Journal of Education and Praxis Research. Volume 1, Issue 1, (2015) 19-25
http://www.cayley-nielson.com/jepr

Agent-Based Modeling for the Climate Change Procedure in Geography Classes

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Abstract

This study has developed a pedagogical approach to teach the climate change procedure in high school geography classes within a perspective of complex systems. Due to the complexity of the theoretical prototype of the climate change procedure, it is necessary to employ the agent-based modeling in computer and group teaching mode. The phase of our pedagogical approach is comprised of three-part sessions: the pre/post quizzes before/after interaction with the simulations and the group activities during the whole class. Compared to the equation-based models and traditional text instruction, this approach has more significant influence on enhance of the students' scores by the exploratory tests and analysis. Moreover, some hybrid method with different models is recommended in the real teaching and learning in high school.

Keywords: Agent-based modeling; Pedagogical approach; Geometry education; Climate change.

1. Introduction

Recently, there exists a trend in high school geography education in which several instructional topics are set within a perspective of complex systems [1]. The domain of "complex systems" has evolved rapidly in the past years, along with the novel ideas and applications of re-comprehending classic phenomena, such as ecological constellation and weather systems. Under these circumstances, an emphasis on world regional geography even in history/geography/biology teaching is used to provide a solid conceptual base for global issues like population growth, urbanization, and climate change at the high school Level [2-4] . According to the literature [5], more and more high schools consider to adding appropriate contents into the existing geography curriculum. However, as the amount emerging contents of them, the geography education has started to come to terms with an unfortunate paradox: despite the procedures in geography as the complex systems, very little foundations of mathematical the students have. This phenomenon even caused a fact that a large number of students could not comprehend the whole phases.

In this paper, we propose a pedagogical approach to teach the Climate Change Procedure (CCP) topic with the help of its agent-based modeling, and then we prove it efficient and pragmatic by the empirical evaluation.

2. Mathematical Modeling

In a systematic viewpoint, the Earth's climate system can be seen as an elaborate type of energy flow system in which solar energy enters the system, is absorbed, reflected, stored, transformed, put to work,

March, 2015

and released back into outer space. The balance between the incoming energy and the outgoing energy determines whether the planet becomes cooler, warmer, or stays the same. Since the amount of energy received approximately equals the amount given back to space, the Earth is approximately in a steady state in terms of energy.

Daisyworld [6], a classic model of complex feedbacks in a simple climate system, is designed to mimic the dominant elements of the Earth-Sun system, and was introduced by James Lovelock and Andrew Watson to illustrate the plausibility of the Gaia hypothesis. Daisyworld implies a global energy balance dictates simply that the incoming energy is equal to the outgoing energy. The global energy balances and the local ones are defined by the following Eq.(1):

$$T_e = \sqrt[4]{\frac{S_0}{4\delta}(1-\alpha_p)}\ , T_i = \sqrt[4]{\frac{S_0}{4\delta}(1-\alpha_i)} \tag{1}$$

where T_e represents the emission temperature of a body while T_i the local temperature of daisy. S_0 stands for the solar luminosity which is relevant to the sun lightness directly. The albedo of daisy i is denoted as α_i, while the average planetary albedo is called α_p. Then the local and global (Eq.(1)) energy balances are combined to form the Daisyworld energy balance, as shown in Eq.(2). After satisfying both local and global equations, the Daisyworld energy balance has an uncertainty as it must be large enough to have different daisy populations and local temperatures, yet it maintains an emission temperature.

$$T_i = \sqrt[4]{q(\alpha_p - \alpha_i) + T_e^4} \tag{2}$$

where q is the heat flux coefficient. Finally, the temperature dependent growth rate a differential equation of daisy area is created, as show in Eq.(3), which means existing some daisy area for daisy growth to occur.

$$\frac{dA_{color}}{dt} = A_{color}(\beta x - \gamma) \tag{3}$$

where β illustrates the temperature dependent growth rate, the x is the available ground for daisy colonization. And the γ despicts the death rate of the daisies.

For a long time, the nature and science disciplines, such as physics, biology, geography, etc., have been dominated by the mathematical models based on equations, i.e., Equation-Based Models (EBMs) [7]. In some of these models, the complex systems are always summarized into several functions like “black box” which reacts to external stimuli and changes, while the internal structure of the system is not explored. In recent years, however, the classical equation-based models have been suffered to many criticisms, which include the weak ability to express complex system; static, unintuitive, hard to be observed and analyzed, etc.

Nowadays, an emerging approach to model the discrete dynamic systems aided by computer simulation is the so-called Agent-Based Models (ABMs) [7, 8], in which the behaviors of individual agents are simulated, using the methods of the paralleling/concurrency computation. Compared to the EBMs, a decentralized approach, ABMs is easier to understand and solve than the analysis of functions for non-mathematicians, especially the students in high schools. Moreover, using the ABMs, implementing large and complex discrete dynamic systems become possible. Naturally, EBMs can be seen as a method that aggregates the concepts, states, and dynamics into the formulae; while ABMs the approach distribute the behaviors and interactions to autonomy agents.

The multi-agent simulation models can be created using various computer programs [9]. In this paper, one of them, Netlogo [10] developed at the Center for Connected Learning at Northwestern University is used, which is quite suited for modeling complex systems with agents can be controlled independently also with interactions among them. Here, we utilize the NetLogo Climate Change model by Tinker R. and Wilensky U. [11] to teach the CCP course in high school classes.

3. Pedagogical Approach

The overall phase of our pedagogical approach is comprised of three-part sessions: the pre/post quizzes before/after interaciton with the materials and the group activities in the middle of the whole class. The completed knowledge point involved includes IFs (influencing factors), LCs (Law Curves) and PTs (Particle Trajectories), which are contained in both Pre/Post Quizzes and group activities as shown in Table 1.

Table 1. Knowledge points in the pre/post quizzes and the group activities

	Pre-Q 1	Pre-Q 2	Pre-Q3	Post-Q1	Post-Q2	Post-Q3	Post-Q4	Post-Q5	GA1	GA2	GA3	GA4
IFs	IF_{albedo}	IF_{cloud}	IF_{co2}	IF_{albedo} IF_{cloud} IF_{sun}	IF_{albedo} IF_{cloud}	IF_{albedo}	IF_{cloud}	IF_{co2}	IF_{albedo} IF_{cloud} IF_{sun}	--	IF_{albedo} IF_{cloud} IF_{sun} IF_2 IF_3	IF_{albedo}
LCs	--	--	--	IC_{temp}	IC_{temp}	IC_{temp}	IC_{temp}	IC_{temp}	IC_{temp}	--	IC_{temp}	IC_{temp}
PTs	--	--	--	--	--	--	--	--	--	HT_{heat} HT_{sun}	--	--

In high school geography classes, it is necessary to import some inspiring quizzes to let students know what they should focus and think on. For another reason, we could use the results from these quizzes to analyze the effect of our pedagogical approach.

Pre-Q1. According to your real experience about climate change, consider the question: “If the metropolis is always hotter than the suburb, regardless of the impact of the wind?”

Pre-Q2. Take account an idea and extreme case, answer the question: “Assume that there not exists any cloud, whether the temperature can keep increase forever?”

Pre-Q3. In line with relevant knowledge, consider the question: “Why the greenhouse gases, such as CO2, could make the Earth warmer?”

Post-Q1. Run the CCP model in Netlogo with the changing of albedo and adding the clouds and CO2 and then watch a single sunlight arrowhead. The question is “What is the highest earth temperature you can produce?”

Post-Q2. Run the CCP model in Netlogo without any cloud and CO2. “Why does the temperature stop rising, continue to bounce around and finally become a constant?”

Post-Q3. Explore the effect of albedo holding everything else constant. “Does increasing the albedo increase or decrease the earth temperature?”

Post-Q4. Explore the effect of clouds holding everything else constant. “Does increasing the clouds increase or decrease the earth temperature?”

Post-Q5. Explore the effect of adding CO2. “What is the cause of the change you observe?”

- **Group Activity 1 (GA1): Observations on the behavior of agents in ABM**

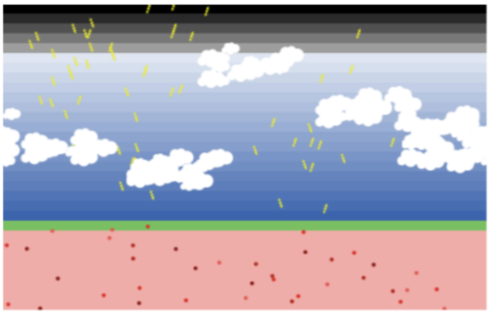
The teacher divides the class into five subgroups of four students each. Each subgroup has a leader responsible for initiating the process and maintaining communication with the teacher and other subgroup members. Each of the following groups might be asked to research and explore the common and unique characteristics of their observations as a subgroup of CCP: Sun brightness Group, Albedo Group, Cloud Group (Fig.1 (a)) and CO_2 Group (Fig.1 (b)).

- **Group Activity 2 (GA2): Heat Trajectory tracing**

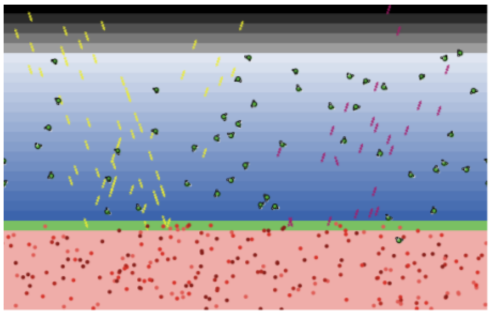
In this group, all of students have to insight into a micro world such as sun brightness (yellow line), emission heats (red discrete line), local heats (red dot), and heat trajectory (red continuous line) as shown in Fig.2. By this activity, the original daisy area as in Eq.(3) of daisyword, e.g., A_{black}, A_{white} and the mechanism of generating balance could well reappear in the Netlogo agent-based model, which can be illustrated in Fig.2(a) and Fig.2(b) respectively.

- **Group Activity 3 (GA3): Data analysis in a concept lattice**

Due to the multifarious factors related to the influence of the temperature, high school students are not easy to clarify the concepts [12,13] and relationships among them. The employing of concept lattice in literature could help them enumerate the possible factors combinations and layering them in an arranged hierarchy as in Fig.3.

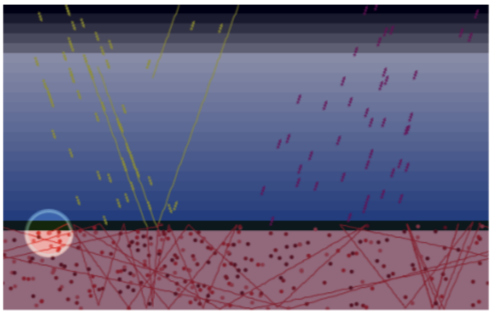


(a) Observation in Cloud Group

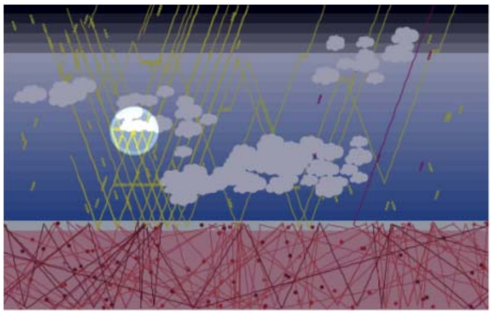


(b) Observation CO2 Group

Fig. 1. Behavior of agents in CCP model..



(a) Heat trajectory tracing in case of A_{black}



(b) Heat trajectory tracing in case of A_{white}

Fig. 2. Heat trajectory tracing.

- **Group Activity 4 (GA4): Temperature curving with dynamic simulation manually**

In the daisyworld model, the temperature dependent growth rate a differential equation of daisy area in Eq.(3). As the students in high schools have little basis on the differential equation theory and Matlab, it is unpractical to curving the variation of temperature in EBM model. However, we can complete it by means of Netlogo ABM. A simple method is to drag the slides of albedo or sun brightness for a period of time interval. As expected, the variation of temperature may be depicted like the Fig.4, which is almost compliant to the result of simulation by Matlab.

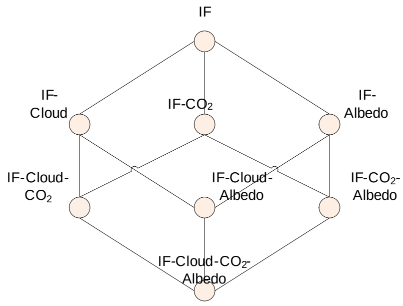


Fig. 3. Concept lattice of Influence Factors.

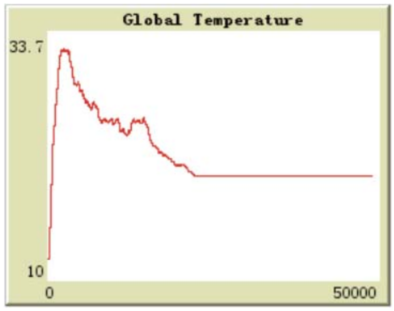


Fig. 4. Temperature curving.

4. Experiments and Findings

This experiment took place during the autumn of 2011 at Xiantao Middle School. For 12th grade students, about 86% of them had well ability of computer operating and programming, while 15% know a little about the differential equation. To compare the effect of ABM, EBM, and LBM (Language-Based Modeling), all the students were divided into six groups.

Firstly, a Wilcoxon signed-rank test [14] was used to compare pre/post quizzes scores for each group. In Wilcoxon signed-rank test, N is the sample size, the number of pairs. For i=1,...,N, let $x_{1,i}$ and $x_{2,i}$ denote the measurements. W is the test statistic according to Eq.(4a), which is the absolute value of the sum of the signed ranks R_i of the pairs, starting with the smallest as 1. In addition, a Kuruskal Wallis H test [15] was also carried out to compare the change in quizzes scores between groups. The test statistic H is shown below in Eq.(4b), where $n=n_1+n_2+\ldots+n_k$ measurements are jointly ranked. The total measurements in all k samples are ranked from 1 to n. T_i is the rank sum for the ith sample, i ranges over 1,2,…,k.

$$\text{(a)}\quad W = \left|\sum_{i=1}^{n}[\operatorname{sgn}(x_{2,i}-x_{1,i})\cdot R_i]\right|, \qquad \text{(b)}\quad H = \frac{12}{n(n+1)}\sum_i \frac{T_i^2}{n_i} - 3(n+1) \tag{4}$$

In Table 2, it is shown that ABM and ABM & LBM groups shared the highest median pre-quiz score and the highest proportion of students who scored more than 60% in the pre-quiz, while LBM and ABM & LBM had the highest median post-quiz score and the highest proportion of students who scored more than 60% in the post-quiz. The Wilcoxon signed-rank test showed that students in the LBM group and the LBM & ABM group significantly increased their score between the pre/post quizzes and large effect sizes were associated with each. There was a significant difference between the pre/post quizzes scores in the ABM group, and a large effect size was associated with this. The difference between pre/post quizzes scores in the EBM and ABM & EBM group was non-significant and the effect size was small. The Kruskal-Wallis H test showed that the difference between the groups with respect to pre-test scores was non-significant (H(6)=0.30, p=0.97), as was the difference with respect to post-test scores (H(6)=2.66, *p*=0.51). The Wilcoxon signed-rank test showed that students in the LBM group and the SDM & ABM group significantly increased their score between the pre/post quizzes and large effect sizes were associated with each. The difference between pre/post quizzes scores in the EDM and ABM & EBM group was non-significant and the effect size was small.

Table 2. Statistics on scores and the results of Wilcoxon signed-rank tests

Group	Pre-quiz				Post-quiz				*W*: Pre-quiz
	median	lower	upper	≥60%	median	lower	upper	≥60%	vs. Post-quiz
ABM	21.25	0	30	45	20.5	7.25	37	50	3.8
EBM	13.5	0	25.5	26	17.5	0	23	39	1.5
LBM	15	8	34	31	23	9	34	60	0.0
ABM & EBM	19.25	0	40.25	43	18	0	45	48	4.1
ABM & LBM	22	4.5	36	53	29.5	12	43	68	4.4
EBM & LBM	18.5	5	38.5	40	19.25	10	40	48	0.0

Table 3. Correlation between the knowledge points in ABM and EBM groups

		Pre-quiz scores				Post-quiz scores				
		IF_{albedo}^{Pre}	IF_{cloud}^{Pre}	$IF_{co_2}^{Pre}$	IC_{temp}^{Pre}	IF_{albedo}^{Post}	IF_{cloud}^{Post}	$IF_{co_2}^{Post}$	IC_{temp}^{Post}	HT_{heat}^{Post}
		ABM/EBM	ABM/EBM	ABM/EBM	ABM/EBM	ABM/EBM	ABM/EBM	ABM/EBM	ABM/EBM	ABM/EBM
Pre-quiz scores	IF_{albedo}^{Pre}	--/--								
	IF_{cloud}^{Pre}	0.63/-0.24	--/--							
	$IF_{co_2}^{Pre}$	0.81/0.43	0.40/0.38	--/--						
	IC_{temp}^{Pre}	-0.26/-0.46	0.13/-0.43	0.60/0.35	--/--					
Post-quiz scores	IF_{albedo}^{Post}	0.84/0.22	0.55/-0.13	0.52/0.39	0.55/0.48	--/--				
	IF_{cloud}^{Post}	-0.41/0.33	1.00/-0.23	0.24/-0.31	-0.28/-0.37	-0.23/-0.12	--/--			
	$IF_{co_2}^{Post}$	-0.15/-0.24	0.41/-0.28	1.00/0.17	0.45/0.36	0.15/-0.30	0.28/0.44	--/--		
	IC_{temp}^{Post}	0.66/0.53	-0.04/0.36	0.43/0.25	0.89/0.39	0.81/0.24	0.56/0.29	0.30/0.68	--/--	
	HT_{heat}^{Post}	0.38/0.70	0.17/0.21	0.83/0.47	0.53/0.48	0.19/-0.24	0.47/0.35	0.90/0.31	-0.07/0.25	--/--

Finally an exploratory analysis of the correlation relationships between answers is shown in Table 3. A correlation of 1.00 indicates that the ranks of the marks in the pre/post quizzes were identical. A large, significant correlation between the pretest score of one question, and the post-quiz score of another indicates that a relationship exists between the two, which indicating that students who had higher scores in the pre-quiz were also able to score highly in the post-quiz in this other question. It illustrates that in the ABM and EBM group, students who had a higher pre-quiz IF_{albedo}^{Pre} score also had higher post-quiz scores for the $IF_{co_2}^{Pre}$, IF_{albedo}^{Post}. Similarly, students who had a higher pre-quiz $IF_{co_2}^{Pre}$ score had a higher score for HT_{heat}^{Post}. The IF_{albedo}^{Post} and $IF_{co_2}^{Post}$ post-quiz scores was also positively, significantly correlated with IC_{temp}^{Post} and HT_{heat}^{Post}. However, it shows that in the EBM group, pre-quiz scores were not significantly relevant to post-quiz scores.

6. Conclusion

In our research, we design a pedagogical approach based on ABM with group mode to teach the climate change procedure in high school geography classes within a perspective of complex systems. By the exploratory tests and analysis, we find that apply the ABM or hybrid mode with other models, such as EBM or LBM, can obtain considerable effect. In contrary, the pedagogical approach using EBM has no significant influence on enhance of the students' scores.

References

[1] Jacobson MJ, Wilensky U. Complex Systems in Education: Scientific and Educational Importance, and Implications for the Learning Sciences. The Journal of the Learning Sciences 2006; 15: 11-34.

[2] Dietz, T., Dan, A., & Shwom, R. (2007). Support for Climate Change Policy: Social Psychological and Social Structural Influences*. Rural Sociology, 72(2), 185-214.

[3] Hestness, E., McGinnis, J. R., Riedinger, K., & Marbach-Ad, G. (2011). A study of teacher candidates' experiences investigating global climate change within an elementary science methods course. Journal of Science Teacher Education, 22(4), 351-369.

[4] Liarakou, G., Gavrilakis, C., & Flouri, E. (2009). Secondary school teachers' knowledge and attitudes towards renewable energy sources. Journal of Science Education and Technology, 18(2), 120-129.

[5] Sadik, A. (2008). Digital storytelling: A meaningful technology-integrated approach for engaged student learning. Educational technology research and development, 56(4), 487-506.

[6] Watson AJ, Lovelock JE. Biological homeostasis of the global environment: the parable of Daisyworld. Tellus B 1983; 35:284-289.

[7] O'Sullivan D, Millington J, Perry G, Wainwright J. Agent-Based Models - Because They're Worth It? Agent-Based Models of Geographical Systems, Part 2 2012; Part 2: 109-123.

[8] Dahlgren, M. A., & Dahlgren, L. O. (2002). Portraits of PBL: Students' experiences of the characteristics of problem-based learning in physiotherapy, computer engineering and psychology. Instructional Science, 30(2), 111-127.

[9] Arbaugh, J. B., & Duray, R. (2002). Technological and structural characteristics, student learning and satisfaction with web-based courses an exploratory study of two on-line MBA programs. Management learning, 33(3), 331-347.

[10] Wilensky U. NetLogo. http://ccl.northwestern.edu/netlogo/. Northwestern University,1999.

[11] Tinker R, Wilensky U. NetLogo Climate Change model. http://ccl.northwestern.edu/netlogo/models/ClimateChange. Northwestern University, 2007.

[12] Southerland, S. A., Abrams, E., Cummins, C. L., & Anzelmo, J. (2001). Understanding students' explanations of biological phenomena: Conceptual frameworks or p‐prims?. Science Education, 85(4), 328-348.

[13] Harlen, W., & Holroyd, C. (1997). Primary teachers' understanding of concepts of science: Impact on confidence and teaching. International Journal of Science Education, 19(1), 93-105.

[14] Lowry R, Concepts and Applications of Inferential Statistics, 2006 (free statistics textbook http://faculty.vassar.edu/lowry/webtext.html).

[15] Spurrier JD. On the null distribution of the Kruskal-Wallis statistic. Journal of Nonparametric Statistics 2003; 15: 685-691.