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Simulation of social processes: application to social learning

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Abstract

The teaching–learning process in a classroom context is simulated by means of the Monte Carlo method. It is found that the structure of the collaborative groups formed by the students may influence their achievements. It is shown that low-achievement students may learn at the expense of their high-achievement colleagues.

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Keywords: Sociodynamics; Teaching–learning processes; Monte Carlo

1. Introduction

The theoretical study of social processes using tools of statistical physics and computer science has attracted the attention of many scientists [1]. Among them, an increasing number of physicists have recently incursioned into areas of research such as Economy [2], Social Sciences [3], Biology, etc. Also, the study of cognitive processes has also developed into an active area of multidisciplinary investigation. The processes of learning and understanding Physics and Mathematics have become the focus of cognitive research (See e.g. a set of interesting articles collected in Supplement 1 in Ref. [4].). The experience gained indicates that the performance of the students can be enhanced using a teaching approach involving collaborative groupwork, in contrast to the traditional method of (almost) non-interactive lectures.

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In order to help the development of teaching strategies, it will be desirable to have a theoretical approach capable of capturing the main features of teaching–learning (TL) processes and having a wide spectrum of validity. Along this idea, we have recently proposed a model for TL process that can be treated mathematically, solved numerically and analyzed statistically [5]. This multidisciplinary approach links psychological and sociological theories of impact [6,7] and recent concepts developed in the field of educational psychology [8] to the well established tools of Statistical and Computational Physics [9]. Within this context, the aim of the present work is to investigate the influence of the structure of the groupworks on the achievement of the students using the already proposed TL model.

2. Basic definitions. The model and the simulation method

The TL model is formulated based on a framework similar to those used to treat spin systems [9]. The cognitive impact (CI) acting on student is the result of those interactions with his/her environment (teachers, peers, bibliography, etc.), capable of modifying his/her knowledge. The student is also a source of CI to other students by persuading and supporting. The persuasiveness, $P_{ij} \geqslant 0$, describes the degree to which the ith student can persuade the jth one. Furthermore, during a discussion, the support, $S_{ij} \geqslant 0$, describes the degree to which the ith student supports the statements of the jth one. Both, S_{ij} and P_{ij}, become enhanced when individuals share similar ideas about the subject under examination, they have social and cultural affinities, etc. The knowledge of the jth student at time t is given by $-1 \leqslant \sigma_j(t) \leqslant 1$, where $\sigma_j(t) = 1$ corresponds to optimum knowledge.

Based on these considerations, the CI of the teacher on the jth student ($CI^{TS}(j,t)$), can be written as

$$CI^{TS}(j,t) = P_{Tj}(1 - \sigma_j(t)\sigma_T) , \tag{1}$$

where $\sigma_T > 0$ and P_{Tj} are the knowledge of the teacher and his/her ability to persuade the jth student, respectively. P_{Tj} depends on many factors, characteristic of both the teacher her/himself and the teacher–individual relationship, such as e.g., the rhetorical ability and the persuasive skills of the teacher, the didactic presentation of the subject of study, etc.

Pointing our attention to collaborative groupwork, the CI of the student–student interaction (supervised by the teacher) $CI^{SS}(j,t)$, is given by

$$\begin{aligned} CI^{SS}(j,t) = \sum_{i=1, i\neq j}^{N} & [P_{ij}(t)(1 - \sigma_i(t)\sigma_j(t)) \\ & - S_{ij}(t)(1 + \sigma_i(t)\sigma_j(t))]\mathrm{sign}(\sigma_i(t)/\sigma_T) , \end{aligned} \tag{2}$$

where, the group has N students. The first (second) term accounts for the mutual persuasiveness (support). The structure of these two terms is similar to that of Eq. (1) and it is plausible since it is expected that mutual support will be larger when the individuals have similar knowledge ($\sigma_i\sigma_j > 0$) while persuasiveness is expected to play a more relevant role in the opposite case ($\sigma_i\sigma_j < 0$). It is also assumed that both S_{ij} and P_{ij} are composed of intrinsic and extrinsic (or interactive) factors, so

$$S_{ij}(t) = S^o_{ij}(\sigma_T + \sigma_i(t)) \tag{3}$$

and

$$P_{ij}(t) = P^o_{ij}(\sigma_T + \sigma_i(t)) , \tag{4}$$

where the intrinsic factors, S^o_{ij} and P^o_{ij}, depend on many causes such as the strength of psychological coupling, affinity of social status, education, rhetorical abilities, personal skills, etc. The extrinsic factor is provided by a comparison established by the individual with the teacher who assumes a leadership role. This factor is included to account for the fact that the model attempts to describe supervised collaborative group work [10]. In fact, the term $(\sigma_T + \sigma_i(t))$ means that both persuasiveness and support between individuals could be either reinforced or weakened when the knowledge of the teacher is taken as a reference level. In addition, the term $B \equiv \mathrm{sign}(\sigma_i(t)/\sigma_T)$ in Eq. (2), explicitly accounts for the plausible fact that an individual with knowledge below the average ($\sigma_i < 0$) has low chance to cause an increment of the knowledge of another individual that is above the average ($\sigma_j > 0$). Also, due to this term, in the inverse case ($\sigma_i > 0, \sigma_j < 0$), the jth individual has great chance to increase his/her knowledge.

The knowledge is a dynamic variable influenced by the CI. So, during a time interval Δt, the knowledge changes as follows: $\sigma_j(t + \Delta t) = \sigma_j(t) \pm \Delta\sigma$. Also, $\sigma_j(t)$ may improve (become worse) with the probability $P_j = \tau_j/(1 + \tau_j)$ and $(1 - P_j)$, where τ_j is a generalized Metropolis rate [9] given by

$$\tau_j = \exp^{\beta_{TS} CI^{TS}(j,t) + \beta_{SS} CI^{SS}(j,t)} , \tag{5}$$

where each process has it own "noise" given by $1/\beta_{TS}$ and $1/\beta_{SS}$, respectively. In fact, for the teaching–student relationship, the noise is due to misunderstandings, disorder in the classroom, inappropriate teaching material, lack of attention of the students, obscure explanations, etc. For the student–student interactions the noise $1/\beta_{SS}$ appears due to disordered discussions, misunderstandings, the lack of a well-organized participative activity, etc. It should be noticed that it is difficult to quantify the noise of the interactions, so $1/\beta$ has been left as a parameter of the model.

The dynamic evolution of the system is simulated using the Monte Carlo technique [9]. During each Monte Carlo time step the knowledge of all the students are update simultaneously, as in a cellular-automata approach. It is assumed that $\Delta\sigma = 0.1$, $\sigma_T = 1$, $P_{Tj} = 1 \forall j$, with $j = 1, \ldots, N_T$, where $N_T = 99$ is the total number of students in the classroom. Also, S^o_{ji} and P^o_{ji} are taken at random in the interval $(0, 1)$.

3. Result and discussion

To study the influence of the structure of the collaborative groups on the teaching–learning process it is assumed that, as a result of a previous diagnostic test, the students

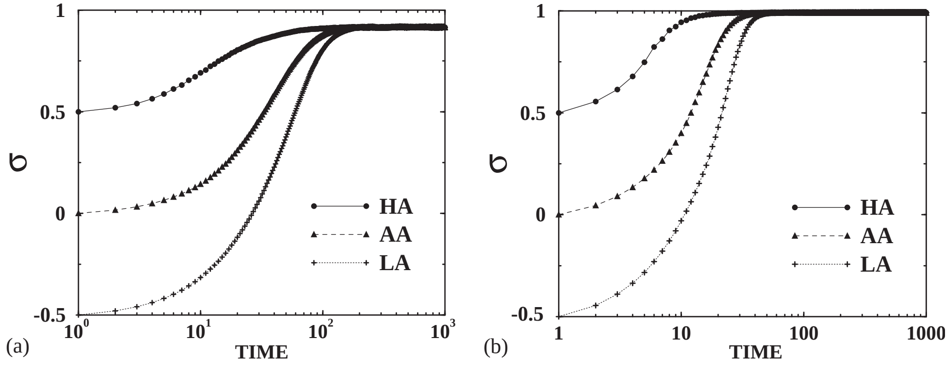

Fig. 1. Plots of the time evolution of the knowledge achieved by the students engaged in collaborative groupwork. (a) $\beta = \frac{1}{3}$ and (b) $\beta = 1$.

can be classified into three different sets, namely "high-achieving (HA) students" with $\langle \sigma_{HA} \rangle = 0.5$, "average-achieving (AA) students" with $\langle \sigma_{AA} \rangle = 0$ and "low-achieving (LA) students" with $\langle \sigma_{LA} \rangle = -0.5$. Subsequently, three different cases are considered. In Case I the students only attend the lectures of the teacher, which corresponds to the so called traditional teaching approach. However, in Cases II and III the students not only attend such lectures, but are also engaged in collaborative work forming groups of $N = 3$ individuals (The optimal group size depends on the nature of the task and the experience of the group members. Group sizes between two and six individuals are recommended in various contexts, see e.g., Refs. [10,11,12]). However, those groups are formed in two different ways: in Case II the groups are heterogeneous and the members are chosen at random. In Case III the groups are homogeneous and all the members of each group are selected so that they have similar initial achievements.

Fig. 1 shows the time evolution of σ for Case III as obtained by taking $\beta = \beta_{TS} = \beta_{SS}$. The occurrence of three distinct time regimes can be observed: For the short time regime ($t < 5$) the knowledge increases slowly. In the intermediate time regime (roughly for $5 < t < 80$) a rapid growth of the knowledge is observed, while for larger time the knowledge reaches a stationary maximum value (σ_M). These time regimes are also observed in Cases I and II.

Fig. 2(a) shows plots of (σ_M) as a function $1/\beta$. For Case I, σ_M decreases steadily when the noise is increased. In contrast, the knowledge achieved by groups (Cases II and III) is more robust and exhibits a sharp drop only for $1/\beta \approx 6$. Also, collaborative work always improves the achievements. From Fig. 2(a) it also becomes evident that the achievements of excellent and very good teachers (smaller values of $1/\beta$) can only slightly be improved by the groups, a fact which it makes difficult to detect differences using tests. This is also difficult in the other extreme case, e.g. for bad teachers and noisy groups, but there is an intermediate regime where the difference is maximum and tests have better chances to detect the improvement caused by the groupwork [13].

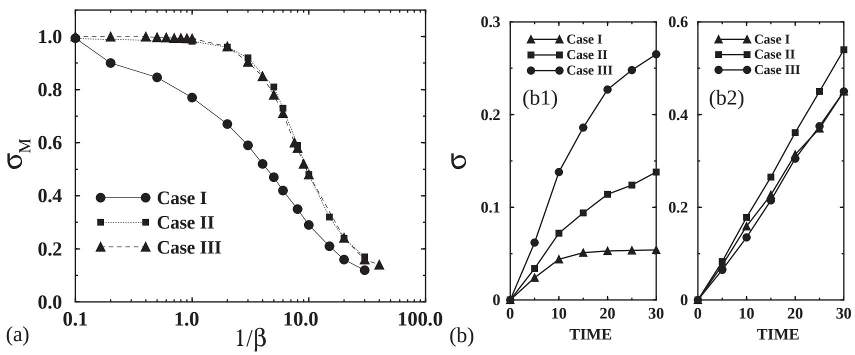

Fig. 2. (a) Plots of σ_M vs $1/\beta$ obtained for different type of groups. (b) Plots of the time evolution of the knowledge obtained for Cases I, II and III, as shown in the figure. The panel b1 (b2) corresponds to high-achieving students (low-achieving students).

From the point of view of physicists, Fig. 2(a) exhibits a typical "transition like" behavior. In fact, in the limit of low noise ($1/\beta \to 0$), that also corresponds to a low "social temperature" (i.e., $1/\beta \equiv kT$), one has an ordered phase with high achievements given by a knowledge (order parameter) close to unity. Also, the disordered state of low knowledge is observed in the limit of large noise. The smooth (Case I) and abrupt (Cases II and III) changes of the knowledge resemble second- and first-order phase transitions, respectively. Of course, true transitions would be observed in the thermodynamic limit only. Since teaching–learning processes take place among a reduced number of individuals, a detailed study of the model in the thermodynamic limit is beyond the aim of this paper. Within this context, it is interesting to mention that, very recently Castellano et al. [14], have studied non-equilibrium phase transitions in a model for social influence earlier proposed by Axelrod [15]. Phase transitions of both, second- and first-order, separating an ordered (culturally polarized) phase from a disordered (culturally fragmented) one, are observed and discussed. The reported behavior [14] and our findings shown in Fig. 2(a) point out that, well established tools in the field of statistical mechanics of critical phenomena, can successfully be used to describe complex social processes.

Fig. 2(b) shows that the influence of the structure of the groupwork becomes evident during the early and intermediate time regime. The left panel (b1) shows that the performance of HA students is always enhanced when they are engaged in groupwork (Cases II and III) as compared to the traditional approach (Case I). However, HA students perform much better when they form homogeneous groups with students having the same achievements (Case III). For LA students (right panel (b2) of Fig. 2(b)) one has a dramatic difference: these students perform much better when they interact with HA students (Case II). Furthermore, when they interact with students of similar (LA) knowledge (Case III) only, their achievements are either worse or indistinguishable as compared to the Case I of traditional lectures. These results suggest that the composition of the groups may cause LA students to learn at the expense of HA students, as documented by numerous studies [16].

4. Conclusions

The influence of the group structure on the achievements of the students studied using an already proposed model for the teaching–learning process [5]. It is found that the performance of low achievement students may be enhanced when they form groups with better students. However, this improvement may be obtained at the expense of the achievements of their colleagues. The dilemma faced by teachers in order to determine optimal grouping strategies becomes evident, due to the fact that the performance of all kind of students cannot be optimized simultaneously. We hope that this type of numerical study will help in the development of a general theory of teaching–learning processes.

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