Multi-agent Based Simulation of Universities as an Innovation Ecosystem Based on Knowledge Flows

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***Abstract*—This work presents the search for a simulation model of a university as an innovation ecosystem as far as educational knowledge is concerned. It is part of the effort to increase inclusion and decrease dropout occurrence made by the ACACIA project. An innovation ecosystem from a knowledge flow perspective conceptual model has been used, and the simulation model is to be implemented in the NetLogo multi agent environment.**

***Keywords*—computer intelligence; knowledge flow simulation, agent-based modeling, education, innovation ecosystems.**

I. Introduction

This work presents the search for a simulation model of the adoption of innovations inside universities. It is widely known that, although not every innovation came from universities, they are the birth place of several high impact revolutionary innovations [1]. However, the new technologies and methods created in the universities are usually aimed at use in society at large, or to add to general knowledge and assist in new discoveries. It may affect the content, but doesn't always change the way classes are taught [2]. Adding to that is the fact that courses such as engineering do not teach students to be lecturers [3], [4]. And since most lecturers and professors, although highly graduated, were educated in such courses, it is customary to put technical aspects ahead of pedagogic needs and techniques [4]. The techniques and methods used in class are usually those that the lecturers enjoyed, or associated to serious well reputed professors, when they were students themselves [3].

On the other hand we have nowadays a high rate of university student dropouts, and that is especially high in technical courses. Among the reasons are repeated failure in courses and poor accessibility to content and lectures by people with disabilities or other specific needs [5]–[7]. Some of these occur because the university has not yet come to adapt largely to include some minorities, such as students with deficiencies, students in psychological distress, indigenous students.

ACACIA (*Apoyan, Cultivan, Adaptan, Comunican, Innovan y Acogen*) is a EU project that seeks to provide solutions to these and other problems in order to contribute to the dissipation of exclusion, discrimination and marginalization caused by disparity or inequality in Higher Education (HE), reducing the occurrence of dropout [8], [9].

Therefore, in order to forecast the adoption of the solutions proposed by ACACIA through its CADEPs (*Centros de Apoyo y Desarrollo Educativo y Profesional*), this work will consider the university as analogous to an innovation ecosystem, and model its components from the knowledge flows perspective.

The second section of this article introduces the ACACIA Project. The third presents the innovation ecosystems concept. The following section presents how this model will be used to model a university. The fifth section presents briefly the agent based modeling of complex adaptive systems, and the sixth section presents how the model is to be implemented in the NetLogo platform. Then the final discussion and references are presented.

II. ACACIA Project

ACACIA is an ERASMUS+ project that promotes cooperation between academic centers for the fostering, strengthening and transfer of best practices that support, educate, adapt, communicate, innovate and welcome the university community [8]. ACACIA, which stands for Support, Enrichment, Communication, Innovation and Refuge, is designed around the integration of experiences, resources, teams, problems and solutions in HE institutions [8]. It is composed by 11 Latin American and 3 European universities.

HE institutions still face many challenges, including student desertion caused by emotional factors; academic, economic, or social marginalization; and communication gaps between involved staff that inhibit the management of collective actions to face the transversal problems related to the access and successful permanence in the university [9]. Against this background, ACACIA seeks to define a model for the organization of such institutions in Latin America to strengthen the adoption and the exchange of best practices between America and Europe [8].

Its main goal is to contribute to the dissipation of exclusion, discrimination and marginalization caused by disparity or inequality in HE. It is deeply rooted on the principle of education for all [9]. To solve this and other problems, ACACIA approach includes [8], [9]:

- The recognition of HE institutions as social and political means to develop inter, multicultural, and multi-lingual education programs matching the several real educational needs;
- Strengthening teaching staff qualifications and skills;
- Using ICT as a tool to complement teaching processes and learning;
- The detection, prevention and eradication of several education problems in the HE institutions.

One of its actions is the implementation of the CADEPs, presented in the next subsection.

A. CADEP

CADEP stands for Professional Educational Development and Supporting Centers. They are supporting centers for educational and professional development. They have an integrated system of modules (*Empodera, Innova, Cultiva, Apoya, Convoca*) which work together to: (i) monitor students at risk; (ii) train and support the academic, technical and administrative staff; (iii) implement new strategies for university teaching and innovative uses of ICT in practical scenarios by stimulating entrepreneurship among students and professors [9].

One the roles of the CADEP, mainly through its *Innova* module, is to propose innovative solutions to support in a general way minority inclusion and to meliorate both emotional state and attention of students in risk of dropout based on ICT technologies. Partly, this is done by supporting the development, the validation and the evaluation of technologies tailored to people with special needs, as well as selecting those which could result in fruitful businesses, be it proposed by the ACACIA research team, by the academic staff, or by the students themselves. If appropriate, supportive guidance for entrepreneur business establishment is provided [8].

However, these new strategies and tools have to be adopted to yield its intended impact on the problems of HE. By doing so universities would be more effective in teaching a new generation of professionals, researches and professors, and at the same time avoid the loss of revenue that comes from the dropout students be it from tuitions or from government paid positions, and also the waste of the money and time already invested in students that leave without graduating [5].

And that is the aim of the current work, to simulate universities as innovation ecosystems to assess the diffusion and adoption of such solutions through the academic ranks.

III. Innovation Ecosystems

In order to understand innovation ecosystems, it is useful to understand its composing concepts.

Reference [10] defines as technological innovations as comprised by "… *implemented technologically new products and processes and significant technological improvements in products and processes. (...) innovations involve a series of scientific, technological, organisational, financial and commercial activities.*", were products cover both goods and services. Reinforcing these concepts, [11] affirms that an idea only becomes an innovation when *"...it can be replicated reliably on a meaningful scale at practical costs*". An idea that has been tested in the lab but not implemented to its end purposes is an invention, and should not be confused with innovation [11], [12].

These definitions lead one to think that innovative organizations are those who create and implement new products and processes. However, [10] also considers as innovative organizations those who adopt methods and technologies that are new to the organization, but not to the world, accounting for diffusion and allowing for the adoption of innovations that come from outside the organization.

The word ecosystem, on the other hand, was created in the field of biology and is composed of the Greek words *oikos* (meaning home), and *systema*, and means the system where one lives.

Reference [13] states that one can consider biological ecosystems of the most various kinds and sizes and identify them as pertaining to a given geographical area. However, [13] also points out that not all authors agree to this, viewing ecosystems as concepts, rather than places. To such authors, ecosystems may or may not exist in the real world, but they do appear to be helpful conceptions that lend predictive power. Hence, ecosystems may be defined by how they are studied as much as by what they contain or their size, employing a "functional ecosystem" approach to emphasize process instead of structure. Under this definition, [13] states that one may consider the biosphere, a lake or even a termite's gut as an ecosystem where cycling and energy flow take place.

The ecological perspective emphasizes driving forces such as environmental resource niches and adaptation, as well as dynamic evolutionary processes, such as variation, selection, and retention [14]. These concepts may be borrowed to infer that innovation ecosystems explain the activities between actors that compete and/or cooperate to obtain resources in a common environment, cycling resources and information. These ecosystems include economic agents and economic relations, as well as non-economic components such as technology, institutions, sociological interactions and the culture [15], with the goal of innovating to obtain competitive advantages, better fitness to its environment and survivability.

Given its flexibility, the term and its analogies have been used interchangeably with concepts such as clusters and global networks [16], [17], ICT platforms and new industries [17]–[20]. In this work, we propose to consider universities themselves as innovation ecosystems regarding the way education and research is done and not the subject of education and research per se. In the next section the innovation ecosystem based on knowledge flows conceptual model will be presented.

A. *An innovation ecosystem model based on knowledge flows*

A Phd thesis being written in UFOPA and UNL is proposing a conceptual model for innovation ecosystems based on knowledge flows and its simulation using multi-agent systems. This model shall be used to model the university as an innovation ecosystem.

The proposed model has 3 types of elements, namely entities, relationships and knowledge, which is contained in entities and flows through established relationships between entities (Figure 1). These elements are immersed in a context provided by the ecosystem support elements present in the environment, which may foster or inhibit the knowledge flows. The environment also provides the selection of entities, and the mechanisms of selection should affect the entities drive to innovate to improve fitness to the environment and survivability.

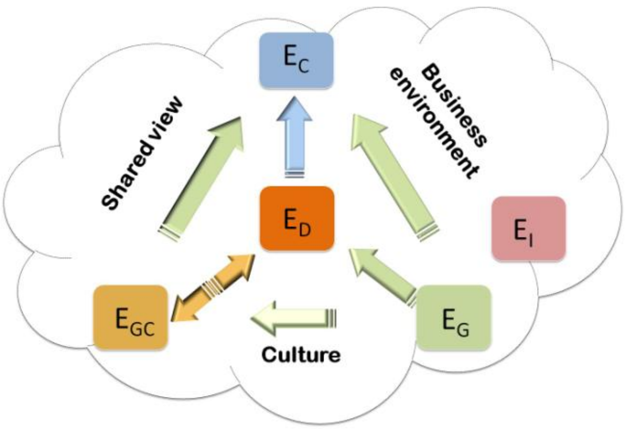

Fig. 1. Innovation ecosystem based on knowledge flows

The existence of all the components in a place does not imply in the existence of an innovation ecosystem. Certain conditions must be met, such as the establishment of meaningful relationships between the entities, the endogenous generation of knowledge or the absorption of external knowledge, the diffusion and conversion of this knowledge into processes and products that meet the environment's demands. That is usually fostered by a fertile business environment (law, market mechanisms, the existence of qualified labor in sufficient quantities, and others), the predominance of a cooperation culture, the will to experience new things, tolerance to error, diversity and risk, the will to innovate, and other factors that may be ecosystem specific [21], [22].

The aforementioned entities may be informal or formal, public or private, nonprofit organizations, government controlled and others participating in the ecosystem, and are classified solely according to their role towards knowledge in the ecosystem. This gives great flexibility to represent entities who embrace roles usually performed by other types of entities. Also, one entity can have more than on role, and even change roles with time.

1) *Entities*

The types of roles entities may perform are:

- Generators: those who generate new scientific/ technological knowledge. Create inventions, or further the state of the art;
- Diffusers: those who absorb, store, process knowledge create by other entities and transmit it to other organizations or people, without significantly furthering the state of the art or providing the society products that embed the knowledge. They may recode, translate and perform other transformations to ease its transfer and make it accessible to entities that lack the absorption capacity to receive it directly from generators;
- Integrators: these entities connect other entities. They create relationships, introduce and establish trust between partners, disseminate cultural values, and create views of how the other entities could interact, although not handling knowledge itself;
- Consumers: those who apply new knowledge into the products, services, processes, methods that are related to their main activities. Through these entities the effects of the new knowledge reach customers and society. They are the innovators in the sense [10] meant.

In real world scenarios entities usually need to embrace more than one role to perform its activities, but the impact it causes in the ecosystem while performing that (those) role (s), is what matters. Not all organizations are known as great inventors, or educators, manufacturers, service providers and network creators, although every entity eventually has to go out of its way and train new employees, or create minor adjustments while manufacturing.

These entities have idiosyncratic characteristics, such as:

- Learn motivation [23];
- Sharing willingness [23];
- Knowledge owned [23].

These variables are impacted by the results of the actions of the entities and the changes in the environment's parameters.

2) *Relationships*

These are connections between entities that may vary in strength. To the purposes of this model, the relationship between two given entities A and B will be characterized as:

- Distance between the entities [23];
- Trust level between entities (A to B and B to A);
- History of relationships between A and B.

Each one of these variables is impacted by the results of actions between the entities.

3) *Knowledge*

The knowledge is contained in the ecosystem's entities and its individuals. Some of this knowledge must be common, allowing them to communicate effectively in a specific domain. Knowledge must flow between related entities in order to diffuse.

Knowledge may be classified in various ways, but in this work it is sufficient to divide it in tacit and explicit, due to the difficulties of diffusion of tacit knowledge imposed by geographical distance, and scientific and technological knowledge as defined by [24].

Scientific knowledge, be it basic or applied, requires researchers with scientific qualification, and is not immediately marketable. The entities who seek it give low importance to its fitness to the market's current demands and economical (and even practical) feasibility, and more importance to truth and to further what is known. Whenever a discovery is made that clearly refutes a past iteration of knowledge, it is held as the standard, the new state-of-the-art. This is the type of knowledge that is characteristic of generators and of some diffusers.

Technological knowledge, on the other hand, is marketable and is the core of a firm's activities. Even previous iterations of a technology still retain some market value, even if it is less efficient or environmentally friendly, and may coexist (even dominate) in the market with newer, possibly better technology. It comprises the knowledge necessary to design, plan, manufacture and organize the activities necessary to create products and services, including those of managerial nature, such as business models [25].

Due to the differences between scientific and technologic activities, the communication between science and technology organizations and personnel is not straightforward. Some transformation of knowledge is necessary, which explains the difficulty of organizations with no scientific staff to access and put to use scientific knowledge found in publications, as it may be difficult for pure science organizations to build to market tolerances and costs. It is necessary to master both types of knowledge to make such transformations.

4) Environment's support elements

The region where the ecosystem is set has tangible and intangible characteristics that make more or less conducive to the establishment of the ecosystem.

Among these are the transportation and communication infrastructure; the shared view; the predominant culture; the law system and its enforcing structure; the available workforce and its quality; capital availability; business practices; and others.

It is hard to take into account every aspect that would make a place better or worse to host an innovation ecosystem, however it is clear that certain environments are better than others, and there must be a parameter to account for that.

5) Model mechanisms

According to [23], knowledge flow potential is proportional to the difference of knowledge between the emitter and receiver (if there is no difference, there can be no flow), to the learning motivation of the receiver; the sharing willingness of the emitter and is inversely proportional to the distance between emitter and receiver. The amount of knowledge transferred is affected by the receiver's ability to learn, and the emitter's ability to convey knowledge.

Adding notions from biological ecosystems, a diffusion mechanism can be devised for the model. Knowledge may be expressed as a DNA string, where each allele represents a certain bit of knowledge, in a similar fashion as [26] modeled the products of its agents. The difference is that here the knowledge of the entities is modeled, and the string of bits is divided in two zones, one for scientific knowledge and another for technological knowledge. In a computational model, this may be seen as a string of bits.

Through crossover mechanisms that pick random portions of bits from the receiver and replaces them by the correspondent bits from the emitter, one can simulate knowledge flow using genetic algorithms as the ones used in [27], [28]. If the difference between the strings of bits is considerable (knowledge difference as in [23]), there is a great chance of picking a bit that is different, and when that happens there is learning. If there is no difference, any bit taken will not cause any difference in the receiver's knowledge DNA string.

The ability to convey knowledge, ability to learn will affect the probability of bits being exchanged. The motivation to learn and willingness to share will affect the trust that each individual has in each other, and along with the distance between them will affect the probability of the entities engaging each other in a knowledge exchange. Integrators may offset these parameters, instilling trust in other entities, introducing partners, sharing a view and acting as trust surrogates. In that fashion, entities who meet through Integrators are more prone to engaging.

The market, although not an entity, also is characterized by a DNA string [26] representing its current demand. It may possess several of such strings, each related to a niche. The market also has resources, and each niche is linked to a portion of it.

Crossover may happen between entities or between the market and the entities, reflecting the "learn by doing" mechanism. Spin off entities or startups may be created by the crossover of fit candidates. The market may also "learn" from the entities and change its demands. The frequency to which that happens will depend on how fast such industry under analysis changes. Also, knowledge generators devise new knowledge by mutating their own strings of knowledge, creating new things. For that, a portion of the DNA string may be left unassigned to any knowledge, and when something new is discovered, it can be assigned to that allele.

Of course, crossovers, mutations and living take time and resources. The resources come from the market, and are split between entities according to its fitness, creating a market share. The amount of resources necessary to stay alive at each iteration is proportional to the total amount of resources of the entity, with a minimum value, but not a maximum. This way fit entities would thrive while unfit entities would starve and die, unless there is interference from some external force such as the government, who may provide resources to those entities who cannot fetch it themselves from the market.

Successful mutations or crossover operations, those who actually change bits and improve fitness and market share, encourage the entities to do it again, improving its learning motivation. Royalties or reputation gains from sharing also improve the willingness to share. Unsuccessful operations affect these parameters negatively. Within a few iterations these alterations will affect the entities behavior, acting as learning from past actions.

Entities with vast resources or with great fitness to market demands usually have a good reputation in the market, drawing partners interested in learning from it (or to copy from it). Entities with no resources nor fitness to market usually don't attract partners, as they are bound to exit the market. This is analogous to natural selection mechanisms in nature [29], and implements the trust the partners have in one another.

A lottery can be the mechanism to choose a crossover partner randomly. Entities with a high reputation will have proportionally more chips, and therefore a higher probability to be chosen. Those who are distant (on the network or geographically) will suffer a penalty in their chances. Each entity may keep a record of the entities it has contacted in the past. It may award a bonus or a penalty to the chances of these entities given the success of their past interactions. The lottery will be held by each entity when it is its turn to act.

With these definitions in mind, it is time to model the university as innovation ecosystem.

IV. Modelling the University as an Innovation Ecosystem

Universities are frequently part of innovation ecosystems when they are integrated with companies and the society, engaged in knowledge transfer. They may also be considered as ecosystems in themselves. In such context, education can be thought of as a service provided by universities.

Analogous to the described innovation ecosystem model, the entities that compose the university would be classified according to their role regarding education knowledge. That may change from university to university, even from course to course inside the same university, but is safe to say that most professors and lecturers may be classified as Consumers. Some professors, those who research in education, may also be considered Generators. Those who teach education methods would also be Diffusers. Some entities may be considered Integrators, if they advocate in favor of education innovation and convince lecturers to learn new techniques.

In such a context, the CADEP is both a Generator and a Diffuser, given its education research team and its role in strengthening teaching staff qualifications and skills.

Some university entities may not be an acting part of this particular ecosystem if they do not deal with education knowledge (teach, research, use it in their activities) or rally professors to learn new education techniques, and the same is true for elements of society regarding innovation ecosystems. They may be part of the environment, especially those who dictate the rules, such as what is mandatory and what is not, altering, for that matter, the demand string against which the actors in the environment will test their own knowledge strings for utility.

Knowledge shall be represented as a string of bits. Each bit represents a teaching technique or method that may (1) or may not (0) used by each consumer. Given this, the diffusion and creation mechanisms would be the same described for innovation ecosystems.

The fitness to the universities demands will affect the amount of resources an agent is given at each iteration, or affect its reputation as an academic. In academia reputation is taken in high regard, and may motivate agents to innovate, or even not do anything for fear tarnishing it. Learning new educational methods takes time and resources, which could be used in other activities that would yield better returns given university policy.

To simulate such an environment agent based modeling has been chosen given its several advantages to simulate this kind of system. These will be described in the following section.

V. Agent Based Modelling of Complex Adaptive Systems

By agent [30] mean an autonomous individual element of a computer simulation, which have their own properties, states, and behaviors. Reference [31] adds that agents are situated in an environment, and are capable of autonomous action in this environment in order to meet its objectives [31].

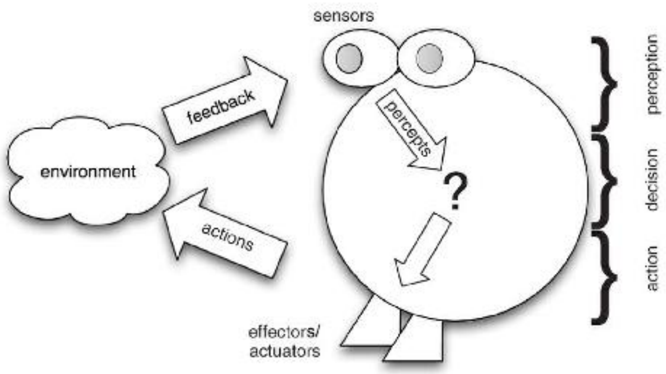

Fig. 2. An agent and its environment [31], [32]

Agents may react to environment changes, and may even act on their own in pursue of their goals, as depicted in Figure 2 [31], [32]. However, goals alone are not really enough to generate high-quality behavior. There a several ways an agent may achieve its goals, and some may be better than others. The notion of utility provides a way assess the degree of happiness the agent would get in different world states. A complete specification of the utility function allows the agent to choose what is best [32].

Also, agents must be able to interact with other agents to achieve their goals. These interactions are constituted by the exchange of information. As a result of these interactions, agents can update their internal state, take additional actions, and even change their interaction behavior [30].

Complexity in this context has to be further explained. Complexity arises when the dependencies among the elements become very important. The removal of one such element destroys the system's behavior to an extent that goes well beyond what is embodied by the particular element that has been removed [33]. Complex worlds cannot be reduced as complexity is a deep property of a system. However, while complex systems can be fragile, they can also exhibit an unusual degree of robustness to less radical changes in their component parts [33].

The "aggregate" or "macro" behavior of many complex systems emerge from the activities of lower-level components, but are not specifically encoded at the individual level [30], [33]. Such a disconnection implies that, within limits, the details of the local behavior do not matter to the aggregate outcome, which can overcome a variety of changes to the lower-level components [33]. This can lead to surprises where behaviors encoded at an individual level result in unexpected behavior of the system at a macro level [30]. .

Using traditional tools to model the world, social scientists have often been constrained to model systems in odd ways. Existing models focus on fairly static, homogeneous situations composed of either very few or infinitely many agents, each of whom is either extremely inept or remarkably prescient, in worlds where space and time matter little. Such simplicity in science is a virtue, as long as the simplifications are the right ones [31]. However, the world lies somewhere in between these extremes. Most systems are not composed by just a few agents and also don't have infinite populations. Agents don't usually have access to all the information about the environment, and are most of the time satisfied with less than optimal solutions.

Reference [30] also points out as a great advantage how easy it is for people to understand agent-based representations when compared to mathematical representations of the same phenomenon. This is because agent-based models are constructed out of individual objects and simple rules for their movement of behavior, as opposed to equational models that are constructed from mathematical symbols [30].

For the reasons exposed above, agent-based models provides an interesting and novel tool for simulating societies, helping understand various kinds of social processes, particularly complex ones. It encodes the behavior of any given number of individual agents in simple rules, and the results of these agents' interactions can be observed as they evolve [30]. They may be heterogeneous, and their environment may mimic space and time. The agents can be even allowed to adapt.

In this work a phenomena-based, top-down approach depicted in [30] has been mainly used, although a few evolutions have been made to the conceptual model given the modeling work underway.

For that matter, given the previous development of a conceptual model in this work, [30] states that a reasonable first step to ABM is to create a more algorithmic description of the preceding textual conceptual model.

VI. Instantiation of the Model

The model will be implemented in the NetLogo [34] environment. Here are presented some of the directives being used in the implementation. The concept and the code are still evolving, and may change towards the final version.

A. *Interface*

The interface will reflect the amount of resources/reputation a particular agent has (through the sizes of the agent), its current fitness to the environments demands (through its color), and who is connected to it at a given time (links). These aspects shall be updated at each iteration, giving the observer a notion of the evolution of the agents' condition.

The figures bellow demonstrate examples of possible interface lay outs.

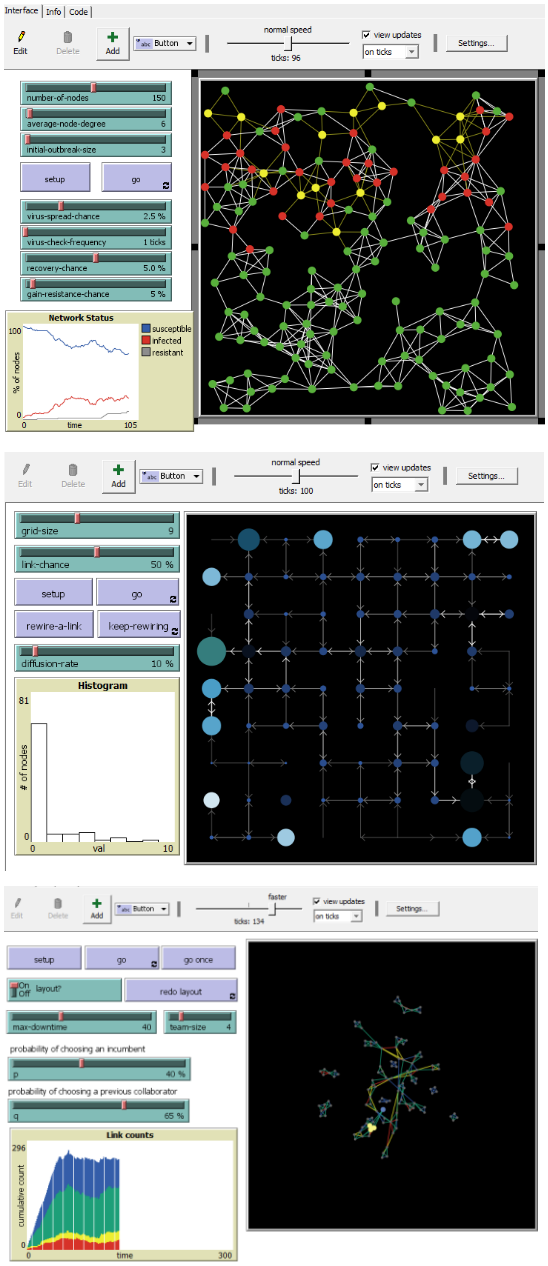

Fig. 3. Layout examples for the model's interface [35]–[37]

B. *The sliders*

There will be sliders to determine:

- Mean motivation to learn (when a file with real data is not used);

- Motivation to learn's standard deviation (when a file with real data is not used);
- Mean willingness to share (when a file with real data is not used);
- Willingness to share's standard deviation (when a file with real data is not used);
- Generators productivity parameter;
- Transformers productivity parameter;
- Environment's permissiveness of innovation;
- University's total resources (to be distributed according to fitness);
- Number of consumers;
- Number of diffusers;
- Number of generators;
- Number of integrators;
- Number of consumer-generators;
- Number of generator-diffusers;
- Rate of the demand string change;
- Number of bits in the knowledge string.

C. *The choosers*

- Space shape: static network; dynamic network; pin-head (good for situations where distance can be ignored)
- Number of niches: 1; 2; 3.
- Payment depends of fitness: yes; no;
- Generate world: from file; from interface.

D. *Inputs*

- Number of iterations until stop.

E. *The outputs (graphs, histograms, reporters)*

- Mean willingness to share;
- Willingness to share's standard deviation;
- Mean motivation to learn;
- Motivation to learn's standard deviation;
- Histogram of agents resources/reputation;
- Graph of number of knowledge interactions x iterations;
- Amount of bits changes x iterations;
- Mean fitness to demand;
- Maximum fitness to demand.

F. *The setup routine*

The setup routine would:

- Clear the world;
- Make patches black;
- Create agents according to the world selected (from file, from interface, type of topography, amount of agents of each type), also creating the agent's knowledge string, its willingness to share, motivation to learn and initial amount of resources (enough for a few iterations);
- Create the knowledge string of the market;
- Assess initial fitness of every agent and update their sizes and colors;
- Reset ticks.

G. *The go routine*

The go routine would:

- Evaluate the agent's fitness, and award the resources in proportion to the agent's fitness relative to all the other agents.
- Collect the resources necessary to live;
- Kill the agents with insufficient resources;
- Generate new agents to replace the ones that are gone, with a knowledge string that is a crossover of live agents (emulating peer selection and the hiring of new faculty);
- Update the reputation list of all agents;
- Ask each agent to run the lottery;
- Ask generators to generate;
- Ask agents with both kinds of knowledge to transform knowledge;
- Update agents sizes and colors;
- Update the output interface;
- Update the environments (university) demand string for the next iteration (random, may or may not happen);
- Check if the clock is equal to the maximum number of iterations, to know when to stop.

H. *The lottery routine*

Would ask each agent to:

- Decide whether it will try to learn or not (random choice given its motivation to learn).
- If positive, too run its own lottery (it will take the reputation list, adjust it for distance and interaction history, and them randomly select a partner given the chances of each agent);
- Once selected, asks the partner if it is willing to share (the partner may check the reputation list to decide, and also randomly decide given its willingness to share);
- If the partner is willing to share, run crossover algorithm;

- Collect resources used in the crossover (may involve paying the resources to the emitter);
- Assess the number of bits changed;
- Assess the new fitness if bits were changed;
- Update motivation to learn (receiver) and willingness to share (emitter) given the number of bits (learning) and effects on fitness.

I. Generation routine

Would ask agents capable of generating knowledge to:

- Evaluate if there is going to be mutation of not (given a productivity of research parameter);
- Randomly select bits to be changed;
- Collect the resources necessary to generate.

J. Transforming routine

Would ask agents capable of transforming knowledge to:

- Evaluate if there is going to be transformation of not (given a productivity of research parameter);
- Randomly select bits to be copied from scientific to technologic;
- Collect the resources necessary to transform.

The fitness function can be measured bit by bit, meaning that each bit will grant either a positive or a negative value to be added. That will tell the mandatory (award negative if not complied to, while it may award or not a positive value if complied to) from the desired (award a positive value if complied to, but will not award a negative value if not complied to). In scenarios created through the interface, which are theoretical, fitness can be assessed by the number of bits (alleles) that are the same in the agent's knowledge string and the environment's (university) demand string.

Single campuses may be considered as a pin head landscape. However, for those universities with campuses in other cities or states, an environment that considers distance may be more suitable, such as a network landscape or a grid landscape. The distance between the nodes will decrease the probability of two entities engaging in crossover.

Environmental factors such as organizational climate, culture, stimulus to innovate, spare time to research and learn and tolerance to mistakes would compose the university permissiveness to innovation. This parameter offsets the motivation to learn.

VII. Discussion

When the model is done it will be time to determine if a model is verified (the code accurately represents the conceptual model) and validated (the model has a correspondence to the real world). Reference [30] provides a method for that.

The model may be validated against real cases. The techniques available in educational research literature and the ones effectively used can be assigned to bits in the scientific and technological knowledge strings. The techniques and methods that are mandatory or desired may be encoded in the university's demand string, and the ones effectively used by each professor may be assessed in interviews and encoded in their own knowledge strings.

Interviews may assess how long it has been since each professor updated their methods and how likely they are to invest in learning and updating their courses may be applied to assess their motivation to learn. Researchers in education may be asked when they last held courses to colleagues, especially from other disciplines, to assess their willingness to share. The university's policy may be assessed to evaluate if it stimulates change, or if they perpetuate its methods through standards and strict unchanging requirements, which may be stated in laws or conventions created by the government or external regulating organizations. That would provide a measure for the environments parameters.

A utility function, derived from salary and incentives/punishments policies could be derived, to assess what professors are encouraged/discouraged or even allowed and forbidden to do.

All the data could be fed into the model, and the real dynamics may be observed and used to fine tune the model parameters. Once the model is validated, it can be used to test scenarios and create hypothesis of how to stimulate innovation in universities. Although this can be done with real data, the model can also generate populations of agents with heterogeneous parameters following a given mean and distribution for each. Therefore, hypothetical environments of a certain characteristic can be simulated and analyzed.

This effort would also serve to accumulate knowledge to simulating innovation ecosystems, helping to develop the model to simulate larger ecosystems.

Such a tool could be of great value to help plan policies to mitigate the problems show in the introduction of this article, and to create a better, more effective and more inclusive university.

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