Diving into Complexity: Developing Probabilistic Decentralized Thinking through Role-Playing Activities

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Abstract

There is a growing interest in role-playing activities, both in school classrooms and in the culture at large. Despite this growing interest, role-playing activities are rare in mathematics and science classrooms. In social-studies activities, a major goal is to help students adopt the perspective of another person. But mathematics and science classes typically discourage this type of perspective-taking; science is usually taught as a process of detached observation and analysis of phenomena, not active participation within phenomena. In this paper, we argue that role-playing activities can play a powerful role in mathematics and science education—particularly in the study of the new "sciences of complexity." We present detailed descriptions and analyses of two role-playing activities that we have organized. Each activity is designed to help students explore (in a very participatory way) the behaviors of complex systems, helping them develop better intuitions on how complex phenomena can arise from simple interactions and predictable patterns from random events.

Introduction

There is a growing interest in role-playing activities, both in school classrooms and in the culture at large. In social-studies classrooms, it has become increasingly common for students to learn historical or economic ideas by playing out roles—for example, acting as a member of the Communist Party in the Weimar Republic, or acting as a candy manufacturer in a mock economy. Meanwhile, fantasy role-playing games (in the spirit of Dungeons and Dragons) have swept through the culture and are now becoming a major activity on the Internet in the form of so-called MUDs (Curtis, 1993; Bruckman & Resnick, 1995; Bruckman, 1997).

Despite this growing interest, role-playing activities are rare in mathematics and science classrooms. In social-studies activities, a major goal is to help students adopt the perspective of another person. But mathematics and science classes typically discourage this type of perspective-taking; science is usually taught as a process of detached observation and analysis of phenomena, not active participation within phenomena.

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In this paper, we argue that role-playing activities can play a powerful role in mathematics and science education—particularly in the study of the new "sciences of complexity." We present detailed descriptions and analyses of two role-playing activities that we have organized. Each activity is designed to help students explore (in a very participatory way) the behaviors of complex systems, helping them develop better intuitions on how complex phenomena can arise from simple interactions, and predictable patterns from random events.

Through our analyses of these activities, we aim to:

- highlight how the study of complex systems could play a more significant role in mathematics and science education

- rethink the role of role-playing activities in mathematics/science learning (in particular, in the study of complex systems)

- examine students' conceptions about systems and complexity—and how role-playing activities can challenge and encourage reformulation of those conceptions

- rethink the uses of "modeling" in education, examining how role-playing activities can complement and supplement computer-based modeling activities

- contribute to a richer theory of learning—one that recognizes the value of participatory, experiential modes of thinking as well as distanced reflective modes

Diving In

Historically, developmental psychologists have placed analytic, reflective modes of thinking on a pedestal, viewing it as the most advanced form of thought. The classical reading of Piaget (Ginsburg & Opper, 1969), for example, describes cognitive development as a one-way progression from concrete to formal or abstract ways of thinking. This view of cognitive development fits neatly with traditional conceptions of scientific thinking and science education. Science educators have traditionally emphasized the importance of detached observation and analysis. And with some good reason: a detached stance can help protect against students projecting their own biases in their scientific observations and analyses.

During the past decade or two, there has been a serious challenge to these views of cognition and of science. A growing number of researchers (e.g., Gilligan, 1987; Lave & Wenger, 1991) have argued that learning and knowing can not be divorced from situated experience. Some researchers have called for a "revaluation of the concrete" (Turkle & Papert, 1991; Wilensky, 1991). In this new view, the detached stance encouraged by traditional science education tends to limit students' engagement with scientific ideas, making it difficult for them to build on their experiences and make strong personal connections to mathematics and science. There is a new appreciation for active participation, and not just distanced reflection, in the learning process. Ackermann (1991) describes cognitive growth as "a dance between diving-in and stepping-out."

Role-playing activities provide a very effective way for students to “dive in.” What might it mean to bring role-playing to mathematics and science classrooms? The activity of “playing turtle” in Logo provides an example (Papert, 1980). In using the Logo programming language, children give commands to a graphic turtle on the computer screen in order to create and explore mathematical patterns. As part of this activity, children are often encouraged to see themselves as the turtle, to better imagine what the turtle should do. To figure out how to make the screen turtle draw a circle, for instance, children will often try to walk a circle themselves, noticing that a repeated pattern of “step a little, turn a little” will produce a roughly circular shape. In this way, students make use of their knowledge of their own bodies to make a normally “abstract” mathematical domain more “concrete.” Papert describes it as a process of “syntonic learning”—leveraging familiar knowledge about your own body to gain a deeper understanding of other knowledge domains.

Complexity

We believe that these types of role-playing activities can play a particularly powerful role in helping students learn about complex systems. During the past decade, there has been a ground swell of scientific interest in the so-called “sciences of complexity”—the investigation of how complex phenomena can arise from simple components and simple interactions. New research projects on chaos, self-organization, adaptive systems, nonlinear dynamics, and artificial life are all part of this growing interest in complex systems. The interest has spread from the scientific community to popular culture, with the publication of general-interest books about research into complex systems (e.g., Gleick, 1987; Waldrop, 1992; Gell-Mann, 1994; Kelly, 1994; Roetzheim, 1994; Holland, 1995; Kauffman, 1995).

Research into complex systems touches on some of the deepest issues in science and philosophy—order vs. chaos, randomness vs. determinacy, analysis vs. synthesis. At the same time, this new field has introduced new objects of study—objects (such as fractals) that were barely conceivable before the study of complex systems and barely renderable without computational media, yet strongly connected to many patterns and phenomena in the everyday world.

In the minds of many, the study of complexity is not just a new science, but a new way of thinking about all science, a fundamental shift from the paradigms that have dominated scientific thinking for the past 300 years. In particular, two dominant paradigms of scientific thinking are being challenged. Whereas scientists have long seen the world in terms of centralized control and centralized causes, the new sciences of complexity tend to highlight decentralized systems. And whereas scientists have long seen the world as a deterministic clock-like mechanism, the new sciences offer probabilistic explanations of phenomena.

The Deterministic, Centralized Mindset

The traditionally dominant paradigms have affected not only the way scientists and mathematicians go about their work, but also the way people in their everyday activities think about the world. Most people have what we call "centralized mindsets" (Resnick, 1994a, 1996) and "deterministic mindsets" (Wilensky, 1993, 1995). These mindsets deeply influence the ways in which people make sense of themselves and their world. As a result, many people have great difficulty understanding phenomena such as the population variations within an ecosystem, the statistical patterns arising from molecular collisions, the emergence of traffic jams on a highway, or the fluctuations and swings of a national economy.

Why have new ways of thinking (associated with the new sciences of complexity) not become more widespread? One major factor is the lack of tools and activities to help people explore decentralized and probabilistic ways of viewing the world. In an effort to remedy this deficiency, some educational researchers (including ourselves) have recently developed computer modeling environments to help students explore such phenomena. For example, StarLogo[1] is a programmable modeling environment designed explicitly to help people explore systems-oriented phenomena—and develop new ways of thinking about such phenomena (Resnick, 1994a, 1996; Wilensky, 1995, 1996).

Here, we focus not on new tools but on a new category of activities—participatory role-playing activities. Our belief is that role-playing activities can support learners in moving beyond deterministic and centralized ways of thinking. The goal is to help students build intuitions about systems and complexity, just as playing turtle helps them build intuitions about geometry.

StarPeople Activities

Since 1993, we have organized role-playing activities in a variety of contexts, such as conferences and university classes (e.g., Resnick & Wilensky, 1993, 1995). The goal of these role-playing sessions is to provoke participants to reflect on their conceptions of complex phenomena and to help them develop probabilistic, decentralized ways of thinking. Since these activities grew out of our research with the StarLogo modeling environment, we refer to them (humorously) as StarPeople activities.

Our first StarPeople activity was very simple. We ask a group of people (we have tried it with anywhere from 20 to 1000 people) to start clapping—and to try to coordinate their clapping into a single, unified rhythmic beat. There is no leader or "conductor": the people must coordinate their claps simply by listening to one another. The surprising part of the experience is how quickly the group can synchronize its clapping. Even with 1000 people, the clapping becomes synchronized within a few seconds, after just a few cycles of clapping. The activity is a simple demonstration of decentralized control, illustrating how patterns can be coordinated without a coordinator, organized without an organizer.

[1] StarLogo can be downloaded from http://education.mit.edu/starlogo/

Overall, our role-playing activities fall into two broad categories. In some activities (such as the clapping example), we provide a goal for the overall group and each individual must decide how to act to help the group achieve the goal. In other activities, participants are given precise rules to follow, then asked to reflect upon the group-wide patterns that emerge. In all cases, the goal is to engage participants in thinking about the relationships between individual and group behaviors, helping them develop a better sense of how large-scale patterns arise from simple, local interactions.

Making the Rules

This collection of activities is intended to be enacted in sequence. In each activity, the goal is the same, but participants use different forms of communication to achieve it. To start, each participant is given a small Post-it note and a pen.

Activity 1. We tell each participant to pick a random integer between 1 and 6 (inclusive), and write it on their Post-it note. Then we tell them to organize themselves into like-numbered groups: all of the 1's together, all of the 2's together, and so on. We do not tell them *how* to get into groups. In all cases that we have observed, some people "naturally" emerge as leaders, shouting out things like "all 3's over here." In a short time, six groups form.

Although this activity is intended primarily as a simple, introductory activity, to serve as a foil for later activities, some interesting probability issues can arise. Often, the groups are very uneven in size, and some participants are surprised at the uneven distribution. We have discussions about the reasons for the uneven distribution.

Activity 2. Each participant writes a new random number on their Post-it. Again, we ask the participants to organize themselves into groups—but this time they aren't allowed to talk. The only way participants are allowed to communicate is by showing their Post-its to one another. They aren't allowed to communicate in any other way: no raising fingers, no stomping feet. Given this restriction, groups form more slowly than in the previous activity. Since it is difficult for individuals to become "leaders," participants need to develop new strategies.

When participants find others with the same group-number, they tend to stay together. Some groups roam together, looking for others with the same group-number. Other groups stay in one place, expecting that "loners" will wander around and find them. Sometimes, a group will send out an "emmisary" to look for "lost" group members. But the restriction on talking makes it difficult for group members to coordinate this type of group strategy.

In some cases, this process does not converge on six groups, even after an extended period of time. For example, sometimes two same-numbered subgroups will each wait in place, expecting that "loners" will find them. This "bug" is an example of getting stuck on a local maximum. Some ways to fix this bug: a group can send out an emmisary, or the whole group can continue to wander as a unit.

The communication patterns are very different than in the first activity. In the first activity, participants could have a global effect by shouting out their numbers. They could also sense globally, by looking around and listening to others. In the second activity, with talking not allowed, each individual can affect only nearby individuals (that is, they have only a "local" effect). Participants continue to have some global "sensing" capability, since they can look around and see other groups. But their access to Post-it numbers is local: they can not "sense" numbers at a distance.

In our discussions with participants, we help draw analogies to the natural world. Many natural-world phenomena are based on local interactions. For example, ants communicate not by "shouting" to one another but by sniffing for chemical pheromones in their vicinity. By restricting talking, we force participants to adopt strategies based on local interactions—in effect, to play the role of individual ants. Although local strategies are common in the natural world, people have weak intuitions about such strategies. By reflecting on their experiences as "ants," and observing the large-scale patterns that arise from their local interactions, participants begin to make connections that help them develop better intuitions about local strategies.[2] The process of "diving in" to their new role enables them to develop insights that would be difficult to attain by distanced analysis.

The activity has also stimulated discussion of how stable patterns can emerge from "random" processes. Many of the particular choices of individual participants seem random—such as whether to turn left or right at any particular time. Nevertheless, the overall patterns that form are quite predictable.[3]

Some participants have remarked that this second activity feels much more "alive" than the first activity. Why does it feel more alive? One person explictly pointed to the combination of "some randomness and some order." Whereas the first activity felt mechanical, with people moving directly to their goals, the second activity felt more organic, with people continually readjusting based on feedback from the surrounding "environment" (Resnick, 1994b).

Activity 3. The goal is the same as in the previous activities: to form like-numbered groups. But this time, we give participants blindfolds, so they can not see one another. Participants can communicate with whispers, but not loud talking. We tell people that they do not have to participate if they feel uncomfortable being blindfolded. Some people (without blindfolds) act as monitors, making sure that participants do not wander into dangerous situations.

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[2] One source of difficulties people have with mathematics is that mathematics is often taught by giving the global rules, but no mention is made of the local interactions that give rise to the global patterns. Statistics, a notoriously difficult subject for many, is usually taught so that the central concept of probability distribution is introduced through the global parameters (mean, standard deviation, skew, moments, ...) of various distributions, but little connection is made between these parameters and the local rules that lead to these effects (see Wilensky, 1995; 1997).

[3] This effect of order emerging from randomness has a paradoxical feel to many participants. Randomness is conceived of as the antithesis of order. Through these activities they come to see that algorithms that incorporate random components can often be a much more efficient and robust path to order than deterministic algorithms (see Martin, 1996; Papert, 1996; Resnick & Wilensky, 1993; Wilensky, 1993).

With these new restrictions, it takes much longer for groups to form. When people find others with the same number, they are very reluctant to ever split apart. They often hold hands or link arms, to make sure not to lose connection with their "family." Each proto-group tends to snake around the room, looking for other group members.

There is often much laughter during this activity. The laughter seems to reflect a combination of nervous anxiety and excitement. Many people are uncomfortable having their sight cut off in this way, and they aren't quite sure what strategies to follow. But there is also an excitement of being confronted with a novel situation and using different sensory modalities to interact with one another.

Sometimes, by random variation, only one person will have a particular number. This activity proves to be particularly difficult for such "singletons." They continue to wander around, not being sure if they will ever find any other group members.

In this activity, interactions are even more "local" than before. In Activity 2 ("look, but don't talk"), participants can use their vision to get a global sense of how and where people are clustering (even if direct communication about group-numbers was local). In Activity 3, with blindfolds, participants get no global information. All of their information comes from people standing very close to them.

With communication restricted, people tend to stay closer to one another. They use sound cues, and even warmth cues, to figure out where other people are. The resulting pattern is more concentrated than in the previous activities. It is not uncommon to see the groups standing right next to one another, distinguished only by the fact that group members are physically linked.

Often, the process does not converge to six groups. As in the previous activity, two like-numbered groups might stop looking for more members, and thus never find one another. But, even with the blindfolds, most of the groups *do* manage to get together. People tend to develop creative strategies for finding one another. For example, the members of a group might stay linked together but stretch out into a line, so that they can "sweep" a larger area, hoping to find additional members—using strategies reminiscent of those used by some micro-organisms searching for food. Sometimes, this behavior emerges naturally. A person at one end of the group might start moving in one direction, while a person at the other end starts moving in the opposite direction. As people in the group feel themselves "stretched," they recognize the possibilities of a new strategy.

Sometimes, people push the limits of the rules—for example, whispering in unison so the the group can be heard at a greater distance. In some cases, these strategies might be planned by a few members of the group and "illegally" communicated to the others. In other cases, the strategies emerge: if several whispers happen to synchronize by chance, the group members might realize that it would be useful to keep all of their whispers synchronized—and they do so using strategies similar to those used in the synchronized clapping example.

Summary. What's the point of these activities? The activities are designed to engage participants in thinking about different types of strategies. Their initial strategies (in Activity 1) are very centralized: one person takes the lead to organize the others. Their later strategies are more decentralized: each person follows simple rules, without any centralized control. The appropriate choice of strategy often depends on what means of communication are available. With global communication, participants choose centralized strategies; as communications are restricted to local interactions, participants are forced to develop more decentralized strategies.

These activities provide a context for thinking about important biological ideas. As mentioned earlier, the activities have an "organic feel" to many participants. The patterns and dynamics that arise in the activities evoke images from the natural world; in describing the activities, participants frequently use analogies to biological creatures (such as ants in a colony). Moreover, the activities provide a framework in which participants can think about the rules and mechanisms underlying the creature-like behaviors. In particular, the activities provoke participants to consider how creature strategies might be constrained (and, in an evolutionary sense, selected) based on the communications capabilities available to the creatures.

The activities also engage participants in thinking about the role of randomness and chance in natural phenomena. The biological analogies provide a meaningful context for understanding the value of a probabilistic approach for thinking about the behavior of all types of systems. Rather than the traditional classroom approach of learning probability through manipulating formulae to calculate the outcome of flipping coins or rolling dice, the StarPeople activities engage learners in experiencing probabilistic behavior within a "messy" system of interactions. By combining deterministic and probabilistic components in their strategies, participants can assess the relative effectives of these different approaches.

We have sometimes used these activities as an introduction to design projects.[4] In several cases, we gave participants the challenge to design behaviors for a colony of

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[4] Often we have embedded these design challenges in stories with local color. In a workshop we gave at the Artifical Life III conference in Santa Fe, New Mexico, we gave the following version of the challenge:

> *A terrible windstorm swept through the Painted Desert. Blue, green, yellow, and white grains of sand were all mixed together. The ants in the desert don't like their new high-entropy environment. They decide to move the sand to form a more interesting pattern.*
>
> *Each ant can perform four simple actions: it can take a step forward, it can turn left by an arbitrary angle, it can pick up a grain of sand (if there is a grain directly underneath it and it isn't already carrying a grain), and it can put down a grain of sand (if it is carrying one). Each ant also has several senses: it can detect whether there is a grain of sand directly under it (and if so what color) and whether there is a grain directly ahead of it (and if so what color). An ant also knows whether it is carrying a grain at the current time.*
>
> *What rules should the ants follow to move the sand into a more interesting pattern? Try to create some of the following patterns:*
>
> - *Move grains of the same color near one another.*
> - *Move the grains into concentric circles, according to color.*
> - *Move the grains into four horizontal strips, according to color.*
> - *Create your own abstract art.*
> - *Draw a picture of a famous person.*

"robot termites." The goal: make the termites gather randomly-scattered wood chips into piles. Participants have proposed many types of strategies. Some of their strategies were deterministic and centralized. For example, one termite could direct all other termites to bring the wood chips to a particular location, or each termite could be responsible for gathering wood chips in a particular region. Other strategies were decentralized and probabilistic. One particularly elegant approach: each termite wanders randomly until it bumps into a wood chip, then it picks up the chip and wanders randomly again until it bumps into another wood chip, upon which it puts down the one it was carrying.

The role-playing activities clearly influenced the ways participants thought about their design projects. In particular, the role-playing highlighted the link between creature strategies and communications capabilities. As participants developed strategies for the termites, they considered what types of communication mechanisms were most appropriate. For centralized and deterministic strategies, they needed complex and "expensive" global communications mechanisms (such as "global positioning systems" for each termite); for decentralized and probabilistic strategies, they could use simpler, local communications mechanisms (such as dropping "bread crumbs" for others to follow).

Following the Rules

There are two fundamentally different ways of exploring the behaviors of systems. In one approach, sometimes called "phenomena-based" (or "backwards") modeling (Wilensky, 1995; 1996), you design strategies for individual parts of a system in an effort to achieve a particular goal for the overall system. In an alternative approach, sometimes called "exploratory" (or "forwards") modeling, you start with rules for the individual parts of a system, and you observe the group-wide patterns that arise from the interactions.

The same two approaches can apply to role-playing activities. In the previous section, we described a set of "backwards" role-playing activities. In this section, we describe some "forwards" role-playing activities, in which participants are told to follow a pre-determined set of rules, and asked to think about the patterns that arise from the interactions.

In one activity, we start by giving hats to half of the people in the room. Then we ask everyone to randomly choose a number between 1 and 10, and we arrange the people into ten groups of like-numbered people. Since the distribution of people with hats is random with respect to the numbering, each group typically includes some people with hats and some people without hats.

We tell people that each of them will play the role of a physics particle. The ones without hats are α particles; the ones with hats are $\hat{\alpha}$ particles (pronounced *alpha-hat*: get it?). We tell them that the particles follow these rules: If a group is dominated by one type of particle (composing at least 2/3 of the group), those particles "expel" the less-common particles. For example, if a group has five α particles and only two $\hat{\alpha}$ particles, then the α particles will expel the $\hat{\alpha}$ particles, and the $\hat{\alpha}$ particles will go to a neighboring group (see figure 1). But if a group has roughly even numbers of α and α̂ particles, none of the particles are expelled—the group is "stable." We tell the participants to follow these rules repeatedly, until no more particles are expelled. Usually, there are several rounds of activity before the system stabilizes.

Many participants are surprised by the distribution of α particles and α̂ particles after the system stabilizes. (You might want to think about the pattern of particles before reading on.) It turns out that most of the groups end up with only one type of particle, either α particles or α̂ particles. That is surprising since most of the groups start out stable, with roughly even numbers of α and α̂ particles.

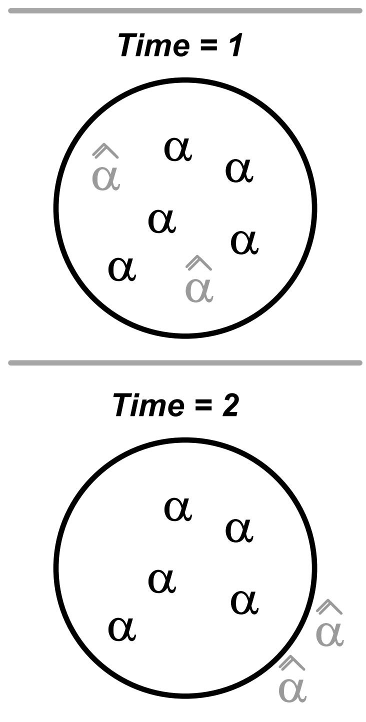

Figure 1: "Minority particles" are expelled from a group

After acting out the simulation, participants try to make sense of the surprising results. It turns out that most participants haven't considered the possibility of a "ripple effect"—the fact that particles expelled from one group can destabilize the next group. Imagine a group with five α particles and two α̂ particles, the two α̂ particles will be expelled to the next group. That group might have been stable, with five α̂ particles and three α particles. But with the two new α̂ particles, the balance changes to seven α̂ particles and three α particles—so the three α particles are expelled (figure 2). But those three α particles might destabilize the next group, and so on.

The failure to take into account the ripple effect is one example of a general tendency people have in trying to make sense of complex systems. They tend to focus on short-term effects at the expense of understanding the larger-scale systemic effects. Similar effects have been studied in detail by systems-dynamics researchers (e.g., Forrester, 1968). In a simulation game set up at MIT (Senge, 1990), participants took on one of three roles: beer consumer, small retail store owner, and beer manufacturer. In the game, many retailers got into deep trouble by not taking into account the ripple effect. They would order many cases of beer in response to pent up consumer demand, forgetting about the lag time it would take the manufacturers to gear up for the new orders. By the time all the orders came in, they would swamp the retail stores creating huge surpluses that would often bankrupt the stores. These ripples would in turn affect the manufacturers who had ramped up for greater production only to find that demand had suddenly vanished. Failing to take into account ripple effects is one important "bug" in people's thinking about complex systems.

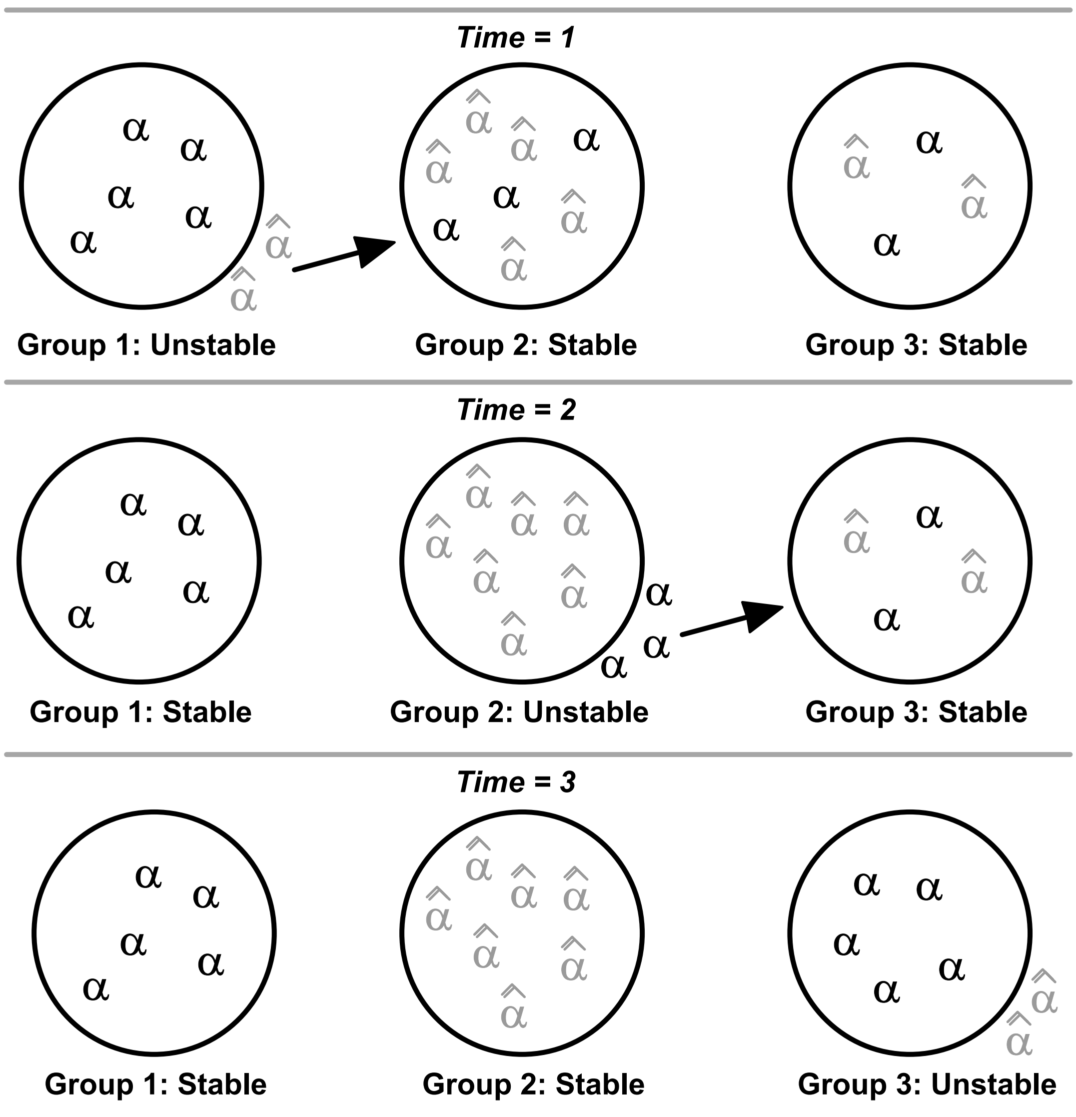

Figure 2: The ripple effect
The figure shows three snapshots, each with three groups.
Reading down shows how the groups evolve over time.
Arrows show the movement of "particles" at a particular instant.

After people have acted out and discussed the simulation with α and $\hat{\alpha}$ particles, we suggest a shift in interpretation. Imagine that the participants represent not particles in a physics problem but people at a cocktail party. The α particles represent men and the $\hat{\alpha}$ particles represent women. Men and women like to be together in a group. But if a group has an abundance of one gender, people of the other gender feel somewhat uneasy and move to a neighboring group. People aren't "expelled," they leave voluntarily, but the effect is the same. In this case, most of the groups at the "cocktail party" end up single-gendered—that is, most of the groups are either all men or all women. In fact, some researchers have proposed that this very mechanism can explain the distribution of genders in groups at real cocktail parties (Schelling, 1978).

Some participants find this explanation enlightening, providing a mechanism to explain previously mysterious phenomena. But others find it disturbing. They argue that human behavior can not be described by a few simple rules. Indeed, many people seem to take it as a personal affront that someone might try to describe human behavior—or, more pointedly, *their* behavior—in terms of a few simple rules. As one person put it: "People are not ants!"

Why do people have this strong reaction? We see several possible explanations. First, the idea that behavior is based on "following rules" conflicts with people's sense of their own free will. They feel as if they are in control of their actions, not following a set of fixed rules. Second, people are bothered by the omission of any emotional or spiritual aspects in the description of the behavior. They reject the idea of a "purely rational" set of behavior rules. Third, the notion of a collection of rules running independently conflicts with people's sense of a whole and integrated self. Fourth, some participants argue that people are able to modify their behavior over time, especially if they are unhappy with the results of previous behaviors. So they react against an activity which (as they see it) is based on fixed and immutable behaviors. They assert that people must assume responsibility for their behaviors; if all behaviors were fixed and pre-determined, there would be no sense of moral culpability. Finally, some people who accept that behaviors might be explained by simple rules react against the idea (implicit in the cocktail-party example) that everyone must follow the *same* rules.

These reactions are understandable. It is certainly true that a few simple rules are not sufficient to fully explain human behaviors—even in a "simple" situation like a cocktail party. But is there something to be gained by modeling human situations in this way? We think so. The point of "modeling" is not necessarily to fully characterize phenomena in the real-world, but to highlight key aspects of those phenomena.

In our view, some aspects of human behavior *can* be modeled with simple rules.[5] These aspects of behavior are often ignored or repressed, since they lead to conflicts with our usual ways of viewing ourselves (and our selves). Our role-playing activities are

[5] We have also found that many aspects of human behavior can be productively modeled with "homogeneous" systems (in which all individuals follow the same rules). Of course, people are very heterogeneous (with many different approaches, preferences, and strategies). But, surprisingly, this heterogeneity of behavior can sometimes be modeled through simpler, homogeneous rules.

designed to provoke people to re-examine the ways in which rules underlie behaviors. Such re-examination can help people avoid or remedy situations in which underlying rules lead to unexpected and undesired effects. In the cocktail-party case, everyone would be happier if the groups had both men and women. But the underlying rules lead to a dynamic that causes segregated groups. Once the groups segregate, a participant might assume that the others actually prefer single-gender groups—and thus would be unlikely to take action to change the situation. By recognizing the possibility that all participants might prefer mixed-gender groups (even though their actions lead to a different result), an individual might feel empowered to suggest changes that would make everyone more satisfied. Paradoxically, it is by ignoring or resisting these types of rules that we become slaves to the rules; it is only by recognizing (and thus becoming able to challenge) the rules that we can take control of the rules for our own purposes.

The case of the cocktail party might seem trivial. But some researchers have argued that similar dynamics are at work in urban housing patterns. Even if people of all races and ethnic backgrounds were content living in integrated neighborhoods, communities might end up segregated by the same mechanism as in the cocktail party. Of course, that does *not* mean that segregated neighborhoods always arise from such benign factors; in many cases, blatant racism is undoubtedly at work. But by understanding the multiple factors that might give rise to urban segregation, we are in a better position to rethink and try to remedy the situation.

Reflections

The StarPeople activities emerged out of our previous work on helping students explore complex systems through computer modeling activities. A common critique of computer modeling activities in educational settings is that the activities are "disconnected from the real world." Just because it is possible to model a particular phenomenon on the computer doesn't mean that it has any relationship to real-world phenomena—for example, it might be based on a totally different underlying mechanism. Computer models that are not "grounded" in some real-world connections can feel like Nintendo games: lots of interactions, but no connections to deep ideas.

In the activities discussed in this paper, we focus on a different type of "connection" for grounding computer modeling. Our emphasis is not so much on connections to real-world phenomena, but connections to personal experience. By participating in role-playing activities, learners can "dive" into mathematical and scientific phenomena, developing new relationships with the knowledge underlying the phenomena. Learners can build upon their sensory and social experiences to help understand (and become engaged with) a variety of scientific phenomena. The importance of forming personal connections to scientific knowledge is all too often ignored in today's classrooms.

The fields of complexity and systems sciences are particularly well-suited for role-playing explorations. Complex systems typically involve a large number of objects interacting with one another in parallel—so there is a natural match for a group of learners interacting with one another in a role-play. More importantly, role playing provides a natural path for helping learners develop an understanding of the causal mechanisms at work in complex systems. By acting out the role of an individual within a system (for example, an ant within a colony or a molecule within a gas), participants can gain an appreciation for the "perspective" of the individual while also gaining insights into how interactions among individuals give rise to larger patterns of behavior.

These role-playing activities can serve as a good entry point for computer modeling activities (in particular, object-based parallel modeling as in StarLogo), in which learners must explicitly articulate rules for the individual objects to follow. But we do not see role-playing as merely a prelude to the computer; role-playing can provide very different sorts of experiences. For example, our StarPeople activities can provide a middle-ground between the strict rules that govern most computer-modeling activities and the very loose structures in most social-studies role-playing activities. In the "making the rules" activities, for example, participants have freedom within specific constraints. By choosing strategies within the constraints of limited communications capabilities (local whispering, blindfolds, etc.), StarPeople participants have more freedom than is typical in a computer-modeling activity, but are still able to get reliable feedback from the system, enabling them to try and test out their theories.

Role-playing is already used in some science classroom activities—for example, some students learn about the solar system by acting out the motions of the planets. But this is a very different sort of role playing than in our StarPeople activities. In playing the planets in the solar system (or, in another example, the electrons and protons in an atom), students are creating a type of visualization of a scientific phenomenon. This activity might be helpful in understanding the relative motions or positions of the planets, but it provides students with little insight into the causal mechanisms underlying the planets' behavior. It focuses more on the results, not the processes and interactions that give rise to the results. In StarPeople activities, our goal was to engage participants in thinking about the dynamics and process of pattern formation in complex systems, not just the patterns themselves.

"Complexity" does not refer to a restricted set of phenomena but instead provides a new and powerful lens for seeing many scientific and mathematical concepts. Perhaps most important from an educational perspective, complexity and systems sciences have the potential to make certain scientific and mathematical ideas more accessible to a broader audience. Models in complexity and systems sciences are often based on interactions among concrete objects—so that learners can make analogies by recruiting intuitions based on their own experience as "objects" interacting with other objects in the world.

Some people might argue that role-playing activities are not appropriate for exploring scientific phenomena. Classic role-playing activities involve people impersonating other people—trying to mimic the goals, intentions, and actions of historical characters or economic actors. But in most scientific investigations, the objects under consideration do not have human-like goals or intentions. Thus, it might seem that human "impersonations" would not provide any leverage for understanding these types of objects or their interactions. Some might see a danger that scientific role playing would confuse social and scientific ways of thinking and knowing.

This view, however, represents a deep (though widespread) misunderstanding of the true nature of scientific learning. It assumes that the deep differences between humans and the objects of scientific investigation (be they ants or molecules) make human experience irrelevant to understanding scientific phenomena. But in fact, practicing scientists often make use of their own personal experiences in making sense of the natural world. Some scientists go a step further and actually adopt the perspective of the objects they are studying. Barbara McClintock, a Nobel-winning biologist who studied the genetics of corn, attributed her greatest discoveries to the fact that she had a "feeling for the organism" and was able to imagine herself as one of the genes within the corn (Keller, 1983).

The challenge, then, is not to root out all personal experiences when trying to understand a scientific phenomenon, but rather to figure out which aspects of one's personal experience are useful—and which are not—in understanding a particular situation.[6] When trying to imagine themselves as ants in a colony, for example, learners can make use of some of their own perceptual experiences and intuitions, but they need to be careful not to assume that ants have the same types of "goals" that they as humans do. We have found that our role-playing activities provide a framework in which learners can start to make precisely these types of distinctions—learning to project only the specific parts of their own experiences that are useful for understanding other creatures and objects.

When learners try to understand the workings of human systems, the problem is, in some ways, the reverse. In the cocktail-party example discussed earlier, some participants strongly resisted the idea that human behavior at a cocktail party can be understood in terms of a few simple rules. But just as some human-like behaviors can be very useful in understanding creatures and inanimate objects, so too can simple creature-like behaviors be useful in understanding some human behaviors.

Future Directions

We have barely scratched the surface with our StarPeople activities. We imagine extending this research along several different dimensions—new types of technological support, new domains for role-playing, new empirical studies.

Our current StarPeople activities use very simple "technologies"—Post-it notes, pens, blindfolds. We believe that new technologies could help overcome some of the limitations of the current StarPeople activities. For example, participants in StarPeople activities could wear "Thinking Tags" (Borovoy et al., 1996)—wearable electronic tags that communicate with one another via infrared signals. These tags (which include a tiny micro-controller and memory) could allow new forms of enhanced (or restricted) communication among StarPeople participants—and, as a result, further explorations of how modes of communication influence strategies for organization. The tags would also allow longer-term activities, in which the tags gather and store data about interactions

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[6] Smith, diSessa & Roschelle (1994) describe a number of interesting examples of how learners adapt their "incorrect" methods derived from early experience to more complex situations.

over extended periods of time. For example, we imagine a group of students participating in an extended simulation of the spread of an infectious disease, in which "viruses" jump from one person's tag to another.

Another limitation with current StarPeople activities is the difficulty of gathering sufficient numbers of participants[7]. One solution is to allow people to participate over the Internet. Each person could control the behavior of a proxy object in a shared virtual space, and then observe the group-wide patterns that arise from the interactions. This type of activity could build on existing MUD environments (or architectures), but would have a greater emphasis on interactions of *collections* of computational objects (including representations of self) in *structured* activities. Of course, this type of activity would remove the physical dimension of StarPeople interactions, but it would allow many more people to participate in StarPeople-like activities while also allowing explorations of new modalities of interaction. In particular, this NetStarPeople approach would allow human-controlled objects to interact alongside programmed objects, thus facilitating greater maneuverability in the middle ground between rigid rules and "rulelessness."

At the same time, there is a need for more in-depth empirical study of how and what people learn as they participate in StarPeople activities—in particular, a finer-grained micro-analysis of participants' learning paths as they participate in—and engage in thinking about—complex systems. There has been very little research in the developmental and cognitive psychology communities on how people make sense of complexity. We believe that StarPeople-based studies could make important contributions to this emerging field of research, helping both in the development of new educational approach for learning about complexity and richer theoretical accounts of how people build new understandings of the workings of complex systems.

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[7] It is rare that people have the opportunity to participate explicitly in group simulations—one exception that comes to mind is the so-called "wave" activity in sporting events.

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