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Teaching diffusion of innovations involving technology startups using agent-based simulation modeling: architecture and design considerations

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Abstract. Entrepreneurship education has traditionally been based on business management education, which has been ineffective in teaching the complex, dynamic, and non-linear nature of entrepreneurship. Recent attempts at entrepreneurship education have involved using computer simulations to reduce time and cost. One type of computer simulation, agent-based modeling and simulation (ABMS), takes into account the behaviors, reactions, and interactions of individual agents and has the potential to capture the behavior of a complex system, such as a market, more accurately than traditional approaches. This study proposes the use of ABMS in a technology entrepreneurship program to teach students about the theory of diffusion of innovations and how to implement various technology strategies, such as pursuing technology leadership or behaving as an early adopter. The simulation will involve a minimal model implemented using NetLogo and students will be able to explore different strategies and experience the advantages and drawbacks of each. The learning experience will be designed based on entrepreneurial process theories, learning by trying/emergence, learning from failure, bounded rationality, effectuation, entrepreneurial cognition, and entrepreneurial management and growth. The goal of the simulation is to provide students with an experiential and adaptive learning environment that allows them to understand as entrepreneurs how consumers adopt new innovations and receive feedback on their decisions. The user interface will show an animation of the model's results and output, some of which include: the adoption curve, adopter profiles, and the social network.

Keywords: Agent-based modeling, Agent-based simulation modeling, Computer simulation, Entrepreneurship education, Diffusion of innovations

1 Introduction

1.1 Context: Entrepreneurship Education

Entrepreneurship involves continuously pursuing novel or better products and business models amidst constraints, uncertainty, and constant change among

participants (or "agents") in the ecosystem [7]. It is a complex, dynamic, and non-linear activity [23]. Entrepreneurship education needs to be flexible and adaptive, but studies show that higher education does not have the necessary flexibility [22]. Traditional teaching approaches to entrepreneurship have been based on business management education, which is inflexible and ineffective [8]. Entrepreneurship research and study concern questions on attaining success through open-ended possible effects based on pre-existing means and avoiding failure in the market [30]. Aside from starting and running a business while enrolled in university, recent entrepreneurship education and entrepreneurial experiential learning attempts involve the use of computer simulations to compress learning cycles, reduce time and cost [1] and to model and illustrate how agent behaviors and interactions in a complex environment involving entrepreneurial ecosystems.

This paper is a part of a larger set of studies using agent-based modeling and simulation for entrepreneurship education [12].

1.2 Agent-based modeling and simulation as a tool to understand the entrepreneurship-related theory of the diffusion of innovations

Agent-based modeling and simulation (ABMS), one type of computer simulation [25], covers interactions among independent agents [19] and the analysis of emergent outcomes from the behaviors and interactions of these agents [10]. ABMS is useful in developing and testing entrepreneurship theory and helps entrepreneurs understand, predict, and explain the potential consequences of their decisions [30]. ABMS takes into account the individuals' behaviors, reactions, and interactions. It has the potential to capture the behavior of a complex system, such as a market, more accurately than is possible in traditional approaches [28].

One theory illustrating the complexity and emergent outcomes brought about by agent attributes, behaviors, and interactions with other agents is the theory of diffusion of innovations. Rogers' [26] theory of the diffusion of innovations is a model that explains how, why, and at what rate ideas and technologies spread [13]. In the context of a social system, it reflects adoption timing and decisions made by individual consumers [27]. The following classification scheme is based on the timing of adoption of the innovation by various groups: (1) innovators, (2) early adopters, (3) early majority, (4) later majority, and (5) laggards [26]. The theory of diffusion of innovations has been a common application of agent-based modeling to date [27,10,18,5,13,15].

1.3 Objective

This study describes the methodology, architecture, and design of an agent-based simulation model and focuses on the theory of diffusion of innovations for teaching and educational purposes. Existing work [28,10]using agent-based models for the diffusion of innovations describes the fidelity, verification, and validation

considerations involved. The output is a minimal model [16] plausible enough for use in education and illustration of the concept of diffusion of innovations.

1.4 Research Questions

This study is part of a larger study on using ABMS for teaching and learning technology entrepreneurship. The aim of the larger study is to cover the viability of using an agent-based model computer for this purpose by building a simulation model for a specific scenario (diffusion of innovations in this case). Meanwhile, this study aims to complement the parent study by focusing on aspects of the human interface adaptability of an agent-based modeling simulator for diffusion of innovations as a teaching tool.

RQ1: What human interface and adaptability features must be present in the agent-based simulation system to teach the concept of diffusion of innovations?
RQ2: What software building blocks are needed to develop an agent-based modeling system as an adaptive teaching tool?

2 Related Work

The design of the learning experience follows concepts related to entrepreneurial process theories, learning by trying/emergence, learning from failure, bounded rationality, effectuation, entrepreneurial cognition, and entrepreneurial management and growth [8].

With the diffusion of innovations as the simulation scenario, students may experiment with various technology strategies—from pursuing technology leadership as an innovator to behaving as an early adopter or a fast follower—and they can experience the respective advantages and drawbacks of these strategies [28]. Garcia [10] offers possible research issues involving the diffusion of innovations that the use of ABMs may tackle: *effects of network externalities*, *word-of-mouth networks*, *modeling tipping points*, and *social networks and viral marketing*. Specific skills imparted by the simulation environment related to diffusion of innovations, as inspired by [28], are market entry, global product launch strategies, pricing strategies, product life-cycle and portfolio management, and technology strategy.

There has been little work discussing using ABMS as a tool for teaching and learning, especially in business and entrepreneurship. Social simulation in business has not been very successful so far, because the emphasis has been on using it as a predictive tool rather than as a learning tool [5]. Related to this, In spite of several studies already having featured diffusion of innovations implemented in ABMS, none have been explicitly tied to teaching or learning entrepreneurship. This study, as well as the larger study it supports, aims to contribute the aspect of contextualizing this tool to be useful for entrepreneurship education.

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may tackle: *effects of network externalities*, *word-of-mouth networks*, *modeling tipping points*, and *social networks and viral marketing*.

Agent-based models visually convey the behavior of the model clearly and quickly. However, designing an effective visualization can be challenging for model authors as most of them do not have visual design training. Work establishing principles for designing cognitively efficient, aesthetic, and communicative visualizations [17] can help modelers improve the visual design with ABM toolkits. This paper will use concepts in [17] to frame discussions on the User Interface elements of the simulation.

3 Approach

The process of modeling and design is usually ad-hoc, driven by the modeler's creativity and natural attitudes toward modeling [14]. While there have been attempts to design the model based on well-established frameworks, there will be gaps left to the discretion of the researchers. This study will use the existing methods described, particularly prototyping, model architecture design, agent and agent rule design, agent and environment design, implementation, and verification. There are limitations of existing work related to the use of ABMS in learning environments and in particular, entrepreneurship education. The study aims to facilitate learning through the assessment of simulation outcomes per iteration based on parameters set by the students. The outcome of each run is logged, analyzed, and presents to the students as meaningful feedback [6] and a set of suggestions for supplementary learning from an LMS in preparation for succeeding simulation iterations. Students also get to reflect on their performance and plans after each simulation iteration.

A process presented in [20] for ABMS development consists of the following general steps: *prototyping*, *model architecture design*, *agent and agent rule design*, *agent and environment design*, *implementation*, and *verification*.

Following the steps outlined in [10], the simulation environment and elements comprise the prototype in this study.

1. Theory operationalization through a cognitive map creation
2. Agent specification
3. Environmental specification
4. Rules establishment
5. Measurement/Data Recording
6. Run-time Specification

4 Design

4.1 Considerations

Previous models can be extended to enable the investigation of a wide range of questions and scenarios related to the spread of innovations within a population.

Existing work [28,10]using agent-based models for the diffusion of innovations describes the fidelity, verification, and validation considerations involved.

Fidelity is the amount of realism in a model[9]. A simulation model of the diffusion of innovations will exhibit fidelity if it accurately and realistically represents the system or phenomenon being studied. In the context of agent-based modeling for the diffusion of innovations, agents can have different demographic attributes (e.g. age, gender, income, etc.), personal preferences (e.g., individual preferences for certain product attributes and individual communication behavior [28]), and social connections.

Validation aims to ensure that the simulation is designed to correctly model the processes that exist in reality with a satisfactory range of accuracy matching the simulated model against what is in the real world [9,16]. A valid model produces results that align closely with real-world data on the diffusion of an innovation. There are several ways a simulation model of the diffusion of innovations can exhibit validity. For example, the model might capture the overall rate, and patterns of adoption within the population, such as the Sshaped curve that is often observed in the diffusion of innovations [11]. The model might also capture the effects of various factors on the diffusion process, such as the influence of early adopters or different communication strategies on the spread of innovation [2]. For this research, the practical approach is *face validity*, that is, processes and outcomes are reasonable and plausible within the frame of theoretic basis and implicit knowledge of system experts [16].

Verification establishes whether the simulated model captures the real-world model scenarios and variables as intended and checks for errors, inconsistencies, or other issues affecting model accuracy and reliability [11].

4.2 Parameterization and Calibration

Calibration is the process of tuning a model to fit detailed empirically supported data. During calibration, parameters and initial conditions are tested and tweaked so that the behaviors of individual agents in the model are consistent with the empirical characteristics of the modeled agents [11]. When working with simulation (particularly ABSM), parameterization and calibration are important due to the models' multi-level structure, and often parameter-rich nature [14]. These will involve both *Fixed* (given or exogenous) parameters that can be estimated from available data or gleaned from the literature (as deterministic values, stochastic distributions, or dynamic functions), and *free* (experimental or variable) parameters that are unknown due to lack of relevant data or model specifications [14]. The appropriate numbers of parameters and variables depend on the goal of the model, and the degree of realism and accuracy needed.

4.3 Applying the process framework

The process applied in this section shall be based on the steps discussed at the end of Section 3 of this paper.

Theory operationalization through a cognitive map creation. Table 1 illustrates the distribution which will serve as the basis of the number of agents initialized per simulation run. These distribution percentages are fixed at this point, and they are applied to the prescribed population (which is variable).

Table 1. Distribution of innovation adoption timings.

Consumer Agent	Type	Pct. of Population
Innovator	innovator (not influenced)	2.5%
Early Adopter	imitator	13.5%
Early Majority	imitator	34%
Late Majority	imitator	34%
Laggard	imitator	16%

For this simulator, agents adapt only to what happens during runtime, which is their only source of data. The agents' behavior is based on predefined rules acting on states rather than additional sources of external data.

Agent Specification. Based on [21], the agents in the model have the following characteristics: modularity, autonomy, sociality, and conditionality. Similar to [15], the number of agents chosen for each type is large enough to allow for a realistic dispersion of agents

Table 2. Provider agents and their initial quantities

Agent	Description	Quantity
Consumer	Entity (person or organization) adopting the innovation	5000
Provider Startup	Main entity offering the innovative product or service	1
Provider Competitor	Entity offering a competing product or service	1

The parameters of the agent model representing sensitivity influencing adoption of the innovation are loosely based on the work presented in [27], which refers to each parameter as an index. The *Feature Sensitivity Index* represents the impact of the product's features on the adoption decision. It represents the combination of the product's features and the consumer agent's sensitivity to the features. This study treats this number as an arbitrary number aligned to the adoption timing characteristics of the group of agents. Unlike in [15] with detailed features, this study will treat feature sensitivity in aggregate and generic. The *Price Sensitivity Index* represents the impact of price on the adoption decision and is calculated by multiplying the consumer agent's sensitivity to price by one minus the product provider agent's price value; this calculation incorporates the positive adoption response to a lower price. The *Promotion Sensitivity Index* represents the product provider's promotional intensity efforts on influencing a consumer's decision to adopt the innovation. The Index is calculated

by first multiplying consumer agent sensitivity to promotional activity by the brand agent's promotion intensity. The result is then multiplied by a value representing the previous interactions that have occurred between a given brand and consumer agent pair. The *Social Influence Sensitivity Index* represents the effect of the social influence on the consumer's decision to adopt the innovation. This index is derived by multiplying the consumer's sensitivity to social influence by the total proportion of consumer agents that have adopted the brand.

Agent Relationships. Literature on ABMS uses edges or the number of edges or spatial links to denote network density, which in turn is expected to have a large impact on adoption and market share development because information spreads faster in more densely structured networks [15]. The current version of this simulation will not have physical edges for now, but relationships will be indirectly formed through proximity between agent nodes. This simulator will adopt the simple rule for consumer agents to query its eight neighbors about their individual preferences for a product and then make an informed decision about whether to adopt the same innovation [10].

Environment specification. Agent behavior is largely influenced by predefined rules specified in the next section and the proximity between two agents. Except for possible competitors of the main provider, nothing else in the environment will influence the behavior of the agents in this simulator.

Rules establishment. As the innovation gets more adoption over time, the product's unit price tends to drop [3]. The pseudocode below shows a simple implementation of that rule. The new price is a factor of the previous price and the percentage of the population already converted. The parameter β is an arbitrary number.

function CALCNEWPRICE($oldprice, population, converted, \beta$)
    return $oldprice \times \left[1 - \beta \times \left(\frac{converted}{population}\right)\right]$
end function

The consumer adoption threshold (CAT) is defined as a function of features, price, promotion, social influence, etc. [27]. This simulation will use a simplified version: given the pre-determined sensitivity for feature, price, promotion, and influence for timing categories, for each converted consumer, try to convert each unconverted physical neighbor (as a substitute for some stronger link for now). Each unconverted agent will be assigned a random number for each sensitivity attribute. If all the random numbers generated pass the threshold, then the neighbor agent gets converted into an adopter. The pseudocode below illustrates the decision on when to convert an agent to an adopter of the innovation.

$feature \leftarrow random(0, 100)$

$price \leftarrow random(0, 100)$
$promotion \leftarrow random(0, 100)$
$influence \leftarrow random(0, 100)$
assign threshold values based on the agent's innovation timing category
if $feature > featurethreshold$ &
$price > pricethreshold$ &
$promotion > promotionthreshold$ &
$influence > influencethreshold$ **then**
mark agent as converted
color agent as green
end if

Measurement and data recording. For each iteration by the student, the simulator generates log files containing 1) the set of sensitivity parameters and 2) the periodic as well as beginning and ending values of adoption rates, market share, and unit price. A set of log files are associated with a specific student user of the simulation.

Runtime specification. NetLogo [29] is an open-source programming language and modeling environment specifically designed for agent-based modeling. NetLogo has been used as a platform for modeling the diffusion of innovations.

Integration with a Learning Management System (LMS) can be done either through file transfer of NetLogo logs or through network/API callouts for content from LMS (through NetLogo's Python Extension). The outcome of each simulation run is logged, analyzed, and presented to the students as meaningful feedback and suggestions for supplementary learning from the LMS in preparation for succeeding simulation iterations.

4.4 User Experience Design Considerations for Agent-Based Models

While ABM visualization guidelines may be challenging due to the broad nature of the models, an attempt to define visualization guidelines [17] will serve as the basis for the user interface of this study's model. In this diffusion of innovations model, the finite states a consumer agent can follow the *cellular automata* category prescription of mapping an agent to a specific color.

Figure 1 shows the state of the simulator before the run. The layout of the agents follows the colors specified in Table 3 and the distribution resembles the curve based on the distribution in Table 1.

Table 3. Consumer agent state and color mappings.

Consumer Agent State	Color
Innovator	Yellow
Early Adopter	Orange
Early Majority	Blue
Late Majority	White
Laggard	Gray
Converted/Adaptor	Green
Adaptor/Captured by Competitor	Red

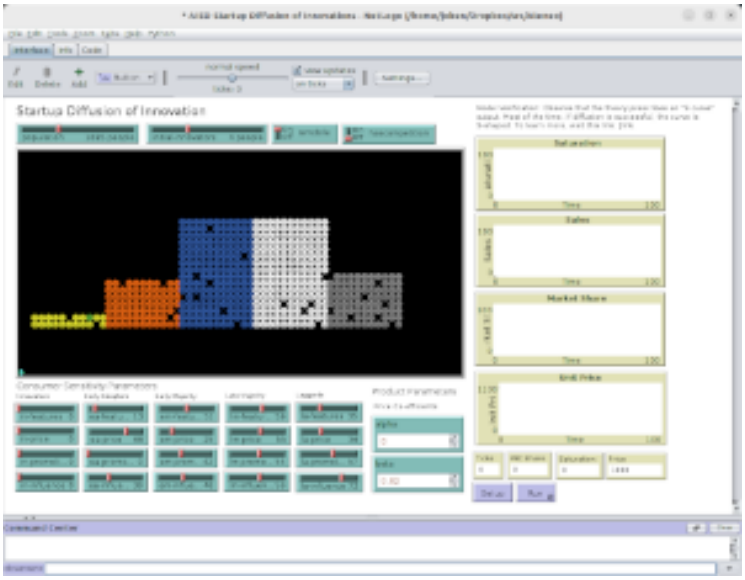


Fig. 1. Simulator state after the run.

The *Mobile* switch allows agents to move around the screen to allow close with other agents and get the chance to influence their neighbors at a particular moment to adopt the new technology. Since one of the limitations of this simulation model is that there are no explicit relationships between agents, nearness or location proximity will be the basis for agents to influence others. If the mobile switch is turned off, the agents laid out in the bell curve will only be able to influence others in a static location. This simplifies simulation runs, but one drawback of this setup is that agents can only directly influence others of specific timing characteristics (which is not what happens in the real world).

Aligned with *face validation*, support for animation must be on the appropriate level of detail and display all relevant dynamic aspects of the elements in a way that they are easily detectable by a human [16].

For this simulator, the expected theoretical S-curves [11] and diminishing prices [4] shall be reflected graphically and animated over time (or ticks in NetLogo). The animation will also show the adoption by consumer agents over time through the changes in states as represented by the colors defined in Table 3.

An animated chart showing overall market revenue over time.

The agents' behavior rules are partly deterministic based on literature and partially stochastic based on ranges of theoretical thresholds to address the model's validity. Even when the student adjusts specific parameters in the model, the agents will continue to behave autonomously based on the programmed rules and behaviors governing the propensity of each agent to adopt the innovations based on the parameters.

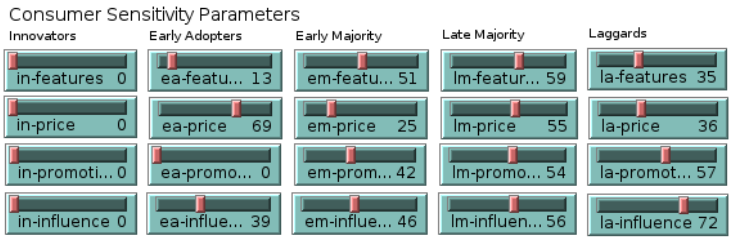


Fig. 2. Simulator state before the run.

Figure 3 shows the simulator's state after the run. The main animation area in the middle of the screen shows the physical dispersion of agents after they are made to move in random directions. With all agents colored green, this indicates a full saturation state. While this may not fit well with the model's overall validity, the simplicity is still within acceptable levels of detail [9] and lends well to discussions of saturation from a teaching perspective.

A chart on the right shows an S-curve for the adaption of the innovations, with all green indicating full saturation. Another chart shows revenue per period, indicating tapering off revenues as the innovation matures and eventually declines.

The characteristics of the revenues chart are generally the same, but the curve is not as right-skewed as [3], where the peak happens in the early stages of the product or innovation life cycle. This is mainly due to the simplification of the price decline formula.

The decline in market share is expected since the simulator introduced a simple scenario with two competitors emerging shortly after the presence of early adopters.

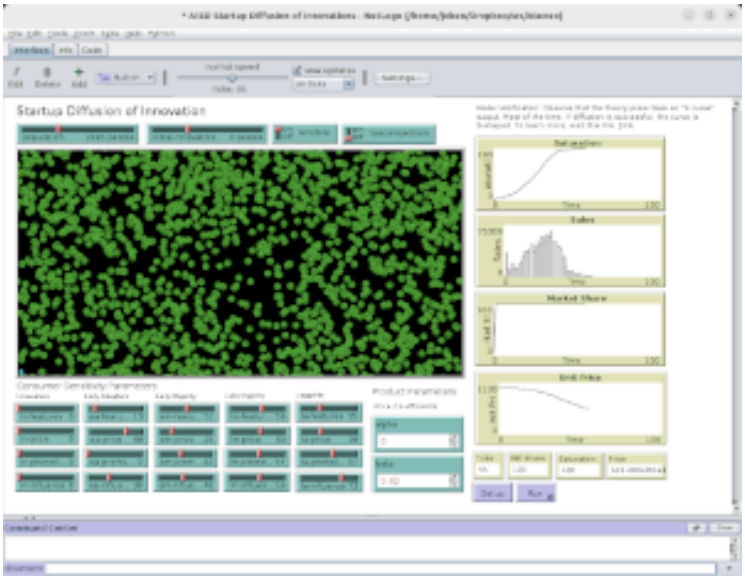


Fig. 3. Simulator state after the run.

5 Limitations

This initial version of the model shall consider only one product to be introduced to the market.

Many mobile agents can display complex spatial or color patterns, but very little visual interaction (if any) with the environment. As such, the background color of the simulator can be left as **black**.

While Netlogo has limitations regarding user interface design options, this study takes the stance that students may be overwhelmed by too many interface elements, so avoiding too much complexity allows students to grasp the intended learning objectives more easily [28]. As the simulator transitions to more empirical data for rules governing the behaviors of agents, future versions of the simulation may incorporate additional user interface and simulator elements.

6 Discussions and Conclusions

Through this study, we demonstrated that the simulator interface can be aligned to concepts involving diffusion of innovations where students can readily visualize the configuration, layout, and animation of agents behaving based on students' manipulation of parameters. User interface design aligns well with goals of fidelity and validity of the underlying simulation model. Each simulation allows agents to adapt to various thresholds set by the students. These address RQ1 involving human interface and adaptability features in the ABMS platform

Aside from the simulation interface, the ABMS environment also allows for capturing logs per simulation run which can be transferred to an LMS. The resulting charts show validity consistent with expected theoretical and empirical outcomes (ex., adoption saturation S-curve). These address RQ2 involving the software building blocks needed by the simulator as an adaptive teaching tool for diffusion of innovations.

While aiming for high validity is conceivably beneficial, limitations on the model were deliberately factored in from a teaching and learning perspective because too much detail may be detrimental [9]. One limitation of this simulation model is that there are no direct and explicit relationships between agents through links, but rather only through proximity to one another. Future versions of this simulation will allow direct relationships and will not be constrained to proximity as the basis for being able to influence others.

Another limitation of the model is that the rules, based on formulas, have been greatly simplified. In the future,ß machine learning (ML) and AI techniques, in turn, will enhance the behavior and capabilities of agents in [24] in future versions of this simulator. Switching to ML-based techniques will will enable future versions of the simulation to incorporate additional user interface and AI-based simulator elements.

Finally, another shortcoming of this simulation is that the behavior of competitors is fixed and lacking. With the introduction of ML and AI techniques, adaptive competitor behavior will make the simulator more interesting to the technology entrepreneurship students as they will see consumer and producer (competitor) behavior.

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