science education has emphasized hastily teaching concepts while neglecting the importance of exploring problems from a learner's own experiences. Consequently, learners tend to become obsessed with complex procedures described in textbooks. Computer simulations are now employed to support learning or training based on constructivist learning principles [21-22]. In a report on educational technology prepared for the American President's office, a committee of science advisors presented a list of the most promising constructivist applications of technology; simulations were at the top of that list [23].

Learning through simulation fits well with constructivist principles, since both focus on active learning and knowledge construction based on interactions between previous experiences and ongoing events. Aldrich (2003) describes simulations as interactive, representational environments that provide learning experiences that require learners to actively construct knowledge [29]. Constructivists believe that learners draw upon prior knowledge to form new schema for discovery learning [30]. When learners are confronted with a new stimulus, they apply their own knowledge bases to accommodate new information and alter their existing schema [31]. When a constructive learning process is embedded in a simulation tool, learners can "learn by doing," have better opportunities to discover interesting primary and secondary issues, and gain hands-on experience to deal with real-world problems.

Learning through simulation can be viewed as an example of Problem-Based Learning (PBL) in that it confronts learners with authentic problems that serve as contexts for practice. As a general model, PBL was developed for medical education in the early 1970s; since that time it has been refined and implemented in over sixty medical schools [32]. Two characteristics make PBL compatible with the theoretical foundation of learning/teaching through simulation:

1. Engagement. Learners often request simulations to assist with learning and to gain a sense of engagement with real-world problems. Consequently, related concepts can be introduced to the learning process. There is no "perfect" educational simulation, but simulations support meaningful learning experiences as long as scenario limitations are taken into account [29].
2. Interaction flexibility. Simulation tools can be used with interaction and feedback to show how complex systems work under different circumstances [29]. Simulated problems are usually complex, often with no single "correct" answer. Learners need to model realistic situations via the repeated

interactive manipulation of parameters. With sufficient practice, learners or novice researchers can learn how to transfer their new knowledge to real-world issues.

3 Epidemic Simulation Systems

CASMIM consists of two layers: an upper layer representing a simplified multi-agent system for simulating heterogeneous cohorts and a lower layer that contains two-dimensional $n \times n$ cellular automata (CA) that represent real-world activity spaces (Fig. 2). The social mirror identities that connect the two layers establish CASMIM as a small-world network model. In CASMIM, each individual in the upper-layer is depicted as a single agent in a multi-agent system; the places that any agent visits on a regular basis (e.g., homes, train stations, and workplaces) are defined as that agent's social mirror identities. In a typical CA, lattices represent abstract agents. In CASMIM, each lower-layer CA lattice represents a social mirror identity.

It is possible for multiple social mirror identities (representing fixed locations that are visited daily or regularly) to be connected to the same agent. The number of social mirror identities for any single agent exhibits a normal distribution. The mirror identity concept utilizes simple social networks to preserve the properties of elements that interact within two-dimensional lattices, thus reflecting such activities as long-distance movement and daily visits to fixed locations. Clusters consisting of a mirror identity and its von Neumann neighbors can represent family members, coworkers, fellow commuters, healthcare workers, relatives in hospitals, or diners in restaurants. Each individual upper-layer agent has a set of attributes that demonstrates its epidemiological progress and social mobility status; these attributes are accessible to all of the agent's social mirror identities. In addition, each social mirror identity has a group of private attributes that represent its current status, location, and special activity locations such as homes, hospitals, or dormitories.

With a few important exceptions (e.g., AIDS), most epidemic simulation models define one time step as equivalent to one day in the real world. Huang et al. incorporated this assumption into their CASMIM design. The statuses of upper-layer agents change simultaneously with their lower-layer social mirror identity statuses during each time step, reflecting their daily interactions. The attributes of social mirror identities and agents vary according to a) the attributes of neighboring agents' social mirror identities, b) a set of interaction rules, c) simulation and epidemic parameters, and d) public health policy parameters. CASMIM can therefore be considered a small-world epidemiological simulation system having such simple social network attributes as population structure, area clustering, space, heterogeneity, localization, and interaction. It also has the social attributes of long-distance movement, daily visits to fixed locations, multiple activity nodes, and the small-world characteristic of low degree of separation. All of these attributes are required for simulating epidemics.

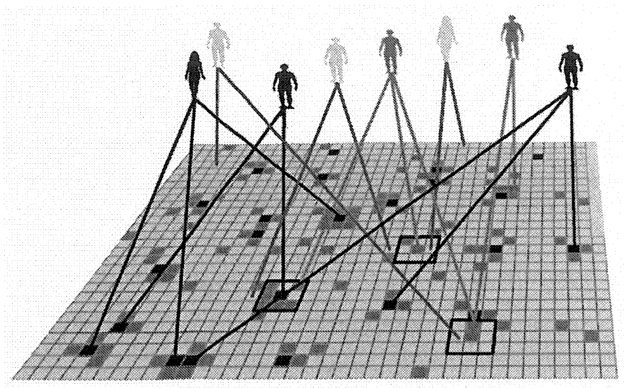

Fig. 2. Cellular Automata with Social Mirror Identity Model (CASMIM).

4 Instructional Experiments

After initializing the CASMIM simulation system and setting its parameters according to information distributed by the World Health Organization (WHO), users can simulate the transmission dynamics of SARS in different areas and compare the effectiveness of various public health policies and disease prevention strategies. For example, knowing that SARS originated in China's Guangdong province allows users to view SARS cases in all other countries as imported and to use the number of cases announced by local health authorities to determine transmission source information (e.g., number of infectious individuals entering a country, time steps during which they entered, and whether they entered as incubated or infected individuals). In two previous projects we simulated public health policies at certain time steps according to actual announcements made by local health authorities, and adjusted our environmental, epidemic, and public health policy parameters according to data reported by WHO [26] and Sebastian and Hoffman [27].

4.1 Experiment 1: Comparing Simulation and Actual Case Results

According to a comparison of actual and simulated SARS cases in Singapore (Fig. 3), the simulated curve we described in [19] had a very close fit with data published by the city-state's health authority for the two outbreaks that occurred between February 25 and May 5, 2003. Emergency public health policies were not activated following the first outbreak, which was attributed to imported cases; the second outbreak was attributed to the compound effects of secondary infections. Several emergency policies were put into effect on March 24, including a ban on visits to patients in hospitals or under home quarantine. The number of new cases dropped dramatically at the beginning of June; soon afterwards, WHO announced that the disease was under control.

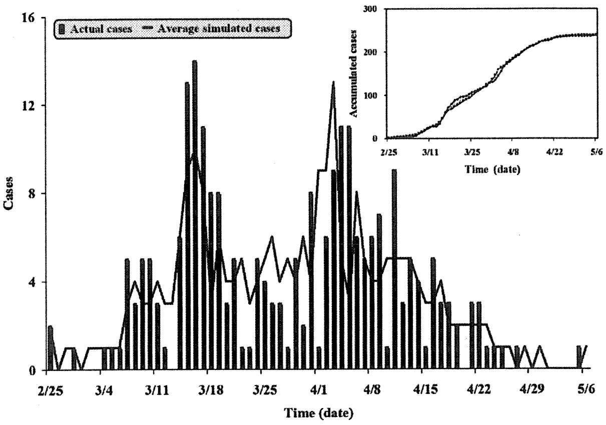

Fig. 3. A comparison of actual and simulated epidemic results for the SARS outbreak in Singapore. Blue bars represent actual reported cases, red line represents an average of results from 20 simulation runs.

4.2 Experiment 2: Analyzing Public Health Policies

The Singaporean and Taiwanese governments implemented temperature measurement policies during the SARS epidemic, going so far as to launch national campaigns that included installing temperature-monitoring equipment and setting up manual temperature measurement stations at various government buildings, clinics, and public transportation facilities. According to our simulation results, when such policies were both comprehensive and compulsory they reduced the number of feverish individuals entering public places. However, in the real world this policy is difficult to set up and enforce, since implementation methods tend to vary, oversights are common, and an unknown number of individuals manage to avoid having their temperatures taken. Our results suggest that a participation rate of between 80 and 90 percent is required for this public health policy to have a positive effect in controlling a SARS epidemic (Fig. 4); it had little effect at a rate of 65 percent or lower. The policy also incurs significant social costs that include distributing thermometers, setting up temperature screening stations, and employing workers to take manual temperature measurements at various public facilities and medical clinics.

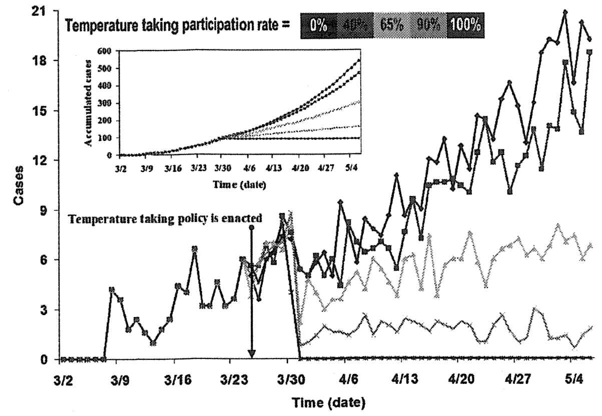

Fig. 4. Results from an instructional simulation experiment focused on temperature measurement policy at different participation levels. We used the eight imported cases reported in Singapore to trigger the simulation. In each 66-day simulation run, the policy was activated on day 24.

4.3 Experiment 3: Assessing Public Health Policy Suites

Different public health policies entail different social costs. Home quarantining is very effective, but requires considerable amounts of labor and material resources compared to temperature measurement and mask-wearing policies. Novices ran simulations of various prevention strategies in order to identify an optimal combination of public health policies in terms of efficiency and cost. According to results, a combination of mask wearing by the general public and reduced contact in public places was the best combination for suppressing the spread of disease (Fig. 5). Enforcing a mask-wearing policy entails some social and financial costs, but limited public contact does not. Furthermore, masks address epidemics at their sources—disease transmission.

A combination of temperature measurement, restricted hospital visitations, and mask-wearing by healthcare workers should be considered a remedial reaction to a contagious disease outbreak, since it does not stop patients who are in the incubation stage or suffering from minor symptoms from spreading the disease to others. In addition, this policy suite requires substantial amounts of labor and material resources. The combination of home quarantine and reduced contact in public places has high social costs, with results dependent upon how well the isolation guidelines are followed. Numerous instances of intra-family infections were reported during the actual 2002-2003 SARS outbreak—evidence that certain prevention strategies were ineffective in controlling the epidemic.

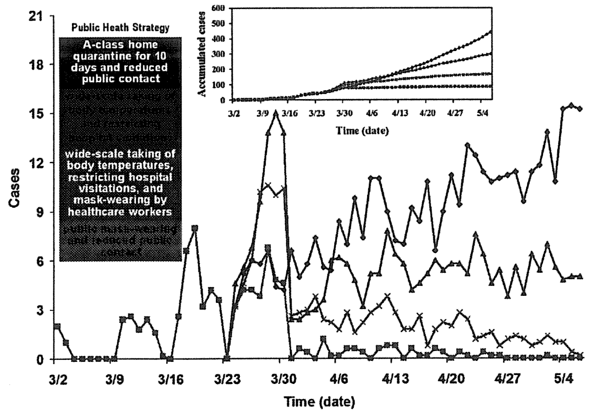

Fig. 5. A comparison of various public health policy suites in third instructional simulation experiment. We used the eight imported cases reported in Singapore to trigger the simulation. Policy suites went into effect on day 24 of our 66-day simulations. Suite 1 (cyan): A-class home quarantine for 10 days and reduced public contact; suite 2 (red): wide-scale taking of body temperatures and a restriction on hospital visitations; suite 3 (green): wide-scale taking of body temperatures, a restriction on hospital visitations, and mask-wearing by healthcare workers; suite 4 (pink): public mask-wearing and reduced public contact.

5 Conclusion

The use of computer-based social simulations to explore social science issues has increased rapidly in the past two decades. In this paper we described three sets of instructional experiments using the CASMIM simulation system for training or otherwise assisting public policy decision makers and epidemiological researchers. Results show that a combination of computer-based social simulation and our instructional experiments can assist learners to achieve their constructivist learning goals. Our instructional experiment results indicate that the CASMIM simulation system meets the requirements of epidemiologists and health policy specialists for analyzing potential epidemic prevention strategies. We believe CASMIM and our experimental sets can assist individuals with little experience in the area of simulation to construct epidemic models for specific and emerging epidemics, and help them to identify appropriate health policies for epidemic suppression.

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