KILT: A Modelling Approach Based on Participatory Agent-Based Simulation of Stylized Socio-Ecosystems to Stimulate Social Learning with Local Stakeholders

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Abstract. A new approach is introduced under the slogan «Keep It a Learning Tool» (KILT) to emphasize the crucial need to make the purpose of the modelling process explicit when choosing the degree of complicatedness of an agent-based simulation model. We suggest that a co-design approach driven by early-stage and interactive simulation of empirical agent-based models representing stylized socio-ecosystems stimulates collective learning and, as a result, may promote the emergence of cooperative interactions among local stakeholders.

Keywords: Participatory agent-based simulation · Social learning
Stylized landscape · Role-playing game · Companion modelling

1 Introduction

An agent-based simulation is said to be "participatory" as soon as some decisions of the agents are entrusted to the participants. A typology of simulations has been proposed by Crookall and his colleagues [1]. They distinguished two types of simulations depending on who controls it, and where the focus is. When the simulation is mainly controlled by the computer, the focus of interaction can be set on computer-participant interactions (participants observe the simulation run in the manner of a cinema audience), or on participant-participant interactions (participants can intervene while the simulation runs or at intervals provided during the run). In any of these cases, the flexibility of the simulation remains limited. A second type is when the simulation is mainly controlled by the participants. The focus of interaction can then be set on computer-participant ("flight simulator" for which generally only one user interacts continuously with the simulation), or on participant-participant. In that last case, participants will be confronted with concrete situations, acted out by the organizers of the participatory simulation workshops, which they must react to.

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This type of interactive participatory agent-based simulation is very similar to what is called a computer-assisted role-playing game in the framework of the companion modeling approach [2–4]. As pointed out by Barreteau [5], there is a striking correspondence between the features of an agent-based simulation and a role-playing game session: agent/player, role/rule, game-turn/time-step, game board/interface. This similarity is due to the fact that, from a formal point of view, a role-playing game is a kind of multi-agent system: it is composed of interacting entities, evolving in a shared environment, each one seeking to achieve a specific goal. Apart from the simulation of agents' decisions, the computerization may also support the following features: (i) recording the decisions of human agents, which enables computing performance indicators (results of their actions) and "replaying" the session during the debriefing; (ii) simulating the dynamics of the resources; (iii) visualizing the updated state of the resources and the positioning of the agents, possibly according to points of view specific to each type of players [6].

In computer science, participatory agent-based simulation represents a fertile ground for improving the techniques of Artificial Intelligence related to supervised learning such as inverse reinforcement learning or support vector machines [7]. Introducing assistant agents with learning abilities can help eliciting the behavior of human participants and also supporting them to make decisions during the course of the simulation [8]. Participatory agent-based simulation sessions have been successfully used as an experimental framework to extract interaction patterns in negotiated (written) elements between participants [9].

By integrating the HubNet module into the NetLogo platform, which allows interconnecting several identical user interfaces to the same simulation, Wilensky and Stroup [10] paved the way for using participatory simulation to facilitate the learning of complex systems to students. One of the first applications of HubNet is called Gridlock[1]. It is a simulation of car traffic in real time where each student controls a traffic light while the teacher controls the global variables, such as speed limit and number of cars. The group is challenged to develop strategies to improve traffic and discuss the different ways of measuring the traffic quality [11]. Another example of the educational potential of interactive multi-agent simulations is given by the experiment on the spread of a contagious disease conducted with US high school students [12]. A network of miniature communicating computers (tags) allows simulating the spreading of a virus among the participants, each of them wearing a tag as a bracelet, only one being initially infected. Participants are challenged to meet as many people as possible without getting sick. To stimulate experiential learning, students were told nothing about how the virus moved from one tag to another, the degree of contagiousness, the possibility for latency.

In such an immersive configuration, the space of interactions does not have to be "re-presented" to the participants. In most of the applications of participatory agent-based simulation anyway, space has to be explicitly represented into the model. This is of particular importance when the target system is a socio-ecosystem. The distribution of a participative multi-agent simulation on several computers is an

[1] http://ccl.northwestern.edu/netlogo/models/HubNetGridlockHubNet.

efficient way of staging information asymmetry between participants. It is then interesting to observe if participants take the initiative to share certain information - initially private - with others. When the objective is to improve the mutual understanding between the participants, it becomes critical to encourage direct interaction between them and to stimulate exchanges. Representing a common visualization space and a support to materialize the decisions of the players with pawns and tokens, a large game board (so that everyone can sit around) is a configuration that answers perfectly to this need. For instance, the environment of the *SAMBA* model, developed in Vietnam [13, 14], consists of a rectangular support filled with cubes, each of the six faces representing a land cover. Players then manipulate the cubes directly to signify the changes in land use corresponding to their actions. But when the simulation includes ecological and/or hydro-physical processes not directly under the control of the players, manually updating the environment by an operator is a tedious operation that causes dead times for the participants.

Using a digital game board provided by the projection on a horizontal flat surface of the computerized representation of the environment was recently tested in rural Zimbabwe. Before presenting the participatory agent-based simulation approach that was conducted with local actors to foster social learning, we propose a review of the applications of participatory agent-based simulation in the field of socio-ecological science, distinguishing its uses with scholars and with stakeholders. We stress the importance to clarify two fundamental features that are interconnected: the degree of realism of the model and the purpose of the modelling process.

2 Abstract, Stylized and Realistic Representations of Space in Agent-Based Models of Socio-Ecosystems

The representation of the environment can range from purely abstract landscapes to realistic ones integrating spatial data from geographical information systems. In the case of an abstract world, the environment of the model does not refer to any particular landscape, like in the *ReHab* participatory simulation tool [15], where harvesters have to collect a resource in an imaginary landscape that is also a nesting and breeding ground for a migratory bird under the protection of rangers (see Fig. 1a).

In an intermediate case, the implicit reference to a given socio-ecological system results in equivalent proportions in the distribution of the modalities of each landscape characteristics (primarily the land use) and possibly also in the similarity of the space configuration, with the integration of typical spatial patterns. For instance, in the *BUTORSTAR* model, the impacts on avifauna of the management of reed beds resulting from decisions made by farmers, reed collectors, hunters and naturalists are simulated in a stylized representation of the Camargue wetland [16]. Similarly, in the *SylvoPast* gaming tool [17] featuring conflicts of interest between a forester and a shepherd in the context of fires' prevention in the Mediterranean region, the proportions of the different types of vegetation cover (see Fig. 2b) are based on empirical data, so that the stylized environment of the model represents an archetypical grazed Mediterranean forest.

It is also the case of the *NewDistrict* interactive and asymmetric agent-based simulation [19] where the impacts of peri-urban development on biodiversity are

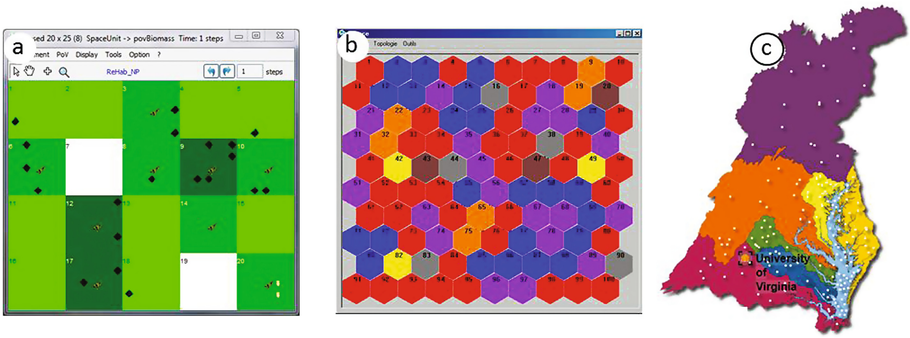

Fig. 1. The three types of environment in participatory agent-based simulation: (a) abstract, like in the *ReHab* game [15]; (b) stylized, like in the *SylvoPast* game [17]; (c) realistic, like in the uva bay game [18].

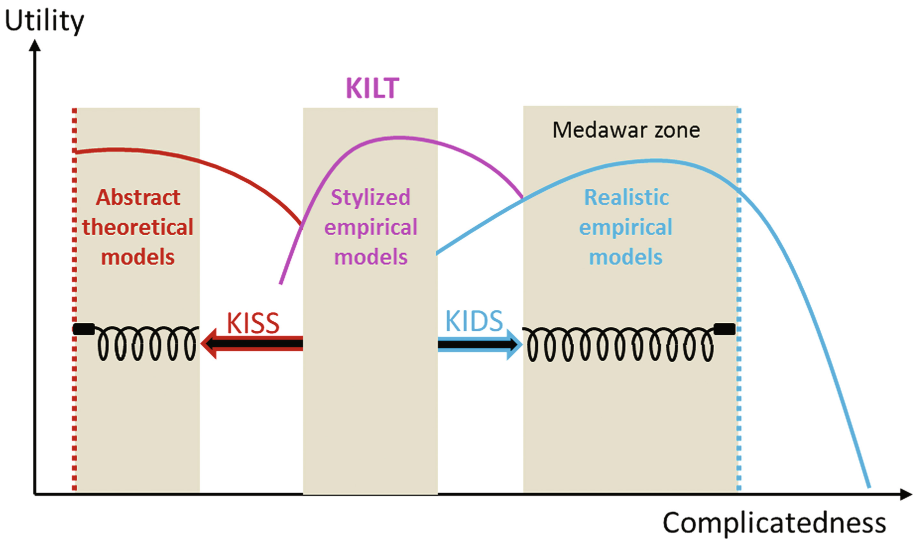

Fig. 2. Utilities of agent-based models according to their complicatedness. The red, pink and blue lines represent the utility functions of the abstract theoretical models, the stylized empirical models and the realistic empirical models. The black springs within the areas of effective use of abstract theoretical models and realistic empirical models symbolize the retraction force exerted by the *KISS* and *KIDS* principles [adapted from 32]

investigated in a stylized landscape. Three ecological processes are simulated (bee colonization, bird migration and water quality), with participants playing the roles of mayor, building contractor, farmer, forester and ecologist, each one equipped with a specific computer interface representing the landscape according to a point of view specific to its activity.

Recent technological advances [20, 21] have reinforced a trend that emerged some fifteen years ago [22–24] to move towards spatially-explicit agent-based models representing realistic landscapes by associating them with GIS. Extensions to integrate spatial data from GIS have been added to the main existing platforms (NetLogo, Mason, RePast). New platforms have been developed focusing mainly on these aspects: GAMA [25] and MAGéo [26]. This type of data-intensive models are becoming more and more popular, due to the increased availability of data, the computing power of computers and the increasing demand from policy-makers and managers for policy and scenario analysis [27]. A recent and emblematic example is the *uva bay game*, a large-scale agent-based participatory simulation of the Chesapeake Bay socio-ecosystem [18]. The game allows players to take the roles of stakeholders, such as farmers, developer, watermen, and local policy-makers, make decisions about their livelihoods or regulatory authority and see the impacts of their decisions on their own personal finances, the regional economy, fish and crab populations and overall bay health. Figure 1c shows the locations of the players (white dots) in one of the 8 watersheds represented in the model.

3 Involvement of Local Stakeholders: Adjusting the Degree of Complicatedness of the Model to Its Purpose

All the examples presented in the previous section were firstly developed to be used with students, for educational purpose. It is quite common to note a dual use of participatory agent-based simulation in the field of socio-ecological science: either support to the implementation of experiential learning in classrooms to teach students who are unfamiliar with the interdependencies of ecological and social dynamics, or a direct use with the actors of the socio-ecosystems. For instance, two gaming sessions of *BUTORSTAR* involving stakeholders of Étang de Vendres were organized, with the aim of increasing their capacity to adopt modes of interactions favoring adaptive management of the environment [28]. This duplication of the target audience (students and local actors) was also performed with *SylvoPast*, *NewDistrict* and *uva bay game*. In these three cases, the tool used with students and local stakeholders was strictly the same. In other cases, the tool initially designed to be used with stakeholders has to be adapted to meet the educational needs of both schoolchildren and the general public. This was for instance the case for the computer-assisted role-playing game designed by a group of researchers and biosphere reserve managers in Ushant Island (Brittany, France) to investigate consequences of land-use changes and fallow land encroachment on landscape, traditional activities and biodiversity [29, 30].

Even when the tools are similar, there is a shift in the purpose of conducting participatory simulation with stakeholders, who are definitively knowledgeable, rather than students. Generally, simulation is viewed as a mean to support experimentation by conducting *what-if* analysis that are not pre-determined, and not anymore as a mean to gain experience [31]. It does not make much sense to discuss the appropriate degree of complicatedness of a model supporting participatory agent-based simulation with stakeholders without specifying the type of stakeholders to be involved and without clarifying the purpose of their involvement [32]. Most commonly, the stakeholders involved are policy-makers and/or managers and the purpose is to gain insight about the functioning of the target socio-ecosystem as a basis for policy and scenario analysis related to agriculture and natural resource management [33].

In such a context of use, the *KIDS* ("Keep it Descriptive Stupid") approach [34] is undoubtedly relevant: models should be as complicated as necessary to answer the specific research question, with mid-levels of complicatedness providing the highest benefit per unit of modeling effort, which is reflected by the existence of what was called the "Medawar zone" [35]. On the other hand, the popular admonition *KISS* ("Keep It Simple, Stupid") that enjoins modelers to fight against their propensity to endlessly refine their model [36] is especially valid for theory-building and education purposes. A common idea is that choosing an intermediate posture in between these two zones of efficiency (see Fig. 2) may jeopardize the achievement of one purpose or the other. The empirical details in such models may hinder the theory building purpose and the stylized components may limit their applications in policy support [32].

Yet we believe there is a *raison d'être* for this type of intermediate stylized empirical agent-based models, which is to stimulate social learning through their co-design with local actors. Social learning has become a central concept in discourse on management issues related to the complexity of socio-ecosystems. Yet the theoretical and practical development of the concept is problematic [37, 38]. Most publications attempt to define its meaning, or to account for its realization in a given situation. Referring to the theory of communicative action [39], the different definitions of social learning emphasize the role of dialogue and intercommunication between group members in facilitating the perception of different representations and the development of collective problem-solving skills [40]. In this perspective, the relational dimension of learning is essential [41].

We advocate that, to fulfill its role of intermediate object allowing exchanges of viewpoints among participants, the model must be connected to reality in a stylized form so that each user can find ways to project features of the socio-ecosystem that make sense for him. To mark the specificity of this approach, we introduce the acronym *KILT* for Keep It a Learning Tool!

The *KILT* approach consists in initiating the process with an over-simplified stylized yet empirically grounded model that enables tackling the complexity of the target socio-ecosystem with a tool that has the status of a sketch. It provides the main features of the final version; however, it is clearly unfinished: there remains an important work of progressive shaping and improvement so that it acquires its final form and becomes usable with people who were not involved in its design.

In this approach, participatory simulation is used from an early stage of the process, as a strategic method to facilitate the co-design. A first version of a stylized agent-based model, deliberately simplistic, is designed by a group of 2–3 researchers. Handled as a participatory simulation tool (the actions of the agents are decided by the participants), it is introduced to a group of local actors to gather their suggestions to adjust it so that it enables discussing an issue related to the target system that was collectively formulated. A group of co-designers is then set up and the model is fine-tuned through a series of successive workshops. Once the design of an operational version is achieved, the tool is introduced to the other kinds of local actors as a support for communication.

To illustrate such a process, we will now present a recent implementation that took place in Zimbabwe.

4 Kulayijana: "Teaching Each Other"

A companion modelling process has been thought to create a fair and balanced communication arena in which local communities and protected area managers would exchange constructively on issues related to the coexistence between human populations and wildlife in the periphery of Hwange National Park, Zimbabwe.

Co-designed with a group of 11 villagers, the agent-based model represents the interactions between agricultural activities, livestock practices and wildlife. The model runs in an abstract virtual landscape that does not integrate specific details of the area, but shares fundamental features with two adjacent areas: a communal area and a forest. To motivate the participation of local actors involved in the co-design of the simulation tool, we chose to initiate the process by crash-testing with them a voluntarily simplistic version, not including some factors that clearly impact the result of their activities, especially crop losses due to extreme climatic events or crop raiding by elephants. During the first test of the game, these on-purpose omissions led to overly positive results of the players, who had all "enriched" dramatically. Although this was very pleasing to everyone, all participants acknowledged it was clearly unrealistic. Drawing on this, the participants engaged in a process of refining the game to make it more realistic while remaining "playable". This process lasted more than a year, with a set of iterative co-design workshops to test and improve the successive versions.

In the context of workshops organized in rural areas in countries such as Zimbabwe, the use of a computer is not always simple. In terms of ease of use, a non-computerized game is much more interesting, and as mentioned above, the use of a physical game board usually improves the direct interaction among the participants. During the co-design process, we therefore introduced a computer-free version with a game board. In this configuration, it was necessary to manually carry out the updates related to crops and fodder growth processes, losses of crop production due to climatic hazards and raiding by elephants, cattle predation by lions, water levels in ponds according to the input of rainfall data, which considerably slowed down the game and made its use very tedious. The local actors themselves felt that this mode of operation was not suitable and requested the return of the computer support. This challenging request was addressed by the use of a short focal projector allowing the horizontal projection of the computerized environment. With the stylized environment projected on a horizontal support, the players were able to position the artefacts making it possible to materialize their actions: the positioning and guarding of their cattle, the sowing and harvesting on their five plots, and the collective guarding of their communal paddock at night to prevent crop raiding by elephants (cf. Fig. 3).

The final version of the role-playing game was tested and validated with other villagers who were not involved in its co-design. In February 2016, a game session involving protected area managers from the study area was co-facilitated by 3 local members of the co-design team. One of them expressed his feelings before this event: "*It's our game, we are proud of what we have done. It shows our life, what we need*

Fig. 3. The virtual game board of the *Kulayinjana* agent-based model [42]

and what we have to live with [wildlife]. I hope they will like the game and see ways we can play together". At the end of the session, one of the managers said: "*This game is great, it could be useful for me to understand better the way they [the villagers] use my forest, and if we could play together and discuss, we could produce good management plans*" [42].

5 Discussion

The case study in Zimbabwe suggests that the horizontal projection of the environment on a physical support serving as a digital game board is an innovation that greatly benefits the implementation of participatory agent-based simulation in stimulating interactions. Other applications are currently underway. In the Poitevin marsh, such type of interactive multi-agent simulation is used to discuss with local stakeholders the relevance of agri-environmental public policies as incentives for farmers to adopt practices favoring the conservation of biodiversity [43]. In the flood plains of the Brazilian Amazon, it is used to better understand how populations adapt their practices to the drastic changes in the hydrographic regime currently observed [44].

In contexts where power asymmetries are strong, strengthening the capacities of the least favored actors constitutes a prerequisite to enable their fair inclusion in concertation processes [45]. Involving them in the co-design of a simplified but still meaningful representation of the socio-ecosystem taking the form of a computer-simulation tool requires some specific attention. Involving heterogeneous participants (here researchers and local actors) in a balanced co-design process is challenging. The rewards, in terms of learning, make the effort worthwhile [46]. Such a process exhibits features that may foster social learning: small group work, multiple sources of knowledge, egalitarian atmosphere, repeated meetings, open communication, unrestrained thinking [47]. The interviews conducted with the 22 local farmers who participated to the three workshops organized to test the "*Kulayijana*" tool indicated that it was found useful (75%) or very useful (25%), that it served as an opportunity to think (40%), learn (28%) and open new perspectives (12%). The self-learning dimension, which was also highlighted by the members of the co-design team, was therefore confirmed by the players [42].

Because social learning entails individual learning, measuring it is very challenging [47]. Scholz [48] recently proposed an analytical framework to monitor and compare the results of participatory approaches with respect to social learning, adding to the definition proposed by Reed [38] in looking for a convergence in the direction of individual learning. Most of the existing work aiming at assessing to what extent participatory modeling can support social learning is based on the use of conceptual diagrams (causal loop diagrams; stock/flow diagrams, cognitive maps), through a statistical analysis of the distributions of concepts' categories in the individual diagrams and in a diagram collectively built [49–51]. Involving local actors in activities like drawing relationships among conceptual entities can be abstruse, especially for those who only had access to rudimentary education. In such a context, we believe it is more suitable to use a concrete playable model.

Visual representations easily grasped by the participants can facilitate socially constructing shared meaning [52, 53]. The constructionist philosophy of learning advocates for mixing media in the model construction: translating one media into another can illuminate one media model formulation by seeing it in terms of another way of formulating it [54]. In the Zimbabwean case presented above, the introduction of a non-computerized version of the model at some stage of the co-design process (see Fig. 4) contributed to reinforce the sense of ownership of the computerized version by mitigating the black-box effect inherent to the use of such high-tech tool.

Fig. 4. Non-computerized (left) and computerized (right) versions of the Kulayinjana model

Providing detailed realistic representations may tend to keep the local actors focusing on some particular features that could distract them from taking a critical distance needed to debate issues in depth and not just superficially. Moreover, tackling conflict situations requires stepping back from the peculiarities on which the existing tensions could easily crystalize. On the contrary, purely abstract representations are likely to appear completely unrelated to the practical difficulties faced by the local actors. A stylized representation constitutes an interesting compromise between these two extremes.

The *KILT* approach does not fall within the scope of the two classical orientations of science, namely theory-oriented science and policy-oriented science (see Fig. 5).

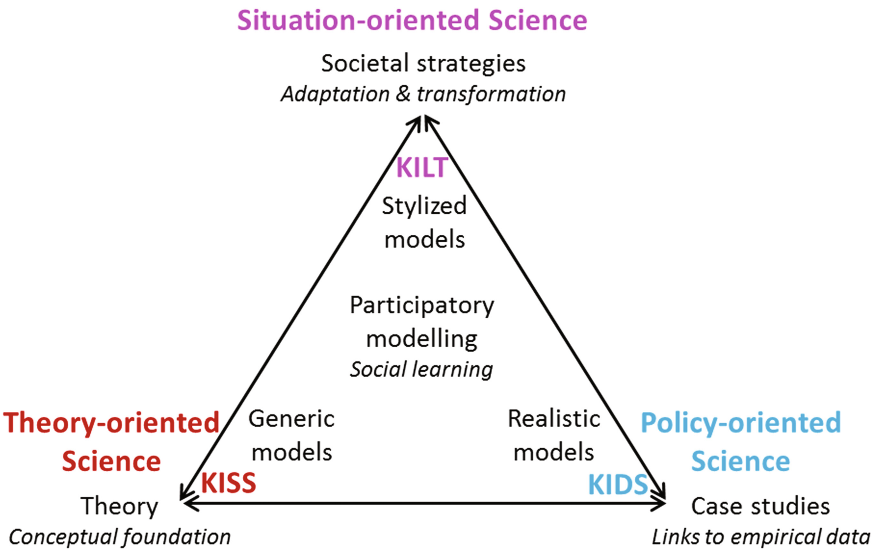

Fig. 5. The scientific orientation inherent to the KILT approach (adapted from [55])

Theory-oriented science -for which the KISS approach is well suited- is intended to consolidate generic knowledge. Policy-oriented socio-ecological science, which aims at supporting policy-makers by assessing the effects of various management rules, will mainly gain from modeling processes implemented according to KIDS principles. Issues arising from local stakeholders could be more properly dealt with by the KILT approach, where the social learning could foster mutual understanding and common agreement leading to collective action.

6 Conclusion

Deeper work is needed to investigate if and why the co-design with local actors of stylized models through the early use of participatory agent-based simulation triggers more effectively social learning. Difficulties arise from the complexity and context-dependence of processes influencing social learning. Moreover, the existing approaches to measuring social learning focus on cognitive learning while neglecting the social-relational dimensions of learning. With the *KILT* approach, the focus is specifically set on how interactive settings of participatory agent-based simulation processes could facilitate social learning. Among the features that account for fostering social learning in collaborative natural resource management, small group work, repeated opportunities to interact, open communication and unrestrained thinking are highlighted [56].

When a small group of researchers from different disciplines engage with local actors in the co-design of stylized models, it has to be very clearly stated that the main purpose is to foster communication through social learning. If any participatory modelling process can potentially lead to such an effect, it is still not so common to set it as the core goal [57]. This situation-oriented science hinges on a transdisciplinary practice in the sense that societies do not know the boundaries that science imposes on them [58].

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