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Transforming Food Systems at Local Levels: Using Participatory System Dynamics in an Interactive Manner to Refine Small-Scale Farmers' Mental Models

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Abstract

Food systems will need to undergo considerable transformation. To be better prepared for and resilient to uncertainty and disturbances in the future, resource users and managers need to further develop knowledge about the food and farming system, with its dominating feedback structures and complexities, and to test robust and integrated system-based solutions. This paper investigates how participatory system dynamics modeling can be adapted to groups at the community level with low or no formal educational background. The paper also analyzes the refinement of workshop participants' mental models as a consequence of a participatory system dynamics intervention. For this purpose, we ran two workshops with small-scale farmers in Zambia. Analysis of workshop data and post-workshop interviews shows that participatory system dynamics is well adaptable to support an audience-specific learning-by-doing approach. The use of pictures, objects and water glasses in combination with the basic aspects of causal loop diagramming makes for a well-balanced toolbox. Participants acquire understanding that is also relevant beyond systems thinking in that is offers a range of practical insights such as a critical evaluation of common food security strategies.

Keywords

adaptation; mental model refinement; food systems; knowledge management participatory modeling; system dynamics; systems thinking

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1 Introduction

Food systems will need to undergo significant transformation and adaptation in order to meet future challenges of achieving food security for all, decreasing environmental impacts and adapting to climate change (Foley et al., 2005, Godfray et al., 2010; Godfray et al., 2011). Food systems are social-ecological systems (SES) that consist of biophysical and social factors linked through feedback mechanisms (Berkes et al., 2003). These mechanisms determine the outcome of food systems over time. A wide range of policy and management actions is available to create positive outcomes at the micro-level in the face of the above-mentioned challenges. For the case of small-scale farmers in sub Saharan Africa, these actions include direct interventions on farm management practices, adoption of new technologies and knowledge management, incl. strengthening networks and local governance (Below et al., 2010). As SES are both complex and adaptive, they require resource users and mangers to continuously test and develop new knowledge and understanding in order to cope with change and uncertainty (e.g., Carpenter & Gunderson, 2001, Thompson & Scoones, 2009, Darnhofer et al., 2010). This reinforces the need for effective knowledge management.

The field of System Dynamics (SD) has a long tradition in facilitating learning about complex systems through the use of system diagrams and computer simulation models (Lane, 1992, Vennix, 1996, Sterman, 2000). It utilizes those tools to develop an understanding of the interdependent structures of dynamic systems, that is, the ability to: understand how the behavior of a system arises from the interaction of its agents over time (i.e., dynamic complexity); discover and represent feedback processes (both reinforcing and balancing) hypothesized to underlie observed patterns of system behavior; identify stock and flow relationships; recognize delays and understand their impact; identify nonlinearities; and recognize and challenge the boundaries of mental (and formal) models (Booth Sweeney & Sterman, 2000).

Participatory system dynamics employs the use of system diagrams (Videira et al., 2014) and computer simulation models (Andersen et al., 2007) in group-settings. While the purpose of participatory SD is commonly the construction of a running simulation model, the process accommodates a range of additional goals: mental model refinement, commitment, the creation of a shared language, consensus and alignment (Rouwette & Vennix, 2006). Davies et al., (2015) confirm the effectiveness of participatory SD in addressing wicked problems in social-ecological systems. This effectiveness, however, might be restricted in contexts in which computer simulation is not possible or not fit for purpose. For instance, computer simulation might erode confidence or lead to wrong conclusions if there are too many uncertainties about the data of the computer model. It might be equally ineffective when working with groups with low or no formal educational background.

As an alternative for the latter, in this paper, we tailor the participatory SD modeling process to groups at the community level with low or no formal educational background by using an interactive learning-by-doing approach. This approach unlocks participatory SD to a relatively new audience and acts as a knowledge management strategy that strengthens local communities through shared systems learning, networking and an increased focus on local governance and empowerment.

The objective of this paper is thus twofold. First, it adapts participatory SD so that it can be used as knowledge management strategy at the community level without being constrained by the educational background of the participants. Second, it explores how this adapted design for participatory SD workshops can facilitate mental model refinement and support decision making at the local level. For this purpose, we designed and ran two participatory SD workshops with small-scale farmers in Zambia. Video material from the workshops as well as interviews at two different times after the workshops allowed us to track changes in participants' systemic understanding of their food security and livelihood situation and options they considered for improving it. This data provides clear evidence that the participatory SD intervention effectively helped participants to improve their understanding of the archetype structures that lock them in a vicious circle of food insecurity and poverty. Additionally, the intervention provided participants with tools to evaluate not only the direct and short-term but also the indirect and long-term consequences of different coping and adaptation options.

2 Methods

A participatory SD process is generally broken down into three distinct stages: (1) problem scoping, (2) workshop planning, and (3) the actual participatory modeling workshops (Hovmand, 2014). The problem-scoping phase involves interviews and discussions to identify the problem of interest. The workshop planning phase designs the participatory modeling workshops by developing a series of activities or exercises and facilitated discussions that are eventually implemented in the workshops and evaluated afterwards. This section describes the participatory SD process in two case study villages in Zambia and the subsequent analysis of video and audio data.

2.1 Participatory system dynamics workshops

Site description

According to the Food Security Index (The Economist, 2013), Zambia belongs to the ten most food insecure countries. Agricultural productivity in the country is held back by a lack of access to input and services, as well as to transport, markets and other social infrastructure. At present, small-scale farmers do not have access to financial services, and even larger enterprises lack access to long-term finance. Soil fertility is decreasing, and agricultural farming systems are one sided. This is particularly the case for small-scale farmers and staple crops, mainly maize production (Neubert et al., 2011). External drivers, such as climate change and economic shocks, are posing increasingly significant challenges to the agricultural sector. Rainfall patterns have changed significantly since the late 1980s and, on average, delayed the onset of the rainy season by one to two months.

We conducted our participatory SD workshops in Chibombo district. Chibombo district is located in the Central Province, about 90 km to the north of Lusaka. It is a farming district where about 90% of the district population depends on agriculture for their livelihoods. The district lies within the Agro-Ecological Region II, spanning from east to west covering the central part of Zambia. It receives rainfall between 800 and 1200 mm per year and is characterized by relatively good soil fertility with limitations due to low nutrient retention and water holding capacity (FAO, 1998). Climatic conditions make it suitable for production of most common crops, such as maize, cotton, sunflower, cowpeas, beans, groundnuts, paprika, soya beans, and tobacco, amongst others. Small-scale farmers are

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responsible for over 75% of crop production in the district. Commercial agriculture is largely concentrated in the south of the district. The case study villages are located in the north of the district where small-scale agriculture is dominant.

Problem scoping and workshop planning

Our case study work started with problem scoping and workshop planning. We conducted in-depth interviews with 20 small-scale farmers where we focused on their dynamic decision making in the context of food security and livelihoods (Saldarriaga et al., 2014). Using these interviews, we inductively developed first hypotheses about problem issues and formalized them in a simplified causal loop diagram (CLD) (Spicer, 2015). CLDs are conceptual tools in which a chain of cause-and-effect relationships is traced through a set of variables that characterize a dynamic issue (Videira, et al., 2014). The CLD represented the main feedback loops driving household food security. To optimize the limited time available for the participatory SD workshops, we decided to build the workshop activities on this CLD, which serves as a conceptual model (Richardson, 2013), rather than starting from scratch.

Figure 1 shows the base CLD used for workshop planning. The CLD links the key stock variables through two major reinforcing feedback loops. Available financial assets (cash), the amount of food produced over the course of a harvesting season (produced food) and the actual food security situation (available food) are at the heart of farmers' concerns. The more cash a household has available, the more inputs (fertilizer, seed, herbicides) they can purchase. More inputs allow farmers to cultivate more land and thus increase the amount of food they produce. Some of this food is sold directly (cash crops) but often it is only sold if there is any surplus between what is produced and what is required to feed the household (represented in the variable available food). The more a household can sell, the more income they generate which adds to the stock of cash. A similar reinforcing feedback loop links livestock to cash (through sales of animal products or animals) and back to livestock (through purchases of additional livestock).

<Figure 1 about here>

We planned on building a similar CLD with workshop participants and to use the CLD to discuss a) mechanisms that cause food insecurity to persist over time, b) stressors to the system and c) options that are available to farmers for improving food system outcomes. The objective of the workshops was thus not to formulate and implement policy and management actions. This is part of subsequent steps in a participatory modeling process. Instead, our purpose was to improve the community understanding of the problem and the key relationships in the system by discussing the archetype structure outlined in the CLD.

To achieve our objectives, we tailored the participatory SD modeling process to contextual considerations such as participants' relatively low education levels and familiarity with learning processes using conceptual and abstracted frameworks for analysis. In this context, we think computer simulations might be confusing, ineffective and even meaningless as a tool to support a better understanding of the system structure and the behavior this structure gives rise to. Moreover, when working at a local community level, the infrastructure itself (appropriate equipment, electricity available, etc.) might be a constraint to showcase computer simulations. To overcome these challenges, we opted for a learning-by-doing approach that employed SD modeling and causal loop diagramming intuitively, without much explicit explanation. Instead, we used pictures and objects such as bags of harvested

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maize, hybrid seed or coins to visualize and clarify the concept of variables. We did not denote link polarity, nor did we explicitly mark loops as either reinforcing or balancing. We introduced regular drinking glasses filled with water as analogies for stock levels to tangibly capture desired states, to illustrate the behavior that feedback loops give rise to and to qualitatively simulate anticipated impacts of stressors and options.

Participatory modeling workshop

The participatory modeling workshop consisted of five main phases. One group facilitator, one modeler/reflector and three research assistants acting as process coaches and recorders (Hovmand, 2014) guided the process in the two case study villages. The workshops lasted approximately three hours with 10-15 participants each. In facilitated working groups, such as for learning, problem solving, or decision making, small size (7 to 15 people) is considered optimal, for it preserves individual positioning, but also gives rise to genuine group processes (Phillips & Phillips, 1993).

Phase one included framing and positioning of the problem, collecting important variables and setting system boundaries. During this phase, we discussed the most important aspects of food security and farmers' livelihoods and collected them as variables on the whiteboard via labels (sheets of paper with terms on them). We further conceptualized and distinguished variables by means of pictures and common objects. In phase two, connections between variables needed to be established by drawing links between variables. Phase three focused on defining desired states for the main stock variables and comparing them to perceived states of the real system. We visualized desired states by filling water into glasses. Subsequently, we used levels in water glasses to visualize actual states and reason about the dynamic implications of full or increasing and empty or decreasing glasses on other variables. Stressors that can change stock levels (both in decreasing inflows as well as increasing outflows) and subsequent effects due to feedback loops were addressed in phase four. Phase five concentrated on options for farmers to increase different stock levels and on how options can have multiple effects on the system, some of them unintended.

2.2 Data collection and analysis

Outcomes of participatory SD interventions go beyond the construction of a formal simulation model. In this paper, we focus on the effects of participatory SD on participants' mental models, and specifically on mental model refinement. The term mental model has a long history in the participatory SD literature (Forrester, 1971; Richardson & Pugh, 1981; Richardson et al., 1994; Vennix, 1996; Doyle & Ford, 1999; Kim, 2009; Rouwette et al., 2011; Black & Andersen, 2012; Groesser & Schaffernicht, 2012). In this paper, we use the term mental model to describe a "conceptual representation of a social problem that can be externalized in the form of a causal loop diagram" (Doyle & Ford, 1999: 414).

Several authors have recognized participatory SD as an ingredient of mental model refinement (Richardson, et al., 1994; Vennix, 1996; Akkermans & Vennix, 1997; Richmond, 1993; Maani & Maharaj, 2004; Rouwette, et al., 2011; Black & Andersen, 2012). During the modelling workshops, participants undergo a paradigm shift in their understanding of how the real world works. This allows them to think holistically and recognize connections between different actions and their effects (Richardson, et al., 1994; Maani & Maharaj, 2004).

 doi:10.20944/preprints201611.0131.v1

Directly evaluating the effect of a participatory SD workshop on participants' mental models is, however, not straightforward, and there are many different assessments proposed in the literature. In this paper, we draw on the assessment measures developed by Hopper & Stave, (2008), who differentiate between basic, intermediate or advanced systems thinking levels (Table 1).

< Table 1 about here >

To evaluate to which extent participants have changed their understanding of the world and incorporated feedback mechanisms and system thinking into their mental models we draw on videos of the workshops, workshop translations, and transcripts. We further substantiate the results by translated and transcribed interview data collected one week after the workshops. The interviews were supported by prints of pictures of the final workshop diagram (Figure 2) as the goal was to better understand if the participants could use the diagram in a meaningful way, and not to plainly test whether they had memorized systems concepts from the workshop. One year after the workshops, we interviewed participants again and asked them what they remembered from the workshops as well as what their experiences had been since the workshops, i.e., whether they had changed anything in their decision making relating to food security.

<Figure 2 about here>

Given that the participants had no prior training of causal loop diagramming or explicit socio-ecological systems thinking, if some level of mental model refinement has taken place as result of our intervention, we would at least expect to see (1) a participant's ability to handle the diagram and its logic to recollect and form causal chain and loop arguments as well as make dynamic inferences relating to the contents discussed during the workshop, and (2) a fair amount of overlapping responses from participants.

3 Results

Over the course of the workshops, farmers developed shared knowledge and understanding of their daily farming and food practice in terms of a farming and food system. Local practice-based knowledge was successfully integrated with science-based system concepts. Farmers developed the basic concepts of a dynamic feedback perspective and, on average, achieved an intermediate level of systems thinking. In particular, participants gained understanding of the following SD and systems thinking concepts:

- From items (orientation on practice) to variables (organization in categories). Participants became able to abstract items and activities that they use on a daily basis into variables as well as cause-and-effect relationships.
- From separate connections and simple causal links to chains and closed loops. Participants became able to link their activities throughout a farming season and the key decisions they make into closed feedback loops.
- From linear chains of events and simple dynamic descriptions of change to dynamic narratives of closed-loop behavior. In particular, participants developed an explicit understanding of reinforcing feedback and how such loops can work both as vicious as well as virtuous cycles.

- Broadening understanding of different food security options, display of conceptual agency in developing varied understandings through critical judgment and evaluating strategies. Participants started reflecting on unintended consequences and direct as well as indirect effects of proposed food security options.
- From a single strategy solution to a given problem to multiple solutions dependent on specific initial problem conditions. Participants explored different food security options depending on the initial situation on a given farm and developed various scenarios.

For the purpose of illustration, we include the analysis of two workshop phases before presenting results from the post-workshop interviews. We use short sequences (episodes) and an analysis of literal explanations from participants to assess mental model refinement.

3.1 Refinement of mental models during workshops

Phase 1: Defining variables

A critical episode took place during the first phase of both workshops (supplementary information 1). After having collected important variables, it was time to specify the meaning of variables by allocating pictures and objects to the respective variable labels. The diagram at this stage consisted of the following labels: cash, food produced, food available, inputs, livestock, water and land. Two pictures (rain and animals) had already been successfully placed. The picture for inputs (fertilizer and seed packs), on the other hand, had to be changed from produced food to inputs, in order to fulfill the requirements of categorical allocation. Thus, the diagram fragments already contained information on categorization and a short history of change and repair. Several participants pleaded for putting the picture of fertilizer and seed packs on the land label. This represents a process-oriented use of implements, as land is where implements need to go in farming. Other participants, however, disagreed and employed a more categorical form of interpreting the task. They put the picture of fertilizer and seed packs on the inputs label and explained that the picture represented these inputs. This involved some discussion where the group stated, challenged, tested and finally aligned their understanding under conditions of categorization.

At this point, we may assume that the group had resolved the tension by arriving at a shared understanding and was ready to move on and work on new challenges based on these insights. However, the new understanding was not stabilized and required another very similar round of alignment and repair. This time, it was not a picture of fertilizer and seed but a pack of actual fertilizer that had to be put. In other words, fertilizer now came in a different modality, which seemed to pose a somewhat different challenge. All in all, it took the group a total of 17 placements of pictures and tangible objects to align and stabilize their understanding of conceptual categorization of things highly familiar to them.

Phase 3: Behavior that feedback loops give rise to

Another critical episode in terms of mental model refinement took place in the third phase of the workshops (supplementary information 2). Right before, the participants accepted the water glass analogy and established desired levels for the three main stocks (cash, produced food and available food) by pouring water into the glasses. All glasses were filled to the brim. Hence, they specified their level of desire with “as much as possible” rather than a

 doi:10.20944/preprints201611.0131.v1

clear amount. At this point, the diagram resembled a simple qualitative SD model with feedback loops. The task now focused on using the diagram to reason about dynamic implications. However, the facilitator did not mention “dynamics” or “behavior” specifically. To initiate reasoning, the facilitator poured out water from the glass representing the amount of cash available and posed the question: “What if only this remains; then?”

The first proposed explanation to this question in the second workshop remained at the stage of open loop reasoning, where the participant explored multiple connections and cross-impact but no further feedback dynamics. A second participant, together with the facilitator and other members of the group, developed a narrative that employed the same conceptual characteristics but that was more detailed in terms of casual links and also more extensive as the narrative expanded beyond prior explanations. The vicious characteristic of the reinforcing loop developed as a consequence of those detailed and extended explorations. Throughout this episode, the participants managed to stabilize the conceptions of existing loops and causal paths as well as their dynamic implications. This understanding increased their conceptual agency and empowered them to use their new knowledge to actively shape subsequent arguments.

After this episode, the water glass analogy remained a crucial anchoring point for subsequent discussions of stresses to the system and finally, the evaluation of available options to shift loop direction towards a virtuous cycle and to increase accumulation in the respective resource stocks.

3.2 Mental model refinement beyond the workshops

Post-workshop interviews further illustrate mental model refinement. Here, we report separately on interviews conducted one week after the workshops and interviews conducted one year after the workshops.

Interviews one week after the workshops

During the interviews and with the CLD at hand (Figure 2), participants displayed a fairly high degree of convergence on systemic issues and option development to increase food security. They converged on their use of language, on their ability to meaningfully draw connections between crucial variables and identify loops. The participants were able to use the conceptions within the diagram while applying them to different scenarios and situational considerations. Also, the participants extended the discussion of issues beyond the visible while remaining able to reason in a concise, systemic way.

Apart from describing the most important causal chains and reasoning along the loops, participants also extensively reasoned about some specific issues or concentrated on specific aspects within the system. The interview excerpt with female participant 7 in workshop 2 (ii_FP7) illustrates a participant’s understanding of how feedback loops work and how different activities or decisions such as purchasing food versus purchasing seed determines whether a reinforcing feedback loop acts as a vicious or virtuous cycle. The participant elaborates on one specific issue – being caught in the poverty trap that threatens food security and limits one’s prospects for progress. According to her, one needs to have enough food to sustain oneself and enough cash to re-start the production process. From there, slow progression is possible. If one has only food but no cash or cash but no food, starting the production loop seems infeasible. Food is sold for cash worsening food

 doi:10.20944/preprints201611.0131.v1

insecurity. Cash is used to buy food, which undermines the purchase of seed. Also, her description holds the notion of accumulation as a process over time:

- *ii_FP7: Because you can have food but if you don't have cash it's a problem, because you start selling the food to solve other problems. ... That's where I want to talk about when you farm here (production loop) it will help you to avoid buying food, because when you start buying food it means that the glass for cash will reduce. So it is better when you find cash you buy seed or fertilizer than buying food, and like that you can improve a bit.*
- *Male interviewer: Okay, so meaning you have improved a bit as well on the glass (cash)?*
- *ii_FP7: Yes but this glass (cash) does not just get full at once. You just do it bit by bit, so it does not get full at once. ...Most of the time, you can be having cash and you can just be buying food. Hence cash cannot manage to reach here (production) and like that you cannot fill in the glass (cash).*

In another exchange with the male interviewer (MI), the issue was explored further, leading to the elaboration of an aspect that further reinforces the vicious cycle. If one has no money to buy certified seed, recycled seed is used, which in turn leads to a decrease in production, consequently worsening food security and prospects for selling produced food at the same time. Also the topic of piecework (laboring work) is explored in comparison with food production as a means for income:

- *MI: Now where does that little money come from? Because we want to know the source of the little money, is it from piecework, maize or what?*
- *ii_FP7: Sometimes it comes from piecework.*
- *MI: Okay.*
- *ii_FP7: When you find that little money before you reach this side (production) ... because when you find cash and it's little, such that you cannot reach here (inputs), it will not be possible for you to buy inputs because you used that little money to buy food, then you will be forced to use the recycled seed for planting. Hence, you will have less produced food.*

Above all, the interviews show the participants' ability to make active, deliberate use of the CLD at hand, which reflects their understanding of some of the archetype structures underlying the dynamic of the system. This evidence suggests participants have incorporated a systemic way of thinking of the problem into their refined mental models and that participants can recognize feedback loop connections between different elements. They verbally recreate and meaningfully embed further understanding of a multi-loop system in a causally consistent manner. And, they actively respond to and frame the conversation in accordance with the interviewer's focus on systemic aspects and options to increase food security and livelihoods.

Interviews one year after the workshops

One year after the workshops, we asked participants what they remembered from the workshops and what their experiences in terms of decision making, food security and livelihoods had been in the meantime. For these interviews, we did not show pictures of the diagrams that had been developed during the workshops. Instead, participants recreated what they remembered from the diagram and the narratives around the diagram. Figure 3 shows diagrams drawn with one participant per workshop. The diagrams illustrate the persistence of participants' understanding of the archetype structures developed during the workshops and some of the diagrams even contain additions by the participants that helped them reflect on the behavior generated by the feedback loops and the impact of various options to improve their food security and livelihood situation.

< Figure 3 about here >

In several interviews, participants commented on how the diagram had served as an eye opener in the sense that it had helped them see the interconnected nature of the different decisions that they make throughout the year. As a consequence, most of them started budgeting for food and/or money in coordination with their spouse to prevent the reinforcing feedback loop between food and money to act as a vicious cycle.

The water glass metaphor remained a strong analogy after one year. This became obvious every time participants listed options beyond budgeting that they had tried out to "fill the water glasses", such as investments in livestock or in small business. The experiences with implementing these options were mainly positive. However, participants also commented on the delicate balance one needs to strike when investing, as purchasing livestock, for example, can erode the remaining cash level too much or create ongoing pressure on the cash and food stocks because of the running costs related to keeping livestock. All these processes create the danger of turning the reinforcing feedback loops in the system into vicious cycles.

The limits to the diagram and narrative developed throughout the workshops became obvious in discussions with participants that focused on the production of charcoal from cutting wood as an option to increase the available cash. While farmers were aware of the long-term danger and side effects of this option, they saw no other short-term option to set the reinforcing feedback loops in motion. They talked about the need to exit the charcoal strategy after some time to avoid the occurrence of unintended consequences and vicious cycles but remained fairly vague about specifics.

4 Discussion

The system dynamics model at the heart of a participatory modeling process (in our case, a mix between a qualitative system diagram such as a CLD and a full computer simulation model) provides a platform for identifying and evaluating the relative merits of different policy and management actions. In line with Antunes et al., (2015), our results show that the SD model helped expand participant ideas about the range of potential policy and management actions by showing system-wide points of intervention. It also facilitated the development and use of shared language and shared content among workshop participants.

4.1 Practical insights

The newly acquired understanding is relevant beyond the workshops and offers a range of practical insights for workshop participants. Here we elaborate on how the workshops provided participants with a differentiated evaluation of common practices such as piecework (laboring work), an appreciation of how the activities of men and women affect each other and how they are positioned within the entire food and farming system, and how the workshops enabled participants to critically discuss how the government, particularly with its fertilizer subsidies, affects the working of reinforcing feedback loops between food production and income, and livestock and income, respectively.

Piecework

Short-term laboring work or piecework is an important coping strategy to ensure food security in the lean season (Kent & MacRae, 2010, Cole & Hoon, 2013). It is undertaken on other people's farm and labor is typically exchanged for cash or food. This exchange enables those short of food and/or cash to navigate through the lean season. However, it can have longer-term consequences in that it may restrict a farm's own ability to cultivate a sustained food supply (e.g., Whiteside, 2000). Discussing piecework as one option to fill up the water glasses on our diagrams lead to a differentiated evaluation of the short- as well as long-term impacts of piecework, not only on the cash variable, but also on all the other variables on the diagram:

- *ii_FP9 9: Yes, so I was saying the only common piecework we have here is weeding the fields for your friend, and they give you money; now I was saying this piecework here in the village, it is quite dangerous. You work in your friend's field, and do the weeding; in the mean time your field will lose out because of weeding for someone, and your crop will die in the grass.*
- …
- *ii_MP2: Piecework is not just cultivating your friend's field; yes piecework is in a lot of ways. Okay let's come back to the same issue of weeding for someone; for instance I get money, and I manage to do my field; and I finish all the programs. Now, there is no money in the house; now there comes, my bull is sick; then someone without oxen wants me to go and weed his maize with a cultivator, that's piecework. And now, I don't have the money, so in such a case; I need to go and weed his maize, in the meantime my field is already done, but then where to get some more money I don't have. So it's better for me to go and weed for someone, and after getting money; I can now go and buy medicine for the bull.*

One of the natural consequences of this differentiated evaluation of piecework as a coping strategy for farmers was to emphasize the need for proper planning. When reflecting on the need for planning, participants transferred the insights from the discussion around piecework to other household decisions and activities:

- *i_MP5: Most importantly I have learnt that, one, I need to have a disciplined budget, because sometimes like some mentioned; the budget needs to be disciplined, for instance you have livestock, and you decide to sell one, treat this as a debt that you need to replace the animal. Because if you take it casually to say, this is my animal and it's okay if I sell it, it means you will not be able to replace it; it means your budget will be disturbed and so everything else will be disturbed. Then also, I have learnt that we need to set goals in everything we do; for instance school going children, usually it's not always that they make it to the next grade that we are required to pay school fees. But rather, it's once maybe the whole year, so if I didn't plan for this and it so happens that the only way out is to sell the food I reserved; imagine how much I would need to raise maybe the required say one thousand Kwacha or maybe if I had to sell some livestock, I would need maybe oxen to raise this money. Then, it simply means my livestock will be affected; and so the most important lesson I have learnt from this is the emphasis on our life circle, the way we need to live, and also the need we have to prepare for the future.*

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Gender roles and their interconnections

The gender distribution among workshop participants was, by design, quite even. Although we never explicitly discussed gender issues, it was quite clear that men and women are responsible for managing different stock variables in our diagram. Gradually, workshop participants started reflecting on their own position within the diagram and the importance of their own or their spouses' decisions for the overall development of food security and livelihoods over time:

- *ii_MP3: Just there on the food reserves, you can do the preparation very well to such an extent that the reserves are full; yes you buy salt for the household, maybe it's actually a sack. Now when our spouses go to fetch water, they start boosting to their friends that we have a sack of salt; don't worry there is no problem. They give maybe a big cup full to their friend until finally the salt is finished, now the question is, will that bag last till the end of the year? It will not reach; which means a problem has now entered there (food availability).*
- …
- *ii_FP2: For instance the men, there (cash) I believe that they have understood, they will not be flirting around taking money to their mistresses; the money will be retained in the homes.*

Eventually, participants acknowledged that men and women in a household had to support each other if they wanted to reap the benefits of the reinforcing feedback loops:

- *i_MP2: Whatever we have discussed here if you try to break any of these; she can remind you, no no, this is not what we learnt.*
- …
- *i_MP2: So that as we go, we can be helping each other*

Role of the government

Another instance of transfer from issues that were explicitly portrayed on the diagram to related issues was a fairly extended discussion of how the government influenced the reinforcing feedback loop between cash and production:

- *i_MP2: We have seen how we are supposed to do things; … Yes government has introduced this fertilizer support program, but then this support program since inception, we find ourselves totally dependent upon it such that others have even died within this program. But then, when we look at this program, my question is; how helpful is this in helping us fill our cups or rather how does this prevent us from filling our cups?*
- …
- *i_MP3: Okay in short where we have shortcomings, the time we are given this fertilizer; normally they delay to give us the fertilizer.*
- *MF: So it comes very late.*
- *i_MP3: Yes Why I say so, it's because we learning conservation farming by ripping; now ripping requires that once you do the ripping, make sure you plant together with fertilizer. Now what happens is that this fertilizer is delayed, and so if you rip*

but you don't plant together with fertilizer, usually the maize doesn't do well; we have seen this from our friends and other people who don't use fertilizer when planting. Yes, the government does bring the fertilizer; but usually it comes very late, and if we very much rely on this, even if we desire to use the new methods of farming, this will not meet our desires, and hence our cups will not be filled because we shall be waiting for fertilizer.

- …
- *i_MP2: So my question there is that, let's take it we are given on time, at one time we are given this; now next year, and the other year should I continue being with them so that I can continue filling my cup or should I plan there to come out, and be independent, and work on my own, and have my own source of income and work without expectation of these government policies?*

4.2 Workshop design features for learning-by-doing approach

The context of our workshops was a natural one, i.e., we had no experimental control that would have allowed us to attribute mental model refinement to specific features of our modeling workshops. Here, we reflect on some features that may have been beneficial for facilitating the observed mental model change.

A substantial amount of workshop time (between 20 and 30%) was dedicated to the identification and discussion of concepts that then became variables in the jointly developed CLD. Using pictures and objects from familiar contexts seems crucial in developing a more conceptual understanding of classifications that are in line with variable and stock definitions in terms of systems thinking. This disentanglement and classification is the very prerequisite for further development of any of the skills and concepts related to systems thinking. However crucial, the assumption about a basic understanding of variables seems so pervasive that it is not even mentioned in existing systems thinking frameworks. We would argue, though, that it is worthwhile spending some time clarifying the definition of variables, also in other contexts.

Computer simulation is an important component of SD in general and of participatory SD in specific. Introducing computers and computer simulation models to our workshop audience, however, did not seem appropriate. Instead, we chose the analogy of the water glass to visualize stock variables in the CLD, to illustrate the behavior generated by the feedback loops in the diagram and to qualitatively simulate anticipated impacts of stressors and options. The water glasses proved to be extremely powerful in achieving these objectives. In addition, they seemed to serve as a bridge for linking farmers' considerations about their real-world farming and food domain with the processes described in the CLD. This was particularly the case when farmers reflected on what they had learned from the workshops and talked about the role of the government in terms of filling the glasses, the need for teaching their spouses about the glasses and the decisions about the glasses that they need to make at different times throughout a year.

5 Conclusions

Resource users and managers such as small-scale farmers possess in-depth knowledge of their food system, together with associated management practices (Berkes et al., 2000). To

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be better prepared for and resilient to uncertainty and disturbances in the future, they need to further develop knowledge about the food and farming system as a system, with its dominating feedback structures and complexities. Such knowledge and understanding is critical for continuous adaptation and for testing robust and integrated system-based solutions (Holling, 2001, Wiek et al., 2011), as feedback structures and complexity often cause well-intentioned solutions to have unanticipated consequences (e.g., Moxnes, 2004; Sterman, 2008).

The purpose of this paper was to study participatory system dynamics in a context where qualitative causal loop diagramming (CLD) is not enough but at the same time, quantitative computer simulations are not suited for the purpose of building intuition into feedback structures and the dynamics they give rise to. We presented a simplified participatory system dynamics workshop design that substitutes computer simulations with a learning-by-doing approach and evaluates the outcomes of this workshop design in terms of mental model refinement. For this purpose, we ran two participatory SD workshops on food security and livelihoods with small-scale farmers in Zambia. We complemented the workshops with follow-up interviews to test the knowledge gained about the complex archetype structures underlying the system behaviour.

Our analyses show that participatory SD is well adaptable to support an audience-specific learning-by-doing approach. The use of pictures, objects and water glasses in combination with the basic aspects of causal loop diagramming makes for a well-balanced toolbox. It provides incentives for engagement through familiar items from participants' day-to-day practice while at the same time posing conceptual challenges that need to be resolved in the group. Furthermore, the understanding of a relatively small number of system concepts is required to allow for a broad range of systemic considerations. These are: the concept of variables as independent entities, disentangled from their daily and procedural use; the conceptual understanding of causal relations between those entities; the conception of a closed loop; the concept of stock levels; the concepts of reinforcement and self-regulation; the concept of cross-impact; and the conception of dependence on initial states.

The two knowledge domains, local or practice-based knowledge and science-based knowledge, clearly interplay: one within which the participants hold knowledge of their real world farming and food domain and one that employs knowledge of the systems thinking domain. The further the process of causal loop diagramming, the less intense becomes the conceptual learning effort but the more complex and fluid becomes knowledge integration. In other words, while in the beginning participants are busy developing understanding of concepts from a systems perspective, in the end they are busy integrating them with other forms of knowledge in more complex tasks such as option development and evaluation.

While we focused on tailoring the participatory modeling exercise to groups at the community level with low or no formal educational background, the applications of this learning-by-doing approach are wider than that. There are other settings where computer simulations might not be appropriate or recommended, even when dealing with participants with a high level of formal education. If participants are not used to analyzing graphs or are unfamiliar with computer modeling techniques, charts produced during the simulation might be confusing, lead to wrong conclusions and diminish confidence in the process. In these contexts, and if the goal of the modeling process is learning rather than elicitation, participants might appreciate an interactive approach just as much or more than reading simulation output.

Modeling of complex systems in a shared learning process such as the processes facilitated by participatory SD becomes more important than the model as a mere product for decision making (Dogliotti et al., 2014). However, it also becomes clear that systems thinking and knowledge integration are only one component of SES transformation. The specific systems thinking competences gained that allow participants to consider a broader variety of policy and management actions and to evaluate them in a different way, are still disconnected from any practical implementation. The current, implicit expectation of this knowledge strategy is that conceptual change and knowledge integration is a precursor to behavioral change. How to facilitate behavioral change from conceptual change, however, is a separate and challenging task. Further research thus needs to investigate which knowledge aspects or heuristics (e.g. "trying to fill the glasses") have a potential to guide farmers in real-life monitoring, decision making and finally implementation of policy and management actions to improve food system outcomes. Next steps in the participatory SD process also need to include more explicitly power and interest issues and their heterogeneity among and across a variety of stakeholders at a variety of levels (e.g., Enfors et al., 2008, Cote & Nightingale, 2011). Such research will help systems thinking and participatory SD move beyond one-time-learning to providing tools for continuous, informed and reflective systems action.

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8 Conflicts of interest

The authors declare no conflict of interest.

9 References

Akkermans, H. A., & Vennix, J. A. M. (1997). Clients' opinions on group model-building: an exploratory study. *System Dynamics Review, 13*(1), 3-31. doi: 10.1002/(SICI)1099-1727(199721)13:1<3::AID-SDR113>3.0.CO;2-I

Andersen, D. F., Vennix, J. A. M., Richardson, G. P., & Rouwette, E. A. J. A. (2007). Group model building: problem structuring, policy simulation and decision support. *Journal of the Operational Research Society, 58*(5), 691-694.

Antunes, M. P., Stave, K. A., Videira, N., & Santos, R. (2015). Using Participatory System Dynamics in Environmental and Sustainability Dialogues. In M. Ruth (Ed.), *Handbook of Research Methods and Applications in Environmental Studies* (pp. 346-374). Cheltenham, UK; Northampton, MA, USA: Edward Elgar Publishing.

Below, T., Artner, A., Siebert, R., & Sieber, S. (2010). Micro-level Practices to Adapt to Climate Change for African Small-scale Farmers. A Review of Selected Literature *IFPRI Discussion Paper* (pp. 21). Washington, DC: International Food Policy Research Institute.

Berkes, F., Colding, J., & Folke, C. (2000). Rediscovery of Traditional Ecological Knowledge as Adaptive Management. *Ecological Applications, 10*(5), 1251-1262. doi: 10.2307/2641280

Berkes, F., Colding, J., & Folke, C. (2003). *Navigating Social-Ecological Systems. Building Resilience for Complexity and Change*. New York, NY: Cambridge University Press.

Black, L. J., & Andersen, D. F. (2012). Using Visual Representations as Boundary Objects to Resolve Conflict in Collaborative Model-Building Approaches. *Systems Research and Behavioral Science, 29*(2), 194-208. doi: 10.1002/sres.2106

Booth Sweeney, L., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review, 16*(4), 249-286.

Carpenter, S. R., & Gunderson, L. H. (2001). Coping with collapse: Ecological and social dynamics in ecosystem management. *BioScience, 51*(6), 451-457. doi: 10.1641/0006-3568(2001)051[0451:cwceas]2.0.co;2

Cole, S. M., & Hoon, P. N. (2013). Piecework (Ganyu) as an indicator of household vulnerability in rural Zambia. *Ecology of Food and Nutrition, 52*(5), 407-426. doi: 10.1080/03670244.2012.719360

Cote, M., & Nightingale, A. J. (2011). Resilience thinking meets social theory: Situating change in socio-ecological systems (SES) research. *Progress in Human Geography, 36*(4), 475-489. doi: 10.1177/0309132511425708

Darnhofer, I., Bellon, S., Dedieu, B., & Milestad, R. (2010). Adaptiveness to enhance the sustainability of farming systems. A review. *Agronomy for Sustainable Development, 30*(3), 545-555. doi: 10.1051/agro/2009053

Davies, K. K., Fisher, K. T., Dickson, M. E., Thrush, S. F., & Le Heron, R. (2015). Improving ecosystem service frameworks to address wicked problems. *Ecology and Society, 20*(2). doi: 10.5751/ES-07581-200237

Dogliotti, S., Rodríguez, D., López-Ridaura, S., Tittonell, P., & Rossing, W. A. H. (2014). Designing sustainable agricultural production systems for a changing world: Methods and applications. *Agricultural Systems, 126*(0), 1-2. doi: http://dx.doi.org/10.1016/j.agsy.2014.02.003

Doyle, J. K., & Ford, D. N. (1999). Mental models concepts revisited: some clarifications and a reply to Lane. *System Dynamics Review, 15*(4), 411-415.

Enfors, E. I., Gordon, L. J., Peterson, G. D., & Bossio, D. (2008). Making investments in dryland development work: Participatory scenario planning in the Makanya Catchment, Tanzania. *Ecology and Society, 13*(2).

FAO. (1998). Wetland Characterization and Classification for Sustainable Agricultural Development. Harare: Food and Agriculture Organization of the United Nations (FAO).

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., . . . Snyder, P. K. (2005). Global Consequences of Land Use. *Science, 309*(5734), 570-574. doi: 10.1126/science.1111772

Forrester, J. W. (1971). *Principles of Systems*. Cambridge, MA: Productivity Press.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., . . . Toulmin, C. (2010). Food security: The challenge of feeding 9 billion people. *Science, 327*(5967), 812-818.

Godfray, H. C. J., Pretty, J., Thomas, S. M., Warham, E. J., & Beddington, J. R. (2011). Linking Policy on Climate and Food. *Science, 331*(6020), 1013-1014. doi: 10.1126/science.1202899

Groesser, S. N., & Schaffernicht, M. (2012). Mental models of dynamic systems: taking stock and looking ahead. *System Dynamics Review, 28*(1), 46-68. doi: 10.1002/sdr.476

Holling, C. S. (2001). Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems, 4*(5), 390-405. doi: 10.1007/s10021-001-0101-5

Hopper, M., & Stave, K. A. (2008, July 20 – 24). *Assessing the effectiveness of systems thinking interventions in the classroom.* Paper presented at the 26th International Conference of the System Dynamics Society, Athens, Greece.

Hovmand, P. S. (2014). *Community Based System Dynamics*. New York, Heidelberg, Dordrecht, London: Springer.

Kent, R., & MacRae, M. (2010). Agricultural livelihoods and nutrition - exploring the links with women in Zambia. *Gender and Development, 18*(3), 387-409.

Kim, H. (2009). In search of a mental model-like concept for group-level modeling. *System Dynamics Review, 25*(3), 207-223. doi: 10.1002/sdr.422

Lane, D. C. (1992). Modelling as learning: A consultancy methodology for enhancing learning in management teams. *European Journal of Operational Research, 59*(1), 64-84. doi: http://dx.doi.org/10.1016/0377-2217(92)90007-V

Maani, K. E., & Maharaj, V. (2004). Links between systems thinking and complex decision making. *System Dynamics Review, 20*(1), 21-48. doi: 10.1002/sdr.281

Moxnes, E. (2004). Misperceptions of basic dynamics: the case of renewable resource management. *System Dynamics Review, 20*(2), 139-162.

Neubert, S., Kömm, M., Krumsiek, A., Schulte, A., Tatge, N., & Zeppenfeld, L. (2011). *Agricultural development in a changing climate in Zambia. Increasing resilience to climate change and economic shocks in crop production* (Vol. 57). Bonn: Deutsches Institut für Entwicklungspolitik.

Phillips, L. D., & Phillips, M. C. (1993). Faciliated Work Groups: Theory and Practice. *The Journal of the Operational Research Society, 44*(6), 533-549. doi: 10.2307/2584511

Richardson, G. P. (2013). Concept models in group model building. *System Dynamics Review, 29*(1), 42-55. doi: 10.1002/sdr.1487

Richardson, G. P., Andersen, D. F., Maxwell, C. A., & Stewart, T. R. (1994). *Foundations of mental model research.* Paper presented at the 12th International Conference of the System Dynamics Society, Stirling, Scotland.

Richardson, G. P., & Pugh, A. (1981). *Introduction to System Dynamics Modeling*. Williston, VT; Waltham, MA: Pegasus Communications.

Richmond, B. (1993). Systems thinking: Critical thinking skills for the 1990s and beyond. *System Dynamics Review, 9*(2), 113-133. doi: 10.1002/sdr.4260090203

Rouwette, E. A. J. A., Korzilius, H., Vennix, J. A. M., & Jacobs, E. (2011). Modeling as persuasion: the impact of group model building on attitudes and behavior. *System Dynamics Review, 27*(1), 1-21.
Rouwette, E. A. J. A., & Vennix, J. A. M. (2006). System dynamics and organizational interventions. *Systems Research and Behavioral Science, 23*(4), 451-466. doi: 10.1002/sres.772
Saldarriaga, M., Nyanga, P., & Kopainsky, B. (2014, July 20 - 24). *Dynamic decision making in coupled social-ecological systems. Smallholder farmers' goals, resources and constraints in improving food security and adapting to climate change in Zambia.* Paper presented at the 32nd International Conference of the System Dynamics Society, Delft, The Netherlands.
Spicer, J. (2015, July 19 - 23). *Representation and dynamic implications of mental models of food systems. A case study of dynamic decision making of small-scale farmers in Zambia.* Paper presented at the 33rd International Conference of the System Dynamics Society, Cambridge, MA.
Sterman, J. D. (2000). *Business dynamics. Systems thinking and modeling for a complex world*. Boston et. al.: Irwin McGraw-Hill.
Sterman, J. D. (2008). Risk communication on climate: Mental models and mass balance. *Science, 322*, 532-533.
The Economist. (2013). Global Food Security Index 2013. An Annual Measure of the State of Global Food Security. London; New York; Hong Kong; Geneva: The Economist, Intelligence Unit.
Thompson, J., & Scoones, I. (2009). Addressing the dynamics of agri-food systems: an emerging agenda for social science research. *Environmental Science & Policy, 12*(4), 386-397. doi: http://dx.doi.org/10.1016/j.envsci.2009.03.001
Vennix, J. A. M. (1996). *Group Model-Building: Facilitating Team Learning using System Dynamics*. Chichester: Wiley.
Videira, N., Schneider, F., Sekulova, F., & Kallis, G. (2014). Improving understanding on degrowth pathways: An exploratory study using collaborative causal models. *Futures, 55*(0), 58-77. doi: http://dx.doi.org/10.1016/j.futures.2013.11.001
Whiteside, M. (2000). Ganyu Labor in Malawi and its Implications for Livelihood Security Interventions: An Analysis of Recent Literature and Implications for Poverty Alleviation *Agricultural Research and Extension Network Paper*: ODI (Overseas Development Institute).
Wiek, A., Withycombe, L., & Redman, C. (2011). Key competencies in sustainability: a reference framework for academic program development. *Sustainability Science, 6*(2), 203-218. doi: 10.1007/s11625-011-0132-6

10 Tables

Table 1: Assessment measures by level of systems thinking (summarized from Hopper & Stave, 2008)

Systems Thinking Level	Skills	SD/Systems Concepts
Basic	Recognizing Interconnections Identifying Feedback Understanding Dynamic Behavior	• System as a whole • Interconnections • Cause-effect relationships • Chains of causal relationships • Closed causal chains, Feedback • Polarity of individual relationships • Polarity of feedback loops • Feedback generates behavior • Delay • Types of feedback structures • Types of behavior patterns
Intermediate	Differentiating Types of Variables and Flows Using Conceptual Models	• Stocks and flows • Material and information flows • General system principles • Conceptual models
Advanced (For some beyond the definition of systems thinking)	Creating Simulation Models Testing Policies	• Relationships in mathematical terms (model equations) • Simulation model • Validation • Model simulation • Policy levers • Effect of changes • Hypotheses • Policy

11 Figures

Figure 1: Highly aggregated causal loop diagram distilled from in-depth interviews with farmers. The diagram shows the main reinforcing feedback loops responsible for livelihoods (represented by the variable „cash“) and food security (represented by the variable „available food“).

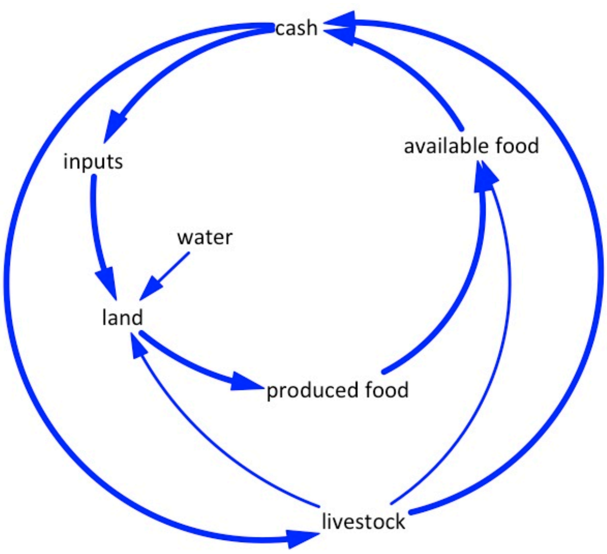

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Figure 2: Final diagrams developed in the two workshops. Variables are written out as well as visualized both with pictures and objects. Water glasses are placed on stock variables to illustrate the processes building and depleting stocks and the behavior that feedback loops give rise to.

Figure 3: Diagrams drawn with and by one participant of each workshop, one year after the workshops were held. The diagrams contain most if not all of the original variables and links and some participants add more variables that seem to be important for reflecting on how participants' decisions dynamically affect food security and livelihood outcomes.