Restructuration in Practice: Challenging a Pop-Culture Evolutionary Theory through Agent Based Modeling

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Abstract

An ordinary, non-scientist person's exposure to science through pop-culture is ever growing. However, science is still believed to have a high threshold of entry. For most people, doing science means going through rigorous training of literature, specialization, and learning formal mathematics. Many people feel that they have no means to figure out which idea is scientifically accurate and which one is inaccurate. More importantly, they only have the trustworthiness of the source as heuristic for believing or not believing in a particular scientific message. In this paper, we argue that agent-based modeling has the potential to lower the threshold of entry to science and to empower people against the flood of scientific messages in pop-culture. To demonstrate our theory in practice, we conduct a thought experiment in which we extract a much debated scientific theory on the evolution of sexes from a BBC Earth documentary and show how one can easily recreate and explore the assumptions of such a theory using the NetLogo agent-based modeling environment. Then, we compare traditional formal mathematics based scientific analysis approach with our agent-based modeling approach and show how the latter affords people with little or no training in high level formal mathematics or evolutionary biology literature to challenge scientific ideas.

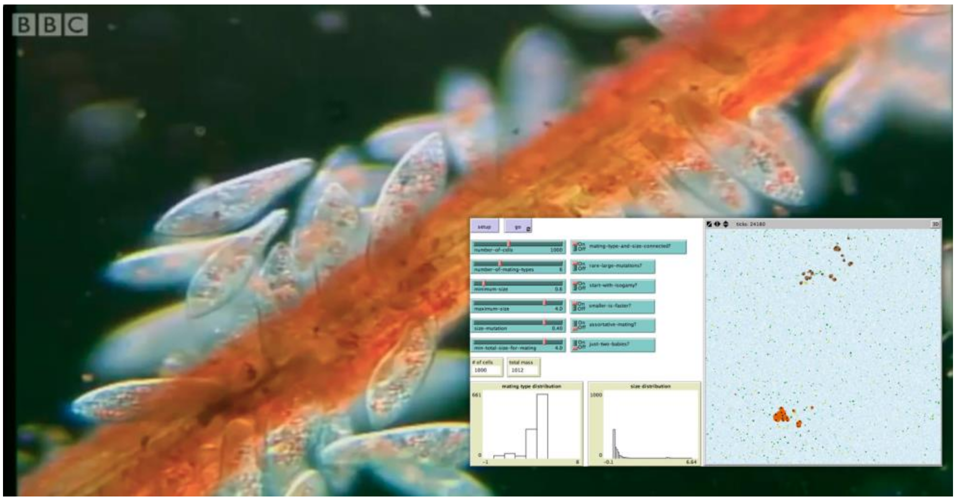

Figure 1. BBC Earth's documentary and the agent based model we developed based on it.

Keywords

Science, literacy, agent-based modeling, restructuration.

Introduction

Research shows that TV and the Internet are by far the main scientific information resources for just plain folks (shortly JPFs), a term coined by Lave (1988) (Brossard and Scheufele, 2013; Horrigan, 2006). JPFs hear about topics like human evolution, depletion of fisheries or the disappearing of honeybees on a daily basis. We begin by asking the following question: How are the JPFs supposed to sift through all the scientific messages that they get through media and examine them? Given that JPFs do not have the time to deeply learn the literature, is there a way to facilitate this process while not becoming an expert in science? Unfortunately, it seems like JPFs currently only leverage heuristics such as trust in scientists or trust in resources when forming opinions about on scientific information, such as believing or not believing in the climate change (Hmielowski, Feldman, Myers, Leiserowitz and Maibach, 2013). This situation shows that JPFs are dramatically underpowered against the scientific enterprise and finding ways to lower the threshold of entry to science is an important challenge for learning scientists. In this paper, we reiterate a constructionist ideal, democratizing science through restructuration (see Wilensky and Papert, 2010), and argue that agent-based modeling has the potential to empower JPFs in their casual interactions with scientific ideas through pop-culture.

So far, a common discourse in the science education literature has been justifying the need for formal science education based on a need for scientific literacy (e.g., Holbrook and Rannikmae, 2007; NRC, 1996). Many researchers argued that school is *the* place for learning scientific practices and preparing for a life dominated by scientific messages. Falk and Dierking argue that this “school first” paradigm is so ubiquitous that most educators or policy makers take it for granted (2010, p. 486). Yet, research has shown that JPFs learn about science mostly out of school (Feder, Shouse, Lewenstein and Bell, 2009). Besides, retention of even basic scientific knowledge learned through formal schooling has always been problematic (e.g. Custers, 2010). Based on such evidence, it becomes increasingly clear that learning about the scientific method and memorizing scientific facts is not enough; facts are easily forgotten and JPFs neither have tools nor time to practice the scientific method. They need better ways to deal with the scientific information thrown at them in their daily lives. We believe that studying JPFs’ out of school interactions with science can inform us in restructuring science education in formal settings. Therefore, we focus on JPFs interactions with science through pop-culture.

Although we agree with the calls for scientific literacy, we believe that we need to rethink its framing. According to Papert, “becoming literate means thinking differently than one did previously” (1993, p. 10). Similarly, diSessa (2001) argues that small changes in learnability can have far greater impact on the eventual impact and theorizes that computers can be *the technical foundation* of a new and enhanced literacy. Lastly, Wilensky and Papert (2010) argue that we need to recalibrate the focus of learning from the means to the object of it. Wilensky and Papert particularly show how agent-based representations are superior to equational representations of science by analyzing both major representational shifts in the history, such as the effects of switching from Roman numerals to Arabic numerals, and strengths of agent-based restructurations of modern scientific phenomena such as kinetic molecular theory and materials science.

Building on these theories, we claim that agent-based modeling has both the power and the potential to play a critical role in lowering the threshold of entry to science and facilitating democratization of scientific knowledge. In addition, we coin the term *agent-based literacy* as a promising approach to rethink JPFs’ everyday interactions with scientific ideas, as well as reframing the very construct of scientific literacy. In particular, we focus on an analysis of how agent-based modeling could empower JPFs to challenge scientific ideas presented in pop-culture. To illustrate our position, we run a thought experiment and demonstrate how a hypothetically agent-based literate JPF can react to a still disputed evolutionary biology theory from a TV documentary and easily challenge it using the NetLogo agent-based modeling environment (Wilensky, 1999) without needing to become an expert in the domain. We also discuss how agent-based modeling differs from the traditional scientific method in challenging the same evolutionary theory in terms of threshold of entry for non-scientist people.

Evolution of Sexes: Challenging a Pop-Culture Theory using Agent-Based Modeling

Let's conduct a thought experiment and explore the learning of an imaginary JFP named Alex, who enjoys following BBC Earth's channel on YouTube. In April 2015, Alex would come across a short documentary titled "Simple sex and the birth of gender" (BBC Earth, 2015), which presents ideas on the evolution of the sexes. Following is the full excerpt of the documentary:

> "The sex is a force to battle because females have a score to settle. And it all started about a billion years ago when simple single celled animals like paramecium rocked the world. Only individuals virtually identical in shape and form but they differ genetically. Only different genetic types can come together and reproduce. They fuse their membranes and exchange some of their cell contents. In this form of simple sex, they part after mating as new individuals. There can be dozens of sexes in these animals, highlighted as different colors, and there are no battles.
>
> But that all changed long ago when one of them *cheated*. A *quirk of evolution* made one of the sexes smaller and this turned out to be one of the most significant events in life on earth. The smaller types were more mobile and so monopolized the matings. But the mates of the little cheats could only produce viable offspring if they grew fat to compensate for their partner's lack of provision. Now one sex was on a path to obesity, the other to athletic swimming. The presence of these sex midgets drove all the other sexes to extinction, except for the huge fatty cells. The small sex, those that cheated, became sperm and the large sex eggs. Gender as we know it was born."

Now let's assume Alex is not literate in agent-based modeling. She would feel this theory compelling and probably believe in it because BBC Earth is a trustworthy news source. However, directly accepting the BBC Earth's theory (BET, in short) could result in Alex developing some misconceptions about the process of evolution. Yes, BET sounds scientifically accurate initially, but some words used by the narrator such as *cheated* and *quirk*, might have led Alex into believing that (1) the process of evolution is one of miracles, and (2) individual agents are consciously trying to gain selective advantage. Conversely, if we assume Alex is literate in agent-based modeling, she would be able to test BET by developing a model in an agent-based modeling environment. In the following section, we describe how one can replicate BET in the NetLogo agent-based modeling environment without any exposure to the evolutionary biology literature.

Modeling BBC Earth's Theory in NetLogo

In order to explore how Alex might go about exploring BET, we went through the process of creating a model that can illustrate how an agent-based literate JFP would approach such a question. Due to the fact that we wanted to think through the lens of a JPF, we did not collaborate with any evolutionary biologist in this process. We developed a simple model of BET and conducted a simple, non-rigorous analysis of the model output. In this section, we begin by explaining our modeling decisions and then describe how the model works.

First step in modeling BET is extracting the assumptions from the documentary. There are six main assumptions of BET: (1) smaller cells move faster, (2) a minimum total size is required for two organisms to reproduce, (3) the evolution of sexes happened among simple single celled organisms, (4) there were more than two mating types initially, (5) mating type is a single gene/trait and it is represented by different colors in the documentary, (6) mating type of an organism and its size are somehow connected. On the other hand, BET gives no explanation on the mechanisms of evolution. Therefore, we have to fill in the blanks with our best guesses. For instance, there is no mention of life cycles of these organisms and the population size so we need to figure out how many agents needed in the system and how would they die. Because we have limited computing power, we decided to have a range of 0-2500 agents in the model. We also decided to have a carrying capacity for the system so we killed agents randomly if the number of agents exceeds a certain number. However, we did not put any natural death mechanism to the system at all. Next, BET assumes that two organisms need a certain amount of material so that their offspring survives but it does not mention what happens if this criterion is not met. Thus, we decided not to allow two organisms to initiate mating if their total size does not exceed a threshold. Third, BET talks about fusion, but it does not say anything about how these organisms are reproducing. In our model, two mating agents hatch new baby agents and then die immediately.

In addition, we wanted to create a model in which the user can change parameters and test different assumptions freely. For some assumptions, we placed an on/off switch (see Figure 2). For example, we wanted to see if speed is really a selective pressure in such a system, so we created a "*smaller-is-faster?*" switch. When this switch is turned on, smaller agents are faster than bigger agents. When this switch is turned off, all agents move with the same speed. Moreover, we did not have any idea on how big or small organisms would be. We also did not know what was the range of size in this organisms, so we had to go with arbitrary values for organism size and size mutations. Still, we wanted to have some sort of tinkering space so we created sliders for each variable such as *minimum-size* and *minimum-total-size-for-mating*.

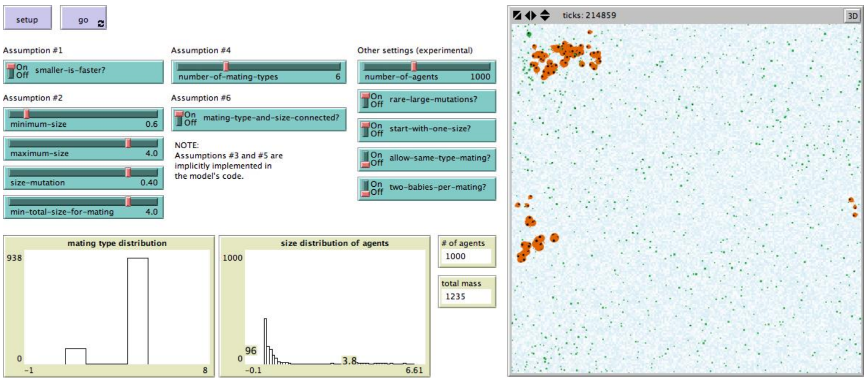

Figure 2. The evolution of sex model based on BBC Earth's theory.

After some tests, we decided to set the variables as shown in Figure 2 for our demonstrative experiment. In terms of defining agent behavior, each agent in our model represents a single-celled organism and follow a very simple set of commands. In each time tick, each agent changes its direction randomly and moves forward. Then, it checks if there is another agent on the same place with a different mating type (color) and enough size to meet the minimum size requirement for reproducing. If it can find such a partner, it initiates mating with its partner. In the mating process, the mating type and the average size of prospective babies are picked randomly from the parents' trait pool. Next, if *two-babies-per-mating?* switch is turned off, multiple babies are hatched based on total size of parents and the size of prospective babies. Otherwise, parents hatch just 2 baby agents after each mating. Finally, both parents die.

Results

We ran the model from a state where all agents start with the same size and with 4 different setting combinations: (1) smaller is faster and more than two babies can be produced, (2) speed is constant and more than two babies can be produced, (3) smaller is faster and just two babies are produced, and (4) speed is constant and just two babies are produced. At each run, we waited for the population to come to an equilibrium point and took screenshots of the graphs. Due to space limitations, we will not be able to dive deeper into the results of the model. However, we share typical final states of all four combinations in Figure 3:

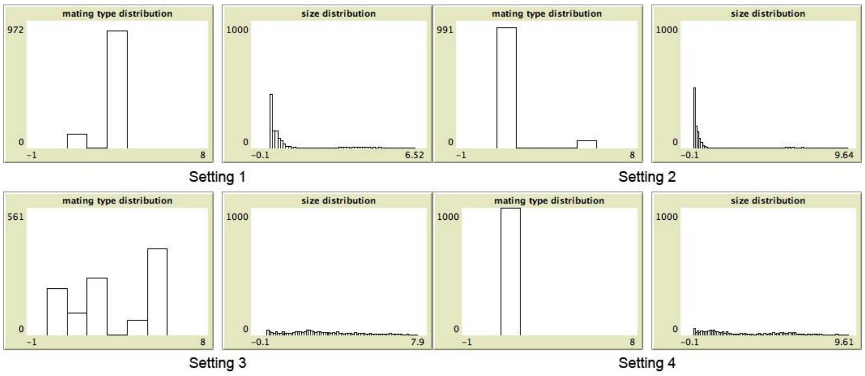

Figure 3. Typical results of four parameter different combinations.

We believe if our plain folk Alex developed such a model, or just even ran it, she would see the emergence of a dichotomous state with numerous extremely small cells and a few very big cells in first two settings. Therefore, she would realize that BET has some explanatory value if the system is setup in this particular way. However, she would also see that there is neither cheating nor a quirk in this process. It all happens through stochasticity and selective pressures in the system. When she took a closer look at the difference between graphs, she would get the chance to test the assumptions of BET, too. Interestingly, there is no substantial difference between smaller cells being faster or all cells being the same speed when we compare the outcome of setting 1 to setting 2. Plus, there is no evolution of small-big dichotomy in settings 3 and 4 at all. It seems like producing more agents in a mating is more important than the speed of individual agents. Particularly, no significant difference between setting 1 and setting 2 shows that the difference is not actually in speeds of the cells. Small agents dominate matings simply because there are many more of them in the system. When this advantage is taken out in settings 3 and 4, big-small dichotomy does not evolve and the model does not end up with a population with two final mating types.

Discussion

Although our model was able to produce a dichotomous state, these findings should not be considered as the proof of how sexes evolved. Instead, our agent-based exploration should be interpreted as a modest exploration of BET and disproof of its assumption about the selective role of agent speed in the hypothetical environment described by it. Likewise, one can rightfully argue that our model is scientifically incorrect because we developed it based on BBC Earth's narration, not on a scientific literature review. However, it still allowed our imaginary JFP Alex to start from somewhere. If Alex had no tools like NetLogo, she would have to first start reading the literature on evolutionary biology. Consider the following excerpt from a paper written by Bulmer and Parker (2002) on this topic:

> "In the ancestral unicellular state the gametic and zygotic survival functions, $g(m)$ and $f(S)$, are likely to be similar in shape and location, leading to isogamy. The development of multicellularity may leave $g(m)$ relatively unchanged, but will push $f(S)$ to the right as the need to provision the zygote increases, eventually leading to anisogamy. This is most clearly seen when the survival functions are sigmoidal, exemplified by the inverse exponential Vance function in equation (2.2). The situation is more complicated in the less likely case when the survival functions are concave, exemplified by the complementary exponential function in equation (2.12)."

Unfortunately, the literature on the evolution of sexes is very challenging for outsiders. In the first place, Alex has to know that this particular phenomenon is called anisogamy, “the occurrence within a population of two gamete types of different size” (Bell, 1978, p. 73), in order to be able to even start a literature review. Then, it is important to realize that there is still no consensus on how anisogamy actually evolved (Blute, 2013). Beyond the literature barriers, Alex also has to know at least the basics of evolutionary game theory (Smith, 1982) to be able to conduct further mathematical analysis in order to challenge BET. Following is another excerpt from Bulmer and Parker’s paper (2002, p. 2382):

> “We assume that fusions occur between gametes of ‘+’ and ‘–’ individuals (mating types). All + individuals produce n_1 gametes of size m_1, and – individuals produce n_2 gametes of size m_2, with $n_i = M/m_i$, where M is the fixed budget for reproduction. Zygotes are of size $S = m_1 + m_2$, and the survival to adulthood of a zygote of size S is $f(S)$. The chance that a gamete of size m will survive to mate is $g(m)$.
>
> Under these assumptions, the reproductive fitness of + individuals is
>
> $$w_1(m_1, m_2) = \frac{Mg(m_1)}{m_1} f(m_1 + m_2),$$
>
> and the reproductive fitness of – individuals is
>
> $$w_2(m_1, m_2) = \frac{Mg(m_2)}{m_2} f(m_1 + m_2).”$$

This is actually the start of Bulmer and Parker’s mathematical analysis and they only talk about how they are going to calculate fitness functions of individuals. Still, even if Alex understands some parts of their paper, it is unfortunately impossible for her to move on from there if she does not have a good background in formal mathematics. Now consider the following code from our agent-based model (gray lines starting with a semicolon are our comments):

```
to maybe-mate
  ; I check if there are any cells here, who is of a different mating type big enough to mate with me
  let potential-partners other cells-here with [
    mating-type != [mating-type] of myself
    and (size + [size] of myself > min-total-size-for-mating)   ]
  ; if I bump into any potential partners
  if any? potential-partners [
    ; I pick one of them randomly and initiate the mating with it
    let my-partner one-of potential-partners
    ; First, we pool our traits so that our offspring inherits the mating type from either parent randomly
    let mating-type-of-babies one-of list ((mating-type) ([mating-type] of my-partner))
    ; Our offspring inherits their average size based on the mating type
    let average-size-of-babies size
    if mating-type-of-babies != my-mating-type [  set average-size-of-babies [size] of partner  ]
    ; based on the total size of me and my partner, the count of baby cells is calculated
```

```
        let number-of-babies ceiling ((my-size + partner-size) / average-size-of-babies) + 1
        ; then we hatch baby agents one by one
        hatch number-of-babies [
          ; each baby inherits the same mating type
          set mating-type mating-type-of-babies
          ; and then mutates its size by adding or subtracting a small random number to the average baby size
          set size average-size-of-babies + random-float size-mutation - random-float size-mutation    ]
        ; after mating, me and my partner die!
        ask my-partner [die]
        die    ]
    end
```

NetLogo code of our agent based model is much more readable and easier to understand compared to mathematical analysis of the evolution of sexes. The primitives of NetLogo such as *one-of*, *hatch* and *die*, require little to no explanation. There is no scientific jargon in our code at all. More importantly, our agent-based model focuses on a concrete process whereas Bulmer and Parker's study focuses on an abstract mathematical analysis. In other words, Alex does not need to be trained to acquire a specific way of thinking.

As a side note, it is worth mentioning that we are not trying to contribute to evolutionary biology literature, at all, while Bulmer and Parker's analysis is built on a very rigorous scientific analysis. Our model, in that respect, is not an effort to do science and it is not comparable to Bulmer and Parker's work. Our goal is to lower the threshold whereas Bulmer and Parker are trying to raise the ceiling. We must also mention that our agent-based code is not a direct equivalent of Bulmer and Parker's equations. The two approaches are distinctly different from each other by nature. In agent based modeling, our focus is on defining the behavior of individual agents and investigating emergent phenomena (Wilensky, 2001), while evolutionary game theory focuses on figuring out strategies that maximize the fitness using equational models (McNamara and Weissing, 2010).

Nevertheless, for our imaginary JFP Alex, who did not study biology formally, challenging BET would have been extremely hard and frustrating if she was agent-based illiterate. She would have no joy in exploring such a domain at all and give up quickly after realizing that she needs much more expert knowledge in order to answer her questions on the theory. However, as an agent based literate person, she can potentially enter the world of evolutionary biology, discover that BET has some flaws, and begin to explore more about the evolution of sexes. It is true that she cannot produce any new scientific theories based on this model, but she can still feel satisfied because this model has potential to empower her against a scientific idea that she is exposed through pop-culture. If she was not literate in agent based modeling, she might have just chosen to believe in the BBC's narrator because it was published by a credible source or she might have rejected it based on her intuitions or superstitions.

Conclusion and Future Directions

In this paper, we proposed agent-based literacy as a way to rethink JFPs' interaction with scientific information in daily life. We argued that people are continuously exposed to a flood of scientific messages through pop-culture but they do not have reliable means to evaluate these ideas other than heuristics about the trustworthiness of resources. The traditional method of challenging these pop-media theories would be diving into scientific literature, which requires understanding heavy jargon and formal mathematical analysis. We argued that agent-based modeling literacy would support a richer participation in scientific practices and conducted a thought experiment based on a pop-culture evolutionary biology theory that we extracted from a documentary. We showed that an agent-based literate person has the power to challenge such a theory and demonstrated how one would develop an agent-based model of this particular theory. Then we compared agent-based modeling with evolutionary game theory analysis.

Based on our current analysis, and also based on decades of constructionist research, we strongly argue that a major restructuration in science is much needed (e.g. Papert, 1993; diSessa, 2001; Wilensky and Papert, 2010; Wilkerson-Jerde and Wilensky, 2010). As part of this restructuration, we need to reconsider the way we conceptualize scientific literacy and teach science in schools. In our opinion, the advent of a computer-based literacy is far more critical than the current operationalization of scientific literacy. We believe that JPFs need more than just heuristics, simple facts, or basic knowledge of the scientific method. We need to lower the threshold of entry to science so that they have better tools and objects to challenge scientific messages thrown at them by entertainers, politicians, or policy makers. In this respect, agent-based modeling is a promising restructuration of science. It is much easier to learn and use compared to the scientific method and complex formal mathematical analyses. It is also much more accessible for JPFs who has neither time to conduct scientific experiments nor access to scientific facilities.

However, we are cautious that we do not propose agent-based modeling as a total replacement for current scientific practices. It would, of course, be absurd to reach in such a conclusion. In addition, we are we are aware of the flaws of our agent-based exploration of the evolution of sexes. In the future studies, we hope to collaborate with evolutionary biologists and develop a better model of anisogamy with correct scientific assumptions and mechanisms. We are also aware of the fact that just one thought experiment has little or no generalizability on the effects of agent-based literacy on lowering the threshold of entry to science. Therefore, our main challenge in future studies is to study the challenges of becoming agent-based literate for JPFs, the potential ways to facilitate this kind of scientific explorations for them, and learning gains of such experiences.

References

BBC Earth. (2015, April 8). Simple sex and the birth of gender - Battle of the Sexes in the Animal World [Video file]. Retrieved from https://www.youtube.com/watch?v=dWa9NmNvChU

Bell, G. (1978). The evolution of anisogamy. Journal of Theoretical Biology,73(2), 247-270.

Blute, M. (2013). The evolution of anisogamy: more questions than answers.Biological Theory, 7(1), 3-9.

Brossard, D., & Scheufele, D. A. (2013). Science, new media, and the public.*Science*, *339*(6115), 40-41.

Bulmer, M. G., & Parker, G. A. (2002). The evolution of anisogamy: a game-theoretic approach. *Proceedings of the Royal Society of London B: Biological Sciences*, *269*(1507), 2381-2388.

Custers, E. J. (2010). Long-term retention of basic science knowledge: a review study. *Advances in Health Sciences Education*, *15*(1), 109-128.

diSessa, A. A. (2001). Changing minds: Computers, learning, and literacy. Mit Press.

Falk, J., & Dierking, L. (2010). School is not where most Americans learn most of their science. *American Scientist*, *98*(6), 486.

Feder, M. A., Shouse, A. W., Lewenstein, B., & Bell, P. (Eds.). (2009). *Learning Science in Informal Environments:: People, Places, and Pursuits*. National Academies Press.

Hmielowski, J. D., Feldman, L., Myers, T. A., Leiserowitz, A., & Maibach, E. (2013). An attack on science? Media use, trust in scientists, and perceptions of global warming. *Public Understanding of Science*, 0963662513480091.

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education*, *29*(11), 1347-1362.

Horrigan, J. B. (2006). *The Internet as a resource for news and information science*. Pew Internet & American Life Project.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge University Press.

McNamara, J. M., & Weissing, F. J. (2010). Evolutionary game theory. Social behaviour: Genes, ecology and evolution, 109-33.

National Research Council (Ed.). (1996). *National science education standards*. National Academy Press.

Papert, S. (1993). The children's machine: Rethinking school in the age of the computer. Basic Books.

Smith, J. M. (1982). Evolution and the Theory of Games. Cambridge university press.

Wilensky, U. (1999). {NetLogo}.

Wilensky, U. (2001). Modeling nature's emergent patterns with multi-agent languages. In Proceedings of EuroLogo (pp. 1-6).

Wilensky, U., & Papert, S. (2010). Restructurations: Reformulations of knowledge disciplines through new representational forms. Constructionism.

Wilkerson-Jerde, M. H., & Wilensky, U. (2010). Restructuring change, interpreting changes: The deltatick modeling and analysis toolkit. *Proceedings of constructionism*.