Chapter 1
Introduction to Community-Based System Dynamics

Logical pictures can depict the world.

(Wittgenstein 1974, 10)

Today's knowledge about something is not necessarily the same tomorrow. Knowledge is changed to the extent that reality also moves and changes. Then theory also does the same. It's not something stabilized, immobilized.

(Horton and Freire 1990, 101)

One way to focus on this problem is to discover that we have no conception of objectivity that enables us to distinguish the scientifically 'best descriptions and explanations' from those that fit most closely (intentionally or not) with the assumptions that elites in the West do not want critically examined.

(Harding 1991, 97)

Why Community-Based System Dynamics?

Community-based system dynamics (CBSD) is a participatory method for involving communities in the process of understanding and changing systems from the endogenous or feedback perspective of system dynamics (Richardson 2011; Sterman 2000; Forrester 1990). In system dynamics, informal causal maps and formal models that can be simulated on a computer are used to "uncover and understand endogenous sources of system behavior" (Richardson 2011, 241) with the goal of solving problems by improving the mental models we use to perceive the system and act.

Mental Models

A mental model of a dynamic system is a cognitive representation of the real system (Doyle and Ford 1998). We use mental models every day from the time we get up to the time we fall asleep, at home and at work or school. As humans, we rely on mental models to solve a wide variety of problems, from organizing a meal during festival to developing a global strategy for preventing chronic disease. When things are

P.S. Hovmand, *Community Based System Dynamics*, DOI 10.1007/978-1-4614-8763-0_1,

going well, we generally have no reason to worry about our mental models, and often our mental models are sufficient for managing the situation at hand.

However, there are times when the problems we're experiencing are a consequence of flawed mental models. In these situations, we are making decisions relying on the wrong set of assumptions and inferences, which are in turn not solving problems and often make matters worse (Dörner 1997; Senge 1990). When this happens in a system where there is feedback, that is, where the consequences of the actions "feed back" to influence the conditions we're responding to, the situation can be disastrous.

In commercial fishing, a declining fish stock can lead to declining revenue for the fishing fleet and a tendency to expand fleets. This expansion accelerates the rate that fish are caught and the decline, leading to even more pressure to expand fleets. The pattern continues until regulations put a moratorium on commercial fishing or ultimately, there are no more fish. The causal chain that drives the decline of the fish stock is a reinforcing feedback loop, whereas the prevailing logic of commercial fishers, "Expand fleets to increase revenue," ignores feedback. The problem from a feedback perspective is that commercial fishers are trying to manage their revenues using a mental model that excludes feedback when the dynamics of the real system are being driven by feedback.

From afar, it can sometimes seem obvious what one should do, but research consistently points out that we routinely make these types of mistakes because we have a hard time recognizing feedback in a system, underestimate the significance of delays between causes and effects, and generally have a difficult time drawing valid inferences about effects when there are two or more causes interacting (Sterman 2000; Dörner 1997; Moxnes 2000).

This does not mean that no one sees the system effects, but then the challenge is often on how to reach some type of agreement about what to do when perspectives differ. For example, there can well be someone who from a combination of experiences, system thinking skills, and wisdom is able to see the system and recognize the actions that need to happen to manage the system better. The problem for this person, however, is that they are often in the minority and, even when they are in charge, may have a difficult time communicating and persuading others to follow a path conflicting with prevailing mental models of the situation.

Causal Maps and Formal Models

In system dynamics, informal causal maps and formal models are used to make our mental models explicit and test hypotheses about the logical implications of our assumptions on system behavior using computer simulation. Examples of informal causal maps include causal loop diagrams and stock and flow diagrams of dynamic systems. Causal loop diagrams (CLDs) such as those shown in Fig. 1.1 are frequently used to show the feedback loops in a system.

In CLDs, the arrows represent hypothesized causal relationships between variables. The basis of these causal relationships can vary from conjecture to evidence supported by rigorous research. The plus and minus signs indicate the direction of influence.

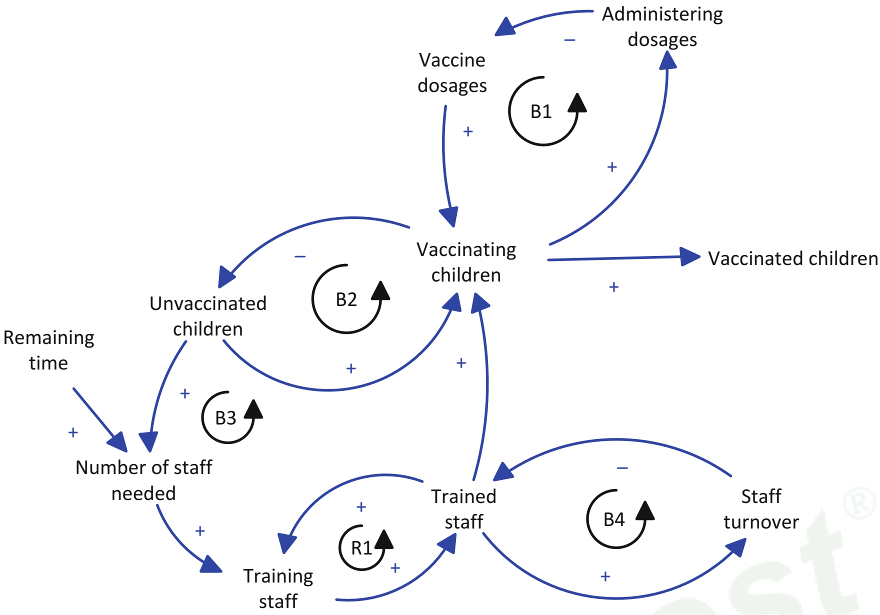

Fig. 1.1 Example of a causal loop diagram

Plus signs mean that *increasing* the cause variable *increases or adds to* the effect variable with everything else being held constant. By the same logic, *decreasing* the cause variable *decreases or subtracts from* the effect variable with everything else being held constant. In Fig. 1.1, for example, the link from vaccine dosages to vaccinating children is positive because increasing the vaccine dosages will increase the rate of vaccinating children with everything else held constant, and decreasing vaccine dosages will slow the rate of vaccinating children with everything else held constant.

In contrast, minus signs mean that *increasing* the cause variable *decreases or subtracts from* the effect variable with everything else held constant, and *decreasing* the cause variable *increases or adds to* the effect variable with everything else being held constant. For example, in Fig. 1.1, increasing the rate of administering dosages will decrease or subtract from the available vaccine dosages with everything else held constant, while decreasing administering dosages will increase the available vaccine dosages with everything else held constant.

In CLDs, feedback loops are typically labeled as either balancing or reinforcing with balancing feedback loops given "B" prefixes and reinforcing loops given "R" prefixes. For example, B1 identifies the balancing feedback loop where increasing the rate of vaccinating children increases the rate of administering dosages which in turn decreases the available dosages, and this "feeds back" to limit the rate of vaccinating children. Likewise, R1 identifies a reinforcing loop where increasing

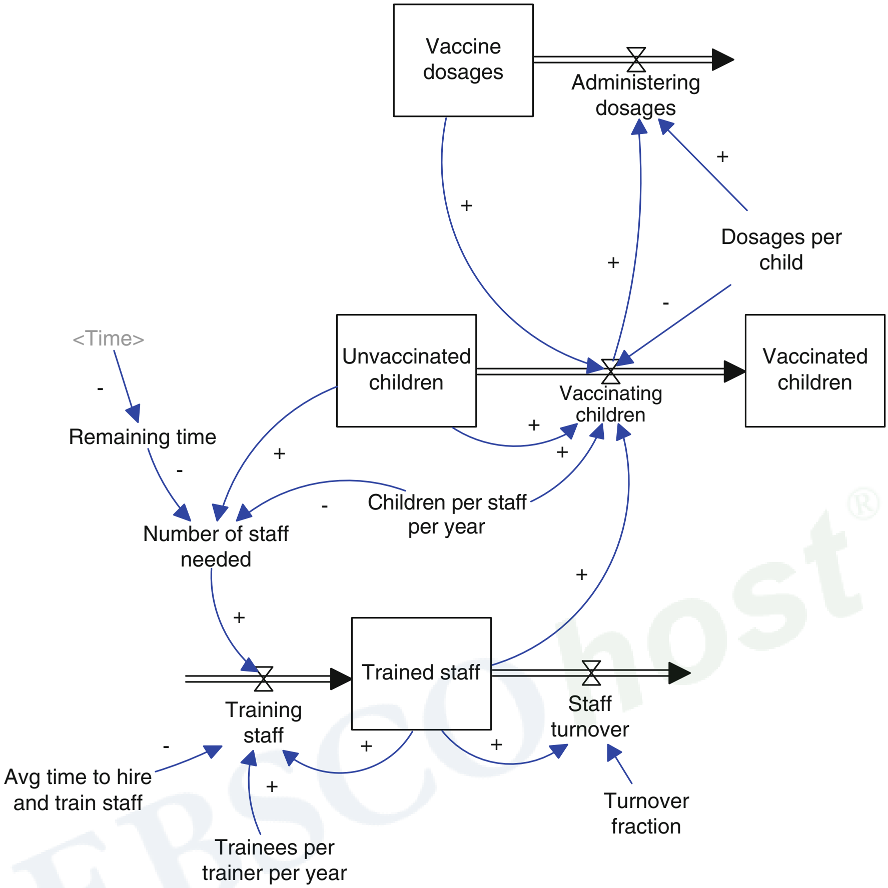

Fig. 1.2 Example of a stock and flow diagram

training of staff leads to more staff, which in turn facilitates a faster rate of recruiting and training more staff.

Stock and flow diagrams (SFDs) are also used to represent systems. An example of the childhood vaccination system is shown in Fig. 1.2 as a stock and flow diagrams. In SFDs, accumulations or stocks are represented as boxes, while flows or rates affecting the stocks are represented as "pipes" or with double lines with triangles representing the valves controlling the rates. The clouds at the beginning and end of the flows or "pipes" represent infinite sources and sinks.

Stock and flow diagrams have the advantage of explicitly representing the accumulations or stocks in a system but often make it somewhat hard to see the feedback loops. However, stock and flow diagrams have a closer correspondence to the underlying mathematical representation in a computer model and are therefore generally easier to translate into equations that can be simulated on a computer.

The main role of computer simulation in system dynamics is to test hypotheses about the relationships between the system structure and system behavior. A running simulation model demonstrates what the logical implications of the model are. Because such models are rich enough in their structure to generate dynamic complexity, simulation models can be viewed as logically entailing a potentially large set of hypotheses that can subsequently be compared against reality (Black 1962).

Informal causal maps and formal simulation models provide a means to make our mental models more explicit and test assumptions. Often the process of developing the model leads to counterintuitive insights about the structure and behavior of a system, which in turn leads to recommendations that often challenge conventional wisdom and therefore pose a challenge in terms of persuading decision makers to act based on these assumptions.

Group Model Building

In describing the motivation for her transition from biophysicist to journalist, Donella Meadows (1991) tells the story of watching in frustration Jay W. Forrester, the founder of the field of system dynamics, trying to explain and persuade viewers on a Boston television show the policy implications from the Urban Dynamics Model (Forrester 1969). Other examples include the controversy surrounding the Club of Rome and the World Model (Meadows et al. 2004), where a large secondary literature emerged that misinterpreted both the purpose and conclusions from the model.

Today, we have the benefit of looking at these models with much more historical data available and confidence in their policy recommendations, but we have in the meantime lost 20–30 years of opportunity for making the policy changes that would address the underlying the issues.[1]

Forrester himself has chastised the view that the problem of translating system insights into implementation of solutions as one of communicating more effectively and persuasively with decision makers:

> One hears repeatedly the question of how we in system dynamics might reach "decision makers". With respect to the important questions, there are no decision makers. Those at the top of a hierarchy only appear to have influence. They can act on small questions and small deviations from current practice, but they are subservient to the constituencies that support them. This is true in both government and in corporations. The big issues cannot be dealt with in the realm of small decisions. If you want to nudge a small change in government, you can apply systems thinking logic, or draw a few causal loop diagrams, or hire a lobbyist, or bribe the right people. However, solutions to the most important sources of social discontent require reversing cherished policies that are causing the trouble. There are no decision makers with the power and courage to reverse ingrained policies that would be directly contrary to public expectations. Before one can hope to influence government, one must build the public constituency to support policy reversals. (Forrester 2007, 361)

[1] It is important to note that this lag between results and policy implementation is by no means unique to system dynamics. In fact, it is common in many areas of scientific research with whole new fields emerging such as translational science and implementation science to address this lag.

Fig. 1.3 Gautam Yadama introduces a reference mode of declining availability of fuelwood to villagers at the start of a Foundation for Ecological Security effort to the engage villagers from Boyapalle, Andhra Pradesh, India

One response to Meadows and Forrester comes in the form of group model building. Group model building (GMB) is a participatory method for involving people in a modeling process. For the most part, GMB has been applied within the context of private organizations and government, often with a group of middle to senior managers, all with the goal of informing a response to a problem, policy analysis, or design of a new program or service (Rouwette et al. 2006). A limited set of cases of GMB have occurred in community contexts (e.g., Stave 2002; Dudley et al. 2008), but with questions arising about the level of participation in the modeling process and to what extent people are actually involved in model development.

CBSD emerged within the GMB discourse as an explicit attempt to involve community members in the modeling process in the spirit of Forrester's critique of the field. CBSD is about building the public constituency to support the policy reversals that can address the root causes of dynamic problems from a feedback perspective. It is about engaging communities, helping communities cocreate the models that lead to system insights and recommendations, empowerment, and mobilizing communities to advocate for and implement changes based on these insights (see Fig. 1.3). To do this, we need to understand what it means to be a community, what kinds of situations we are looking at where CBSD can have benefits in terms of complex systems, and what it means for people to participate in a process to develop informal causal maps and formal models that can be simulated on a computer.

Defining Community

There are a many ways to define the term “community” from definitions based on geographic boundaries to loose networks of associations (Fisher and Sonn 2007). Take, for instance, the fact that neighborhoods, small towns, metropolitan areas, professional societies, universities, organizations, and Internet forums are all referred to as communities. How we define “community” determines who is involved, how the issues get framed, who the stakeholders are, how we understand the politics and power, and even what language we use.

In social science, defining community is often a means to provide an operational definition for a population and means to judge the appropriateness of a sampling strategy for generalizing results. In this sense, defining community is often treated as a scientific act. But here, by the very nature of the activity in CBSD, we need to be conscious that defining the term “community” as well as a specific community is a “speech act” and an act power.

A speech act is doing something with words (Austin 1962). For example, an apology or joke is a speech act in that giving the apology or making the joke happens through the act of speaking. Including someone into a family (e.g., “You’re a member of our family now”) is also a speech act. Likewise, membership in a community is often through speech acts (e.g., “Of course, you’re a member of our community!” or “They aren’t a member of our community even though they live here”). What is important to recognize is that this is also an act of power, and specifically, an assertion about who gets to determine who is in and outside a community.

Being a recognized member of a community comes with certain privileges (and obligations), one of which is to determine access to the community by extending and withdrawing membership (Fisher and Sonn 2007). In marginalized communities where conditions are often determined by persons outside the community, reasserting the right of a community to define community on its own terms is fundamental to reclaiming control of access (Frye 1983).

While this can sometimes lead to musings about the essential membership characteristics and identity politics, it is important to recognize that from a pragmatic perspective, communities routinely define and redefine boundaries to suit different purposes (Heyes 2000). For example, a community may draw narrow boundaries when considering the distribution of vegetables from a community garden and broad boundaries when discussing the potential placement of a new school or health clinic. What is critical to recognize in CBSD is that the drawing and redrawing of boundaries is a fluid process and something that is done by those within the community.

It is also important to be aware that when communities extend membership to outsiders such as the members of the modeling team, that this is best viewed as provisional, and more specifically conditional on the behavior of the modeling team, in addition to coming with obligations as a provisional member of the community that is essential to establishing and maintaining trust. What this means in practice is that membership privileges are not transitive, but obligations are.

In CBSD, we therefore begin to understand what is meant by asking those who already have ties to the community how they define community and continually trying to understand their use of the term "community" within the context of their discussions. There is generally no best set of persons to start this process, and one must be critical of how status and incentives to participate can distort interactions.

This requires a certain amount of self-awareness of one's own status and privilege, sensitivity to cultural diversity and how power and privilege operate within a community, and paying attention to distinctions that community members might draw between a definition of community imposed upon them and one that they can extend.

For example, a rural village dependent upon a forest for their household needs and livelihoods may feel powerless to change the behavior of commercial harvesters, who see themselves as separate and unaccountable to the village. However, by the village extending their sense of community to include some of the commercial harvesters, the villagers make the commercial harvesters endogenous to their community and can organize to make the commercial harvesters aware and accountable for their actions in the forest. This may not be sufficient to change the behavior in a way that leads to a sustainable forest, but it is often a necessary precondition for mobilizing communities and empowerment.

Ultimately, how we approach the question of defining community is process over time that begins with how we approach and engage communities. Chapter 3 will go into more detail about the process of engaging communities and how one develops a team to guide the process and builds capacity to both understand definitions of community and design and facilitate group model building sessions with communities.

Complex Problems

From the outset, the types of concerns we are focused on in CBSD are often difficult and complex problems. Some are difficult because they are complicated—they involve a great many moving parts and details—while others are complex because they involve many potential interactions and explanatory pathways.

A normal response to complex problems is to try and reduce them into smaller components and explore more detail complexity. We see this in everyday life as individuals try to organize their social realities through the creation of finer categories and jargon. Yet the increasing amounts of detail may ultimately add very little to our overall understanding of a problem.

Complex system problems that have the characteristic that what makes them hard to understand are the emergent behaviors of the parts interacting as a system. That is, when the "sum of the whole is greater than the sum of the parts," it means that a system behaves in ways that could not be predicted or reduced to properties of the individual components. When this happens, we say that the behavior of a system emerges from the interaction of different elements. Since the interactions are determined by the structure of the system, we say that *structure determines behavior.* This represents a subtle but profound shift in our viewpoint.

When we can understand a system by understanding its component parts and then infer what a system will do, what matters most are strength of associations between causes and effects. *Increasing fishing will increase revenue. Increasing studying will improve grades. Increasing access to care will improve health. Decreasing taxes will improve the economy. Shortening commuting times will reduce traffic.* In this view of linear causality, the effects that matter are proximate to the causes, meaning that the closer the cause is to the effect, the stronger the effect. By the same logic, the further away one moves from the original cause, the weaker the effect until the effect is indistinguishable from a random disturbance. One can, using this logic, ignore the consequences of long causal chains since they get lost in the noise. When this is the case, *strength of association determines behavior*.

However, when *structure determines behavior*, we are saying something fundamentally different. Now it is the fact that there is a reinforcing feedback loop, for example, that explains why the system behaves as it does. The power of feedback loops is that the effects accumulate as they move around the loop. *More fish caught leads to fewer fish, which makes it more difficult to catch fish, which leads to fewer fish being caught. Or, more births lead to larger populations, which lead to even more births and even larger populations.* When *structure determines behavior*, it is less important what the actual harvest rate is or what the actual birth rate is than the fact that it is positive and embedded within a feedback loop. Changes in the strength of association will generally have little impact on system behavior, whereas changing the structure will.

One frequently puzzling consequence of *structure determines behavior* is that the same structure can produce different types of behavior. The reinforcing feedback loops that produce exponential growth, for example, can also produce exponential decline. So if *more income leads to greater assets, which leads to higher academic achievement, and this leads to even greater income* is true as a virtuous cycle of accumulation of wealth and educational attainment, this same structure can also drive a vicious cycle of declining income and educational attainment. It is *one system* that can produce *two different system behaviors*.

This notion that the same system can produce different behaviors is called dynamic complexity and differs from the idea that systems are complicated or hard to understand because they have many different elements, which is referred to as detail complexity (Sterman 2000). While the fact that the number of elements and connections in a system can be overwhelming in its detail complexity, the primary concern of system dynamics is on understanding dynamic complexity. It is dynamic complexity, not detail complexity, which arguably poses the greatest challenge to understanding complex systems.

In a dynamically complex system, the same basic structure generating desirable behaviors during one period can drive undesirable behaviors in another period. For example, the feedback mechanisms that drive our early success in building cooperation in a community can be the same feedback mechanisms that later lead to conflict

(Hovmand et al. 2009). What becomes challenging is that someone advocating for more of the previous efforts to build cooperation is not wrong when they claim *it was effective*, but now the situation has changed, and what was once the source of success is now driving a pattern of failure.

The focus of CBSD is on understanding and solving problems that involve dynamic complexity. It is in dynamically complex situations where understanding the structure is essential to being able to both identify potential strategies for improving the system and implementing the strategies in a timely manner. This means, among other things, that one wants to first frame the issue as a dynamic problem, that is, one that involves one or more variables changing over time. The process for doing this in CBSD will be discussed in Chap. 3.

Participation

If people in a community are to be involved in developing informal causal maps and formal models that can be simulated, we first need to have a clearer understanding of what it means to participate in a modeling activity. Delineations of what is and is not group model building rest on different views of what constitutes participation and thereby determine whether or not a given activity fits under the heading GMB.

This also has political implications. For example, if a nongovernmental organization (NGO) or government seeks true participation to inform both the policy design and its implementation, then the claim is that the results have some type of true buy-in from one or more communities. A "slight of hand" can happen, however, if the process that involves communities yields an informal causal map, but the results used to inform policy making vis-à-vis a formal computer simulation model are only loosely related. In this kind of situation, the community believes it has participated and informed the policy making process as does the government or NGO sponsor of the project. Minimally, this can lead to misinformed policies. At its worst, it can result in the co-optation of marginalized communities and a participatory process by persons seeking to reinforce a status quo at the expense of marginalized communities. It is therefore essential to be clear on what we mean and how we define participation.

There is also a tendency to view participation as static as opposed to a dynamic process. Participation as a static concept focuses primarily on whether or not someone was involved at a particular point of time. So we look at the participation in a meeting and draw a conclusion about whether or not there was true participation. But participation can also be viewed as varying over time and a dynamic process. Someone might be quiet in one meeting and cautiously assessing the responses of facilitator, later speak up and get more involved, and eventually become an active leader in the group and drive the decision making. It is this latter view of participation that is critical to CBSD because few if any communities come prepared to do or understand system dynamics.

Fig. 1.4 Students from Ritenour High School reviewing clustered graphs over time on scaling up and sustaining systems thinking in schools in the Brown School Social System Design Lab, Washington University, as part of the Systems Thinking in Schools Institute, St. Louis, MO

In CBSD, community participation varies over time, from being involved as a passive source of information to active community mobilization and action (Kumar 2002). The essential point to recognize is that one wants to help design and facilitate a community process that moves participation along this continuum. In this sense, one is successful if participants move from being sources of information in a survey or structure elicitation exercise to active participants in making decisions about a model's development. On the other hand, one would have been ineffective or failed from a CBSD perspective if they started and ended a project with more or less at the same level of involvement. Participation in CBSD should therefore be seen as a process of building a community of practice around a model that empowers individuals to effectively use a model in a way that is consistent with its purpose and limitation (Lave and Wenger 1991). Figure 1.4 shows an example of Ritenour High School students leading a daylong workshop as part of the Systems Thinking in Schools Institute. The students have been involved in various group model building workshops over the years starting wtih participation in a group model building workshop.

Community Based

It may take several projects in a community before there is a critical mass within the community to become active in decision making around a model and use the tools for mobilization and action. This speaks to the fact that often the goal of a group model building project is not so much to build a model or analyze a policy as it is to increase awareness, capacity, and motivation for a subsequent group model building project (Rouwette et al. 2006). Some point out that how models built over the course of several distinct projects in one community with high involvement in modeling at one stage and less involvement in the modeling at a later stage can lead to social learning and capital development (Stave 2010). However, this aspect of system dynamics modeling—that modeling can happen multiple times on different topics within the same community—is often overlooked in the group model building literature and privileges views of learning and social capital at the level of individuals, teams, or groups over the larger collectives such as the organizations or communities.

CBSD takes a more explicit approach to working at the community level over the course of multiple engagements over time with different groups, with each group being seen as distinct even when there may be a significant overlap of individuals from one group to the next. Groups in this sense are and should be viewed as distinct because each group starts with new goals, expectations, norms, and dynamics that emerge and have to be managed in a group model building process. In this sense, CBSD is very much in line with the term "group" in the phrase "group model building."

While each group is seen as different, they are also increasingly connected in community settings through social networks in community-based efforts. Individuals from one project talk with others in their social networks. Over multiple projects within the same community, stories about causal maps, models, and the group model building experience accumulate and get transmitted to other parts of the community. Capacity and motivation develop for additional projects, but now more focused on community and driven by community members and often motivated to move more into formal computer simulation model building and analysis. The insights and results from these more rigorous analyses "feed back" into other conversations within the community. In CBSD, participation and results from multiple causal mapping and formal models with computer simulation within the same community coexist and reinforce insights.

This also means that the question of whether the goal in CBSD is limited to mainly informing the conceptualization of a model versus being involved more directly in the formulation and testing of a formal computer simulation models is somewhat meaningless. A snapshot of any one project within CBSD would not capture the larger context of what led up to the project, how the project participation and results interacted with other current projects, or how the project might fit into a longer term strategy to build one or more formal simulation models. In CBSD, there is, over time, high community participation in all stages of building a model from identifying the problem to conceptualization to model formulation and testing.

The central idea in CBSD is therefore recognizing that the continuity in the participatory modeling process comes not from continuity of individual participation in group but instead from continuity of working in the community (hence the term "community based"[2] in CBSD) *and* emphasis on building models (hence the fit

[2] Some have characterized the approach as better described as community driven, while others would see this fitting under the umbrella term of community-engaged research, but neither of these emphasize the importance of basing activities in a community in a way that facilitates accumula-

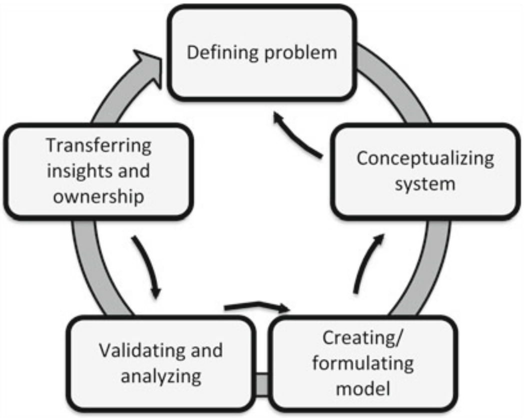

Fig. 1.5 Overview of the modeling process

between CBSD and term "model building" in "group model building").[3] This idea drives much of the content in this book, from the three stages of a CBSD project to the use of scripts to the assessing readiness and building capacity for CBSD in a community.

To visualize this, it is helpful to consider the system dynamics modeling process more explicitly over time. Figure 1.5 shows a typical cycle of a modeling process starting with problem definition that includes defining the reference mode, conceptualizing the system that focuses on identifying the various elements of the system and how they are related, creating or formulating a formal model that can be simulated, validating and analyzing the results to develop policy recommendations, and transferring insights and ownership of the model to the participants in the process. The process is highly iterative, requiring the one or more previous stages to be revisited as the group develops insights about the system, as indicated by thin, counterclockwise pointing arrows.

Most descriptions of the system dynamics modeling process have something similar to Fig. 1.5, and the tendency of viewing projects as single projects leads one to expect that one must pass through all stages of the modeling process in order to consider the project complete and successful.

In CBSD, multiple projects are distributed across various issues and time but exist within the same general community allowing the social learning and social capital around one or more models to accumulate over time. One way to illustrate this is in Fig. 1.6 where the *x*–*y* coordinates in the plane represent where a project is at any given time along the *z* or vertical coordinate. Initially, several projects may focus on defining the problem, and some may cycle back.

tion over time. Hence, I prefer the term "community based," and it is consistent with the common usage of a community-based participatory research (Minkler and Wallerstein 2008).

[3] The earliest articulation of this appeared in Hovmand et al. (2008) with work funded by the National Science Foundation (SES-0724577) and the Missouri Transformation Project, funded by the Substance Abuse Mental Health Services Administration Mental Health Transformation State Incentive Grant (McFarland, Chair; Goon, Co-Chair; SM57474- 01).

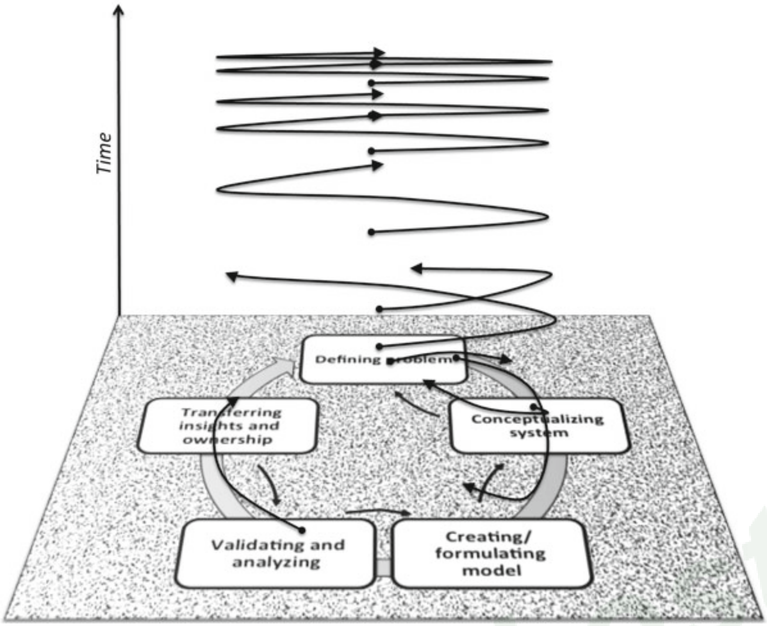

Fig. 1.6 Overview of multiple projects in a community in CBSD

A by-product of this process is that people are being educated in system dynamics and group model building and the capacity for identifying appropriate problems and engaging more effectively in system dynamics and group model building is increasing. So over time, more complex projects are undertaken that pass through additional stages of modeling until modeling projects routinely begin to complete all stages of the modeling process, and over time with even more capacity, the time required decreases.

Conclusion

This chapter has sought to motivate the case for CBSD and establish some of its main conceptual foundations. In doing so, key terms such as "mental models," "community," "participation," "group model building," "dynamic complexity," "informal causal maps," and "formal models" have been identified although not always defined. The overriding priority has been to describe these terms in a way that aligns with the pragmatics of conducting CBSD in diverse settings. In the chapters that follow, we will place more emphasis on the practice of engaging and involving communities in the process of understanding and changing systems from the endogenous or feedback perspective (Fig. 1.6).

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