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COMMUNICATION TECHNOLOGIES AND THEIR EFFECT ON CULTURAL HOMOGENEITY, CONSENSUS, AND THE DIFFUSION OF NEW IDEAS

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ABSTRACT: *A view of communication technologies as creating artificial agents and affecting the information-processing capabilities of agents is forwarded. The constructural theory is adapted to account for agents varying in their information-processing capabilities and, hence, to account for technology. Given this theoretical modification, the constructural model is used to examine the impact of different communication technologies and sociocultural landscapes on the rate at which information diffuses and the time it takes for the society to reach cultural homogeneity and consensus. The findings suggest that as the available communication technologies change, the role of the sociocultural landscape in effecting social change varies. Paradoxically, this research suggests that mass-communication technologies that enable greater competition among messages and greater message complexity will enable faster information diffusion than will those technologies that inhibit competition and message complexity.*

INTRODUCTION

A group of friends leaves the theater and begin discussing the play they have just seen, *West Side Story*. "What a poignant portrayal of racial tension in the inner city" says one. "Well," says another, "I think it was a better rendition of Shakespeare's *Romeo and Juliet* than the original." On and on the comments go. Interpretation aside, it appears that each individual learned something different from the play. Contrast this "actuality" with the common assumption made by the government when it broadcasts the emergency alert signal: that through telecommunication channels such as radio and television, the majority of the society will be reached with the same message—"here's what to do in an emergency." One expects different individuals to learn different information when ideas are passed by word-of-mouth.

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Rumors, for example, are routinely distorted. However, most people expect less distortion when the ideas are presented by mass media (debates such as that between the friends who saw *West Side Story* not withstanding).

As communication technologies emerge, different patterns of social behavior are expected to emerge. Newspapers, for example, were once expected to shape the beliefs of the masses (Lippman 1922) and, therefore, to have the potential to possibly create a homogeneous culture, but today's resultant culture is hardly homogeneous. The phone was expected to facilitate within-house communication and so minimize interaction with servants, but it is instead used to keep families in contact (del Sola Poole 1977). Indeed, such technologies may alter some of the fundamental ways in which education and the ties between individuals affect social behaviors such as cultural-homogeneity, consensus, and diffusion. Clearly there is an expectation that mass-communication will lead to more rapid information exchanges and to more individuals simultaneously acquiring the same information (Williams 1961). Therefore, mass-communication technologies should increase the rate at which information is diffused and homogeneity and consensus are achieved. However, communication technologies are not the sole determinants of social behavior, even the behavior that emerges from interaction. Rather, as is frequently noted, interaction and social behavior are affected by a host of other factors (see, e.g., Axelrod 1984; Blau 1967, 1977; Homans 1950; Turner 1988). Many of these factors are structural—for example, the size of the population. Still other factors are cultural—for example, the complexity of the culture. These factors also affect the rate of social change. At issue is whether communication technologies and the sociocultural landscape interact with each other in effecting social change.

This article presents a theoretical examination of this issue. The impact of various aspects of communication technologies and sociocultural landscapes on cultural homogeneity, consensus, and diffusion are examined using simulation. This examination takes place using a modification of the constructural model (Carley 1990, 1991a). Constructuralism is a dynamic processual theory of social change that provides an integrated and dynamic view of cognition, interaction, and the sociocultural environment in which the environment through interaction affects cognition, which motivates interaction, which alters the environment. Previous studies have shown that constructuralism: (1) predicts change in interaction over time better than either balance theory or exchange theory (Carley 1990); (2) is consistent with a wide range of results on social interaction (Carley 1991a); and (3) is consistent with research on intergenerational tension (Carley 1991b). The implications of the constructural perspective for societies affected by print and authoring has been examined in detail by Kaufer and Carley (1993). Here, I expand the constructural framework to include at least the rudiments for dealing with technology. Then, using the expanded theory (and the associated expanded model), I explore the implications of this theory regarding the ability of communication technologies to effect social and cultural change.

This article brings together two largely disconnected lines of research—that on social structural influences on information diffusion and that on communication

technologies. The concern here is with that aspect of sociocultural change (changes in homogeneity and consensus) that results from the diffusion process. Thirty years ago, Katz, Levin, and Hamilton (1963:238) argued that the "underlying assumption was always that informal communication among adopters was the key to diffusion." A great deal of research has added specificity to this claim, finding that ties between individuals are important to information flow. Yet, while many researchers acknowledge the importance of social structure to the diffusion process (Rapoport 1953), there are relatively few studies of how the social structure affects information diffusion (Rogers 1983:25). Notable exceptions, however, have shown that differential levels of within- and between-groups ties, the strength of ties among individuals, and the level of integration impact information diffusion (see, e.g., Becker 1970; Burt 1973, 1980; Coleman, Katz, and Menzel 1966; Granovetter 1973, 1974; Lin and Burt 1975). Whereas this literature demonstrates the role of social structure (and, to a lesser extent, culture) in effecting social change through information diffusion, it ignores the role of communication technology. The dominant underlying model of communication that pervades this work is one-to-one, face-to-face communication.

In contrast, the literature on communication technologies largely ignores the role of the extant sociocultural landscape. Instead, much of the literature focuses on technological features and usage (Enos 1990; Rice and Case 1983; Sproull and Kiesler 1986), its psychological and social-psychological consequences (Eisenstein 1979; Freeman 1984; Goody 1968; Kiesler, Siegel, and McGuire 1984; Rice 1984), or historical accounts (Innis 1951; del Sola Poole 1977; Reynolds and Wilson 1968). Admittedly, a common question asked is whether communication technologies will replace or enhance existing networks or social structures. Further, predictions and evidence regarding changes to social structure abound, such as: that print made possible the professions by enabling regular and rapid contact (Bledstein, 1976), or that electronic communication increases connectedness and decreases isolation (Hiltz and Turoff 1978). The question at issue here has not been asked: *Is there an interaction between structure and technology—that is, does the type of sociocultural landscape that facilitates rapid diffusion (and, so, homogeneity and consensus building) change as the type of communication technology available changes?*

AUGMENTING THE THEORY: CONSTRUCTURALISM AND TECHNOLOGY

According to constructuralism, both the individual cognitive world and the sociocultural world are continuously constructed and reconstructed as individuals concurrently go through a cycle of action, adaptation, and motivation. During this process, not only does the sociocultural environment change, but social structure and culture coevolve in synchrony.

Carley (1991a:332-336) defined the following primary assumptions in describing constructuralism:

1. Individuals are continuously engaged in acquiring and communicating information.
2. What individuals know influences their choices of interaction partners.
3. An individual's behavior is a function of his or her current knowledge.

In addition to these primary assumptions, there were a series of implicit assumptions that upon explication serve to clarify and expand the primary assumptions.[1] Following is an expanded list of assumptions, numbered to clarify their relation to the primary assumptions:

1a. Individuals, when interacting with other individuals, can communicate information.
1b. Individuals, when interacting with other individuals, can acquire information.
1c. Individuals can learn the newly acquired information, thus augmenting their store of knowledge.
2a. Individuals select interaction partners on the basis of relative similarity and availability.
2b. Individuals engage in interaction concurrently (thus, an individual's first choice of interaction partner may not be available).
3a. Individuals have both an information-processing capability and knowledge, which jointly determine each individual's behavior.
3b. Individuals have the same information-processing capabilities.
3c. Individuals differ in knowledge as each individual's knowledge depends on his or her particular sociocultural and historical background.
3d Individuals can be divided into types or classes on the basis of extant knowledge differences.

As axiomatized, constructuralism has little to say about the role of communication technologies. Working within the constructural framework, however, we can begin to address the effect of technology. In order to do this, the constructural theory needs to be augmented by: (1) broadening the notion of individuals to the notion of agents, and (2) adding assumptions relating technology to agent capabilities.

As White (1992:8) notes, "Persons ... are neither the first nor the only form in which identities appear." That is, individuals are not the only type of agent. *Agents* is a generic term referring to both real actors (human or animal) and artificial actors (either active ones such as robots or organizations, or passive actors such as books). According to Carley and Newell (1994), agents can be characterized in terms of their information-processing capabilities (that limit what the agent can do) and knowledge (that determines, within these limits, what the agent will do). As axiomatized, constructuralism focuses on how the information-processing capabilities of a certain type of agent—individuals—result in social change. To extend constructuralism, other classes of agents must be added and assumptions

about individuals must be either generalized to general agent behavior or treated as a special case peculiar to a class of agents. Programatically, when we think in terms of agents' assumptions, the list of foregoing assumptions change. Assumptions 1a through 1c are seen as dependent on the information-processing capabilities of the agent and, so, peculiar to only certain classes of agents. For example, some agents may not be capable of learning. Assumptions 2a, 2b, and 3a are common for all agents. Assumptions 3b, 3c and 3d should be altered as follows:

3b′. All agents within a particular class have the same information-processing capabilities.
3c′. Agents differ in knowledge as each agent's knowledge depends on the agent's particular sociocultural-historical background and information-processing capabilities.
3d′. Agents can be divided into types or classes on the basis of extant differences in either or both their information-processing capabilities and knowledge.

Consider the impact of technology. Technologies, particularly communication technologies, can be characterized by the way in which they alter existing agents (add/delete capabilities) or create new artificial agents. Thus, to begin to encompass technology, constructuralism can be augmented by adding the following assumptions:

4. Technology can alter the information-processing capabilities of existing agents.
5. Technology can, though need not, create artificial agents with unique information-processing capabilities.
6. Technology can alter both what knowledge is available and its initial distribution across the population.

Let us consider these assumptions. According to assumption 4, technology can enhance (or degrade) an agent's information-processing capabilities. Such capabilities include, but are not limited to, how much information an agent can process, and with how many others the agent can communicate simultaneously.[2] Radio and television, for example, increased a speaker's opportunities to communicate to the masses. Technology can, as suggested by assumption 5, create artificial agents. An example is the robot, which has a limited ability to follow instructions. More to the point, technology creates "agents" by extending the human agent. A book,[3] for example, can be viewed in this light. The author writes a book and so encapsulates, in an essentially unchanging fashion, some of the author's knowledge at that point in time. The book, as agent, can engage in multiple simultaneous interactions (as multiple people read different copies) and has a unique set of interaction-processing capabilities: to wit, it cannot select a partner but must be selected, and it can send information but neither receive information

nor learn. The book qua agent is very static. It follows from assumptions 4 and 5 that, given the peculiarities of a certain technology, assumptions 1a through 1c may change. As to assumption 6, note that as technologies emerge, new concepts, methods, and vocabulary (all components of knowledge) also emerge. There is also a more subtle effect. The agents who use the new technology—such as the first "authors" after the advent of the printing press or the first users of electronic mail—engage in the exchange of the new knowledge associated with that technology and create new ideas, which they disseminate using the new technology. Only those who have access to the new technology have initial access to these new ideas.

Collectively, these assumptions increase the theory's flexibility. Even though these assumptions suggest that technology can change the agents' information-processing capabilities (and, hence, whether they can select interaction partners), they do not suggest that technology alters the agents' basis for selecting interaction partners. Thus, agents which can select partners, still do so on the basis of relative similarity and availability. Technology alters agent availability and knowledge and so influences who is chosen as a partner when, but not how partners are chosen. Agents discriminate among other agents only in terms of relative similarity and availability; thus, an artificial mass-communication agent (such as a book) relative to the single human agent has an advantage—it is widely available. However, this artificial agent is also disadvantaged—its knowledge is unchanging and so will, over time, become less relatively similar to other agents who, like humans, are capable of learning.

INCLUDING TECHNOLOGY IN CONSTRUCTURAL MODEL

This paper takes as its starting point the formulation of the basic constructural model presented, supported, and analyzed in detail by Carley (1990, 1991a). Here, only a brief outline of the basic model will be presented, along with a more detailed discussion of those portions of the model that are altered by the new assumptions.

According to the basic formulation, there is a fundamental interaction-shared knowledge cycle in which the agents engage. During this process, the agents continually cycle through the three phases of action, adaptation, and motivation. During the action phase, agents can communicate to, and receive information from, their interaction partners. During the adaptation phase, agents can learn, augment their knowledge, and as a result cognitively reposition themselves in the sociocultural environment. During the motivation phase, agents select potential interaction partners.

Now, consider how agents' information-processing capabilities can affect their behavior during each phase of this cycle. During the action phase, an agent's capabilities determine whether the agent can communicate or receive information, how much information can be communicated or received, and how many interaction partners can be simultaneously accommodated. During the adaptation phase, an agent's capabilities determine whether the agent learns (or forgets), the procedure for learning and whether the learning results in any repositioning.

Finally, during the motivation phase, an agent's capabilities determine whether the agent tries to select an interaction partner and, if so, how many partners are selected.

In order to further specify the changes in the basic model, various technologies and the associated classes of agents are considered next. The particular technologies of interest are communication technologies. Research has demonstrated that various communication technologies can have profound social, and even psychological, consequences (see, e.g., Price 1965; Rice 1984; Sproull and Kiesler 1991). Such consequences are dependent on various features of the technology. One salient feature of many such technologies—such as books, television, and radio—is that they enable mass-communication or one-to-many communication. Another salient feature of many communication technologies—such as books or video tapes—is that they enable some of an individual's ideas to remain intact and unchanged over time and to be communicated without the individual being present, thus admitting communication at great geographical and temporal distances (Kaufer and Carley 1993). By examining a set of communication technologies, each with different salient features, classes of agents can be defined. For the sake of discussion, each class of agent that is examined in this paper has been given a name that characterizes the dominant feature:

- *People:* These agents are capable of only one-to-one communication, can select interaction partners, and can learn. These agents can interact with only one other agent during a particular Time Period and during this interaction can both send and receive information.
- *Books:* These agents are capable of one-to-one or one-to-many communication, cannot select interaction partners, and cannot learn. These agents, during a single Time Period, can interact with all of the agents by whom they are chosen as interaction partners and during this interaction can only send information.
- *Orators.* These agents are capable of one-to-one or one-to-many communication, can select interaction partners, and can learn. These agents can interact with one or more other agents during a particular Time Period and during these interactions can send information to all the listeners but can receive information from only one "speaker."

Clearly, these agents do not span the space of all possible agents. These agents are stylized such that they separate two communication characteristics of interest—one-to-many interaction and learning. Books, unlike individuals (i.e., people or orators), cannot learn. People, unlike mass-communicators (i.e., books or orators), cannot engage in one-to-many interactions. Further, these agents are interesting from a sociohistorical perspective as they have well-defined analogs in the real world and/or are associated with major historical periods.

The class *people*, for instance, corresponds to the basic human scenario sans technology. Each agent has a base of knowledge which can be communicated to

others and which grows as information is acquired from others (i.e., they learn). Such communication occurs slowly—for example, during face-to-face interactions. A society of such agents corresponds, roughly, to a preprint, pre-telecommunications world where individuals are prohibited from gathering en masse to listen to a speaker. Another analog is the small group engaged in a task requiring only individual exchanges and no group meetings.

In contrast, the class *books* corresponds to the agents made possible by the modern printing press circa 1450 (see Kaufer and Carley 1993). Books are Giddens' (1987:216) cultural object, where the culture or information is separated from the source. Books as agents are unalterable in their knowledge but infinitely available. A society composed exclusively of such agents would correspond to a library, the works of knowledge growing covered with dust as they remained unused and unchanged over time. A society composed of people and books, which is what is examined in this article, is more interesting in that, although the books cannot change, the people can as they read the published books.

Finally, the class *orators* corresponds to a basic mass-communication society. These agents each have a base of knowledge which they can communicate to others and which grows as they acquire information from others, and learn. Such communication can occur slowly or quickly, depending on whether the agent is engaged in a two-way exchange of information to a single other or "teaching" to a crowd. A society of such agents corresponds, roughly, to a scholarly convention or a technologically enhanced community, where through telecommunication each individual can communicate with a single other, gather en masse and listen to a speaker, or be the speaker communicating to the gathered crowd. Another analog is the small group engaged in a task that requires both one-to-one interactions and group meetings.

Despite these technologically induced differences, these three different classes of agents have similarities. Many of these similarities take the form of additional constraints on communication and learning. These constraints, in effect, are the simplifying assumptions made in the basic constructural model. All agents, when they communicate, send a single piece of information, and all information known by the agent is equally likely to be communicated. Person-person, person-book, and person-orator communications all take the same amount of time. None of the agents forget, and learning (when it occurs) is perfect.

Let us now consider some of the theoretical implications. According to this theory, asymmetries in two agents' probabilities to interact with each other can occur simply because (1) each agent evaluates his or her probability to interact with the other relative to his or her relationship to all other agents in the society, and (2) two agents may have different relationships to others in the society (i.e., their ego networks differ). In other words, relative evaluation in addition to differential information-processing capabilities, given different ego networks, produces asymmetric behavior. Imagine that information is distributed unequally across the society—that is, some agents know more than others know. Then, for a particular pair of agents, the agent who knows more is less likely to initiate

interaction than is the agent who knows less (assuming both agents can initiate interaction). Therefore, over time, since individuals can learn and books cannot, individuals will become less likely to choose the book over another individual as an interaction partner. If an individual makes a discovery (new information) and does not put it in a book, since individuals can learn, over time the individual will become less likely to tell others of the discovery. In contrast, if the discovery appears in a book, since books do not learn, the book will remain constant in "its tendency" to communicate the discovery. The book's message does not become "diluted" over time as it cannot start to communicate other messages.

DESIGN OF STUDY

The constructural framework is used to examine the relative impact of communication technologies and the sociocultural environment in effecting social change at the rate at which information diffuses and cultural homogeneity and consensus are achieved. In order to do this, two definitions are needed. First, the simulated societies and the classes of agents within them need to be described. Second, measures need to be defined for these rates.

Characterizing Societies

In order to simplify this analysis, I will consider societies that can be characterized as single group societies; that is, there are no barriers to communication in the form of different predefined within- and between-groups ties. Individuals, however, will vary in the strength of their ties with other individuals, based on differences in what they know. Within these societies, factors that can effect change are the size of the population (number of people), the complexity of the culture (number of pieces of information), the initial level of education (percentage of possible knowledge known by an individual; hence, the average strength of tie among the individuals in the society, and the available communication technologies. To understand the impact of sociocultural environment, a set of societies varying in these dimensions was simulated. Specifically, the societies had either 6, 12, or 18 individuals (variable Population); a culture composed of either 10, 20, or 30 pieces of information (variable Cultural complexity); and, the pieces of information were distributed such that each person initially knew either 25%, 50%, or 75% of the pieces of information in the culture (variable percent Known). This last variable, percent known, can be interpreted as the level of initial education. Neither these variables nor combinations of them are auto-correlated (see Table 1).

Each society was examined under six communication scenarios. In the first scenario, one-to-one, all individuals in the society fall into the class "people." The innovator's message contains a single idea—the new idea. In the second scenario, 1 simple book, there are two types of agents—people and books. There is a single book, which contains only one piece of information—the innovator's new idea. All other agents in the society fall into the class called people. The third scenario, 2 simple books, is like the 1 simple book scenario but with a second book that

TABLE 1
Pearson Correlation Matrix

	P	C	K	PC	PK	CK	PCK
P	1.000						
C	-0.000	1.000					
K	0.000	-0.000	1.000				
PC	0.577	0.756	0.000	1.000			
PK	0.679	-0.000	0.679	0.392	1.000		
CK	0.000	0.756	0.577	0.571	0.392	1.000	
PCK	0.471	0.617	0.471	0.816	0.694	0.816	1.000

Note: These correlations are identical regardless of the type of communication scenario. For each type of communication scenario, the number of observations is 27.

contains another innovator's new idea. In the fourth scenario, 1 complex book, there are two types of agents—people and books. There is a single book, which contains 5 pieces of information—the innovator's new idea and 4 other ideas known by the innovator and some other individuals in the society. All other agents in the society fall into the class called people. The fifth scenario, 2 complex books, is like the 1 complex book scenario but with a second book that contains another innovator's new idea and 4 other ideas. In the sixth scenario, one-to-many, all agents fall into the class "orators." In this case, the innovator's message is quite complex and contains all the information known by the innovator including the new idea.

As previously noted, the agents in these scenarios separate two important aspects of how communication technologies affect agent capabilities—the ability to learn and the ability to communicate to multiple individuals at once. In addition, the specific communication scenarios described vary along two other dimensions—competition and complexity. That is, in the 2 simple book, 2 complex book, and one-to-many scenarios, the mass-media agents implicitly compete with each other for the scarce resource "other individuals' time." Any individual having access to a one-to-one communication technology competes with others for a specific person's time, but since only two individuals can interact with each other at a time, there is no competition for groups as there is in the case of the mass media. Further, in the (1 or 2) complex book and the one-to-many scenarios, the message that is being simultaneously communicated is more complex. In these scenarios, each of the "listeners" or "readers" may be learning something different from the "speaker" or "text." In the other scenarios, each individual is learning exactly the same piece of information.

By setting up the societies in this way, a 3X3X3X6 experimental design has been constructed. Each cell is a society uniquely characterized by its sociocultural landscape and the classes of agents as defined by the communication technologies. A Monte Carlo approach is taken for estimating the mean of each cell. Each society

examined was simulated 100 times, thus making the variance within a cell negligible. Any measures of social change measured for a cell represents the average behavior across 100 societies. Due to processing constraints, the behavior of each society was measured for 500 time periods. At this point, the vast majority, but not all, of the simulated societies had reached their ultimate states.

Measures of Sociocultural Change

Many different societal-level behaviors can be measured. I focus on those previously identified as being potentially affected by communication technologies—that is, cultural homogeneity, consensus, and diffusion. As previously noted, communication technologies are expected to effect the rate at which a society achieves these factors. That is, a common suggestion is that mass-communication technologies enable the agent to communicate one-to-many and, therefore, will speed things up. Mass communication should decrease the time to cultural homogeneity, the time to consensus, and the time it takes a new idea to diffuse, relative to the time it would take if agents could only communicate one-to-one. In addition, one might expect that the more information that is available through mass-communication technologies (in other words, the higher the number of books, the more orators, and so on), the faster the society becomes culturally homogeneous and consensual. In other words, more information, more quickly communicated, will generate rapid cultural homogeneity and consensus. Or, one might expect that the more information that is available through mass-communication technologies, the slower the society will become culturally homogeneous and consensual. The argument is that increased information increases the competition among ideas for an individual's attention. This increased competition may mitigate any advantages gained by the increased speed of communication. Thus, one might also expect that as mass communication becomes more prevalent, particular ideas will diffuse slower due to the increased competition among ideas. One might also expect that the diffusion of a new idea will be abetted by having agents who know only the new idea and cannot learn (i.e., simple books) as such agents cannot dilute the message. In contrast, one might expect that the diffusion of a new idea wil be abetted by having orators, as they can learn the new idea and then rapidly disseminate it. Clearly, other expectations also exist. But notice that, when we consider only how communication technologies affect agent capabilities, a series of often-contradictory expectations seems to arise. We can examine these expectations and locate a set of internally consistent expectations (in that they all follow logically from the same model) by utilizing the constructural model.

In order to precisely define measures of the rate of information diffusion and the rate at which homogeneity and consensus are achieved, I use the following variables:

K = the number of pieces of information such that each piece is known by at least one agent in the society.

I = the number of individuals in the society.
$F_{ik}(t)$ = whether individual i knows piece of information k at time t. $F_{ik}(t)$ equals 1 if i knows piece of information k at time t, otherwise 0.
V_k = the force of the piece of information k relative to the decision that is to be made. V_k equals 1 if the piece of information k suggests that the decision should be positive, −1 if the piece of information k suggests that the decision should be negative, and 0 if the piece of information k suggests that the decision should be neutral.
$B_{ii}(t)$ = individual i's actual decision (or belief) at time t.
$B_{ij}(t)$ = individual i's view of individual j's decision (or belief) at time t.

As an aside, it is important to note that the proposed measures can be calculated either for each group or for the entire society. For comparability across all societies examined, I calculate these measures using only the individuals (i.e., societal agents capable of learning).

Diffusion

Diffusion occurs when a new idea discovered by one individual becomes known by others in the society. There exists a single innovator—an individual who discovers a new idea—in each of the societies examined. Initially, this idea is known only by the innovator. If the innovator is in a society with books, the innovator may "write" a book that contains the new idea (and, perhaps, other information). Each time period, the level of diffusion is measured as the number of individuals sharing at least one of the ideas the innovator places within the message.

Cultural Homogeneity

At each time period, the level of cultural homogeneity is the average percentage of available information shared by any two individuals (see also Carley 1990, 1991a). Mathematically, this can be stated as:

$$\textit{Cultural homogeneity } (t) = \frac{\sum_{i=1}^{I}\sum_{j=i+1}^{I}\sum_{k=1}^{K} F_{ik}(t) \times F_{jk}(t)}{\binom{I}{2} \times K} \times 100.$$

Consensus

At each time period, the level of consensus is simply the percentage of unique dyads having consensus. Consensus is defined using a fixed valuation scheme. The underlying conception is that each individual needs to make a decision. This decision takes the form of an "answer" (yes, no, or neutral) to some "question." Each of the available pieces of information can influence this decision. Each piece

of information either: provides support for the affirmative decision, supports the negative decision, or provides no support. This support is defined as the valuation for that piece of information. These values are randomly distributed across the pieces of information such that half the facts have a +1 value and half have a −1 value. All individuals with access to the same information are expected to make the same decision (hold the same belief); thus, the valuation scheme is constant across all individuals in the society. The individual's decision is determined for each individual as the sign of the sum of the information known by the individual weighted by the value of each piece of information. Mathematically, this can be stated as:

$$1 \text{ if } \sum_{k=1}^{K} V_k F_{ik}(t) > 0$$

$$B_i(t) = 0 \text{ if } \sum_{k=1}^{K} V_k F_{ik}(t) = 0$$

$$-1 \text{ if } \sum_{k=1}^{K} V_k F_{ik}(1) < 0$$

Two individuals are said to concur at a particular time, just in case their decisions are the same. Consensus is thus measured as:

$$Consensus\ (t) = \frac{\sum_{i=1}^{I} \sum_{j=i+1}^{I} B_i(t) = B_j(t)}{\binom{I}{2}} \times 100.$$

Over-Time Performance

Consider first the behavior of each of these measures over time. For example, Figure 1 shows the over-time behavior of a representative society. These patterns are typical of all societies examined. That is, eventually, for the societies examined, every individual will end up knowing all the information that anyone else knows (Carley 1990, 1991a). Thus, eventually, cultural homogeneity, consensus, and diffusion will be 100%. Moreover, for all societies examined, regardless of the sociocultural landscape or the communication technologies, the basic shape of the curves remains the same. What does vary across societies is the location of particular peaks and valleys and the time required to reach (or almost reach) the ultimate condition.

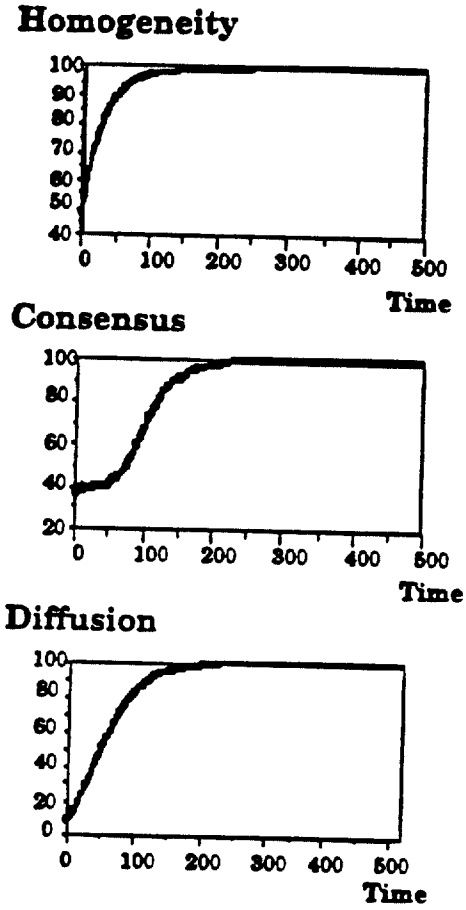

Figure 1

Given that the shape of the curve is the same, the operational question becomes: at what time does the society reach (or almost reach) the ultimate condition.[4] Three over-time measures are used:

1. *Time to Diffusion* - the time at which 90% of the individuals share at least one fact with the innovator.
2. *Time to Cultural Homogeneity* - the time at which the average number of facts shared by any two individuals is 90% of the total number of facts.
3. *Time to Consensus* - the time at which 90% of the dyads have reached consensus.

These near-end measures are used, rather than the time until the ultimate condition occurs, for two reasons. First, ultimate measures can be afflicted by

recalcitrant learners—namely, the lone individual who is missing one fact and must wait until someone happens to locate this fact. Second, given the cap of 500 time periods, the near-end value is a more accurate behavioral predictor.

COMMUNICATION TECHNOLOGIES: DETERMINANTS OF CHANGE

The results demonstrate that mass communication does speed things up. In addition, the type of communication technology has other more subtle effects. First, consider each of the three factors (population, cultural complexity, and percent known) separately, as shown in Figures 2-4. In each of these figures, the time to cultural homogeneity, consensus, and diffusion is shown by plotting the average time for all societies with a given characteristic. For example, in Figure 2, we see that the average time to diffusion for all societies with a population of size 6 is just over 100. Recall that there are 54 (3X3X6) types of societies (each simulated 100 times) at each population level. The average is across all 5,400 of these societies.

Essentially, the "pattern" that appears in these three figures is the same regardless of the communication scenario. That is, as the population increases, the time to cultural homogeneity and consensus decreases and the time to diffusion increases (see Figure 2). As the complexity of the culture increases, the time to cultural homogeneity, consensus, and diffusion increases (Figure 3). As the percent known by the individual increases, the time to cultural homogeneity and consensus decreases and the time to diffusion increases (Figure 4).

The communication scenario changes the time required to achieve the final condition. Figure 5 shows the average time for each of the three measures, given a particular communication scenario across all types of sociocultural landscapes (27). The figure shows that things occur most quickly when all individuals in the society are orators. Just having a mass-communication technology available is not sufficient. Both competition among innovators having access to the mass-communication technology and the complexity of the information in the mass communications affects how fast social change occurs. Mass-communication technologies can speed things up, but only under the right conditions.

Now consider interaction effects. The various interaction terms are as follows. The combination *population * cultural complexity* reflects the number of possible sociocultural ties that an individual can have. *Population * percent known* reflects the probable number of individuals who will know a particular piece of information. *Percent known * cultural complexity* is the probable number of pieces of information initially known by each person. Finally, *population * cultural complexity * percent known* is the probable number of ties that each person initially has. In Tables 2, 3, and 4, the regression coefficients are shown when the sociocultural landscape variables are regressed on time to cultural homogeneity (Table 2), time to consensus (Table 3), and time to diffusion (Table 4). In each table, the first column examines all societies. The following six columns correspond to the six different communication

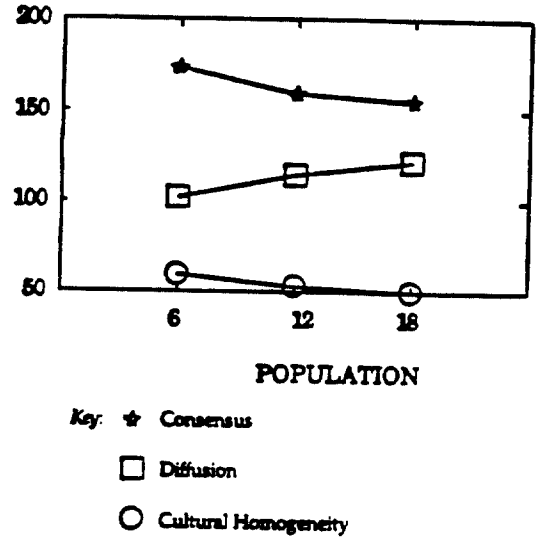

Figure 2
Impact of Population

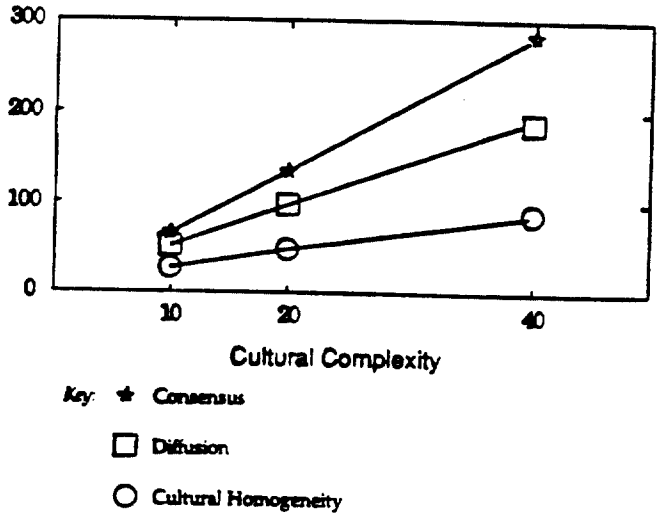

Figure 3
Impact of Cultural Complexity

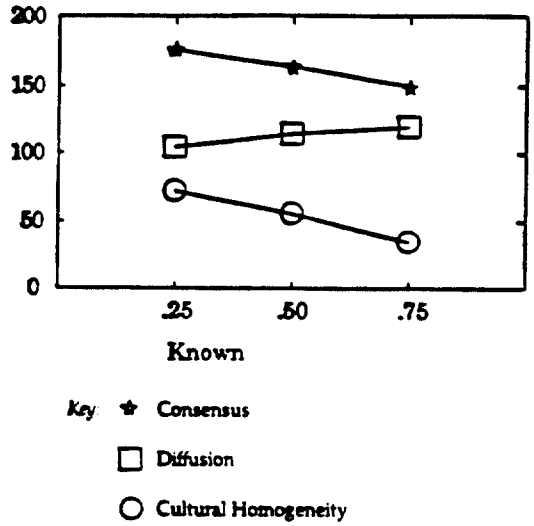

Figure 4
Impact of Education

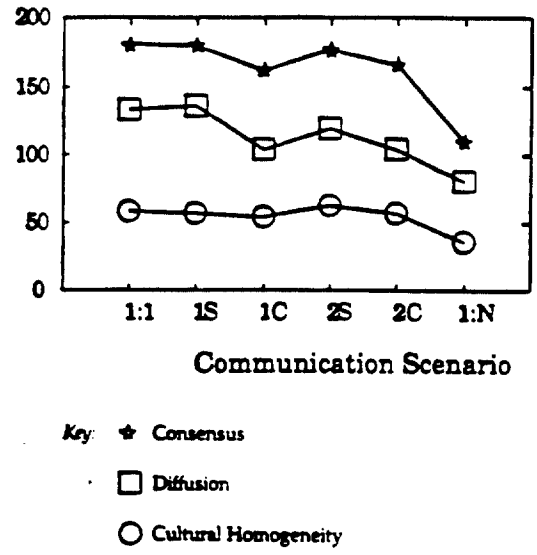

Figure 5
Impact of Communication Scenario

TABLE 2
Predictors of Time to Cultural Homegeneity

	Overall	*1:1*	*1 Simple*	*1 Complex*	*2 Simple*	*2 Complex*	*1:N*
R2	.904	.996	.997	.997	.997	.997	.998
P	-0.018	-0.035	-0.006	-.072	-0.071	0.060	0.030
C	1.766***	1.841***	1.837***	1.787***	1.847***	1.922***	1.793***
K	-0.004	-0.023	0.008	-0.066	-0.030	0.069	0.026
PC	-0.431*	-0.442***	-0.439***	-0.407***	-0.426***	-0.603***	-0.361***
PK	0.076	0.101	0.046	0.0118	0.151*	0.018	0.029
CK	-1.070***	-1.085***	-1.108***	-1.064***	-1.111***	-1.251***	-1.118***
PCK	.218	0.172	0.208*	0.188	0.218*	0.361**	.224*
N	16200	2700	2700	2700	2700	2700	2700

Note * $p < .1$, ** $p < .01$, *** $p < .001$ (two-tailed).

scenarios and show the results of a regression analysis performed on the mean for each type of society.[5] As can be seen in Tables 2-4, which variables are significant when all cross-terms are taken into effect remain essentially the same across all communication scenarios. As the complexity of the culture increases, it takes the society longer to reach cultural homogeneity. There is simply more for people to learn, and so it takes longer before they all learn it. However, increases in the number of possible ties and the amount of information initially known decrease the time it takes the society to reach cultural homogeneity. Essentially, the more possible ties, the more ways there are of potentially getting information; the higher the amount initially known, the less there is for people to learn. The communication technologies slightly alter the strength of these relations but leave the actual

TABLE 3
Predictors of Time to Diffusion

	Overall	*1:1*	*1 Simple*	*1 Complex*	*2 Simple*	*2 Complex*	*1:N*
R2	.849	.987	.986	.994	.982	.998	.989
P	-0.079	-0.047	-0.150	-0.085	-0.050	-0.068	-0.104
C	0.598**	0.602**	0.381*	1.123***	0.259	0.889***	0.783***
K	-0.065	-0.002	-0.146	-0.101	-0.013	-0.087	-0.073
PC	0.166	0.065	0.331	-0.161	0.504*	0.058	0.203
PK	0.049	-0.047	0.107	0.097	0.015	0.066	0.108
CK	0.090	0.116	0.335	-0.295*	0.420	-0.088	-0.097
PCK	.171	0.342	0.100	0.343*	-0.054	0.199*	0.176
N	16200	2700	2700	2700	2700	2700	2700

Note * $p < .1$, ** $p < .01$, *** $p < .001$ (two-tailed).

TABLE 4
Predictors of Time to Consensus

	Overall	*1:1*	*1 Simple*	*1 Complex*	*2 Simple*	*2 Complex*	*1:N*
R2	.905	.996	.996	.993	.996	.995	.995
P	-0.026	-0.015	-0.046	-0.063	-0.091	0.071	-0.015
C	1.376***	1.348***	1.271***	1.486***	1.377***	1.704***	1.438***
K	-0.027	0.005	-0.057	-0.049	-0.091	0.051	-0.035
PC	-0.348	-0.360**	-0.287*	-0.326*	-0.304*	-0.566*	-0.321***
PK	0.074	0.021	0.088	0.120	0.132	0.006	0.110
CK	-0.404*	-0.369**	-0.256	-0.469*	-0.347**	-0.633**	-0.479***
PCK	0.206	0.314*	0.214	0.128	0.149	0.25	0.242
N	16200	2700	2700	2700	2700	2700	2700

Note: * $p < .1$, ** $p < .01$, *** $p < .001$ (two-tailed).

relationships intact. In addition, mass-communication technologies, particularly those that are more competitive and complex, strengthen the potency of actual ties; in these cases, the greater the probable number of ties each person has, the longer it takes the society to become culturally homogeneous.

As the complexity of the culture increases, it takes longer for an innovative idea to diffuse. This is the dominant factor affecting diffusion. Basically, the more there is to know, regardless of the number of people who actually know each piece of information or how many people share how many pieces of information, the longer it takes the new idea to diffuse. The fundamental factor at work is that in a highly complex culture, there are more pieces of information implicitly competing for the attention of each individual. The higher the cultural complexity, the less likely that the new piece of information will be communicated and, so, learned. Mass-communication technologies—far from decreasing the effect of culture—actually increase the impact of culture. The more competitive and complex the communication scenario, the greater the impact of culture. In addition, complex communication scenarios have a tendency to strengthen the benefits of education and the potency of ties. Specifically, when these technologies are present, greater knowledge breeds faster diffusion and greater social contact breeds slower diffusion.

As the complexity of the culture increases, it takes longer for a society to reach consensus. However, increases in the number of possible ties and the amount of information initially known decrease the time it takes the society to reach consensus. Essentially, the more possible ties, the more ways there are of potentially getting information; also, the higher the amount initially known, the more likely individuals are not only to learn faster but also to learn the same things, and so concur. By and large, the communication technologies slightly alter the strength of these relations but leave them intact. However, when there is no mass communication (that is, the one-to-one scenario), the more actual ties, the longer

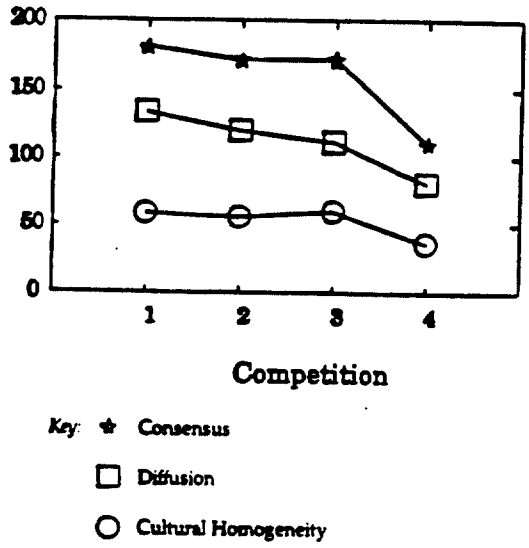

Figure 6
Impact of Competition

it takes the society to reach consensus. Basically, under this scenario, people tend to group together with their preferred interaction partners and, so, become more like the preferred partners and less like others. Mass communication mitigates this effect and the impact of amount known is strengthened by having a communication scenario that admits complex messages.

The potential impact of the competitiveness and complexity of the communication scenario has been alluded to. In Figures 6 and 7, the average time to cultural homogeneity, consensus, and diffusion are shown at each level of competitiveness and complexity. For competitiveness, there is a four-point scale range from no competition (one-to-one), slight competition (1 simple or 1 complex book scenarios), moderate competition (2 simple or complex books scenarios), and strong competition (orator society). Figure 6 shows the average time for each of the three measures, given a particular level of competition within a communication scenario, across all types of sociocultural landscapes. For communication complexity, there is a three-point scale ranging from low complexity (the message contains only the innovative idea, i.e., one-to-one and simple book scenarios) to moderate complexity (the message contains the innovative idea plus a few other ideas, i.e., complex book scenarios) and strong complexity (the message contains many ideas other than the innovative one, i.e., orator society). Figure 7 shows the average time for each of the three measures, given a particular level of complexity within a communication scenario, across all types of sociocultural landscapes.

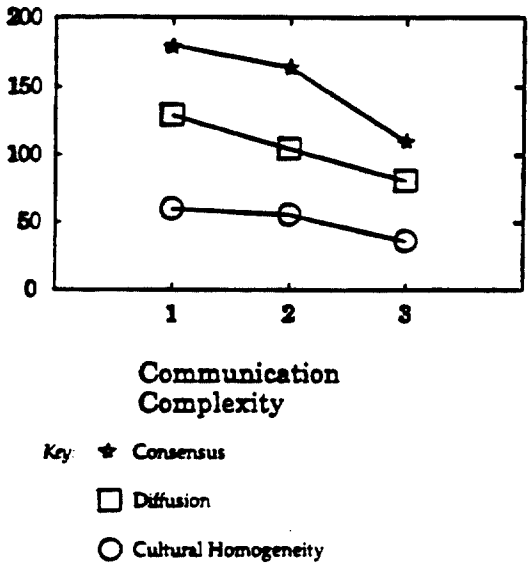

Figure 7
Impact of Communication Complexity

Together, Figures 6 and 7 show that increases in the competitiveness or the complexity of the communication scenario enable the society to more quickly reach cultural homogeneity and consensus. Competitiveness and complexity also enable new ideas to diffuse faster.

DISCUSSION

This paper has examined the relationship between communication technologies and the sociocultural landscape. The constructural model was adapted to examine the impact of communication technologies on social change. This adaptation was facilitated by thinking of technology as both forming new agents and altering the information-processing characteristics of other agents. This approach, far from personifying technology, is advantageous as it facilitates a systematic examination of the properties of the technology and the agent, making it possible to study what Collins (1979) has termed the *formal* and *informal* means of producing culture.

In pursuing this analysis, many important aspects of communication technologies were considered, including one-to-many communication, competitiveness, the complexity of the message, and the ability of the agent to learn and, so, adapt its message over time. The value of the current study lies, in part, in that it demonstrates a systematic procedure for considering the impact of these and other characteristics of communication technologies within the framework of a dynamic model of individual and social behavior. Nevertheless

many aspects of communication technologies have not been considered. Such aspects include, but are not limited to: the extent to which a technology serves to expand the agent's memory and, thus, mitigates any impacts due to forgetting; the extent to which the technology does not admit certain types of messages to be communicated; the extent to which the technology hides or makes ambiguous various status cues, and so forth. Future studies may consider these and other characteristics. Such studies would give us a better understanding of the factors affecting knowledge diffusion and cultural production.

Finally, the impact of communication technologies on information diffusion may be even greater than that portrayed in this study. Here, the measure of diffusion was examined over time until 90% of individuals had learnt all the ideas in the message. The more complex the message, the more that individuals must learn before we can say that the message has been diffused. Nevertheless, message complexity leads to more rapid diffusion of a single novel idea. If the communication technology enables more complex messages, the rate of diffusion may increase over that shown here.

CONCLUSION

This study suggests that simply having a mass-communication technology available is not sufficient to effect positive social changes. Putting a new idea in print or making it available in a film, without tying it to the current culture, actually makes it harder for individuals to learn the new idea. The "book" will simply grow dusty waiting for readers. The readers, having nothing in common with the book, have no motivation to interact with it other than chance, so the new idea will languish. Making the book more complex, putting multiple messages in it—some of which are known already by at least some of the individuals in the society—actually makes it easier to diffuse the new idea. This is true even though different individuals may emerge from interacting with the book with different ideas. The reason is simple: the more complex the message, the greater the likelihood that a majority of the individuals in the society will recognize something in the message and, so, be willing to interact with it further. This increases the likelihood of the new idea diffusing. Moreover, such complexity facilitates the rapid emergence of cultural homogeneity and consensus. Mass communication of a complex message simultaneously reinforces to multiple members of the society the information known already by a few.

Ironically, competition for an audience speeds diffusion. The more books in print, the more films, and the more radio shows, the faster innovative ideas diffuse. Although it is not clear from the analyses run in this study, such competition actually may be detrimental to the rapid emergence of cultural homogeneity and consensus, because each new competitor brings a new idea, thereby increasing the cultural complexity. However, holding cultural complexity constant, as is effectively done in the one-to-many scenario, competition aids the rapid emergence of cultural homogeneity and consensus. Competition has this social advantage

because, in a competitive situation, there is greater uniformity of access to the mas communication technology and, therefore, greater ability to rapidly disseminat information known by only one individual.

This study suggests that factors that are beneficial for effecting the rapi emergence of cultural homogeneity and consensus are not necessarily benefici for diffusion. Education and population benefit the development of cultur homogeneity and consensus but not diffusion. Communication technolog however, has a complex effect on diffusion. The dominant effect of mas communication technologies on cultural homogeneity and consensus is to facilitat their rapid emergence. However, with respect to diffusion, communicatio technologies actually alter the impact of various structural factors. In multigrou societies, this effect may be even stronger, future research should examine thi possibility. In this study, however, new ideas are shown to diffuse more slowl when the message is simple, when there are more ties, and these same ideas diffus more rapidly, when the message is complex, again when there are more ties. Thi suggests that models of diffusion have to be concerned not only with the learnin process but also with the social structure, the culture, and the communicatio technology.

The results of this study are consistent with the seeming inconsistencie discussed in the introduction. Mass-communication technologies can, when the are used to deploy complex messages, lead to a situation where different reader and different members of an audience may emerge with different knowledge eve when the learning procedure is not fraught with interpretation and errors. Despit this lack of initial agreement, mass communication can effect, as one hopes woul occur in an emergency, more rapid diffusion of information. Moreover, suc technologies can encourage the emergence of a common homogeneous culture But, such an effect is an eventuality. In the short run, mass-communicatio technologies can actually degrade cultural homogeneity and consensus.

NOTES

1. This should not be interpreted as a complete list of assumptions necessary for buildin the formal model. In building the model, many additional assumptions were made– such as, that individuals do not forget, and that the individual chooses randomly, wit equal probability, from all information known to him or her when choosing a piece o information to communicate. Many of these modeling assumptions are not part of th theory per se but are expedients in creating a simple model consistent with the theor that enables one to engage in theory building. In contrast, the expanded list o assumptions should be viewed as assumptions of the theory itself.
2. Kaufer and Carley (1993) discuss this in terms of the author's reach. They argue tha communication technology, particularly print, by extending the author's information processing capabilities (which includes the ability to send, receive, analyze, and lear information) has extended the author's ability to reach an audience. Thus, print make it possible for the author, because the author need not be physically present, t communicate with multiple people at once, communicate with more people

communicate simultaneously across a greater geographic area, and communicate acr a greater span of time than is possible verbally.

3. The term *book* is used here in a highly general fashion, to encompass any written mater that is printed and mass-circulated, such as newspapers and articles. Though each ty of media would have slightly different properties, such as the expected half-life, ea admits the one-to-many communication and, as an artificial agent, is incapable learning. These latter two properties are central to the results discussed in this pap
4. For additional details on the impact of print-based technologies on the early portio of these curves, see Kaufer and Carley (1993).
5. When a regression is performed on the means rather than on the underlying populati there are four main effects: (1) the coefficients are correct, (2) the standardized coefficier are slightly high, (3) the significance of the coefficients is underestimated, and (4) t fit of the equation (R^2) is slightly overestimated. In a regression on the means, t dependent variable is a set of means such that the independent values are identi for all of the values averaged to create a specific mean. In this study, the means we computed over 100 values. The central limit theorem applies.The standard deviatio of the means are small and each mean becomes a highly reliable point estimate of t location of the true underlying distribution.

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