The Classroom as A Complex Adaptive System: An Agent-Based Framework to Investigate Students' Emergent Collective Behaviors

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Abstract: This study applies agent-based modeling methodology to investigate individual and social factors underlying inequitable participation patterns observed in a real classroom in which an experimental collaborative activity was implemented. We created agent-based simulations of simplified collaborative activities and qualitatively compared results from running the model with the classroom data. We found that collaboration pedagogy emphasizing group performance may forsake individual learning, due to preference for short-term group efficacy over individual long-term learning. The study may inform professional development and pedagogical policy.

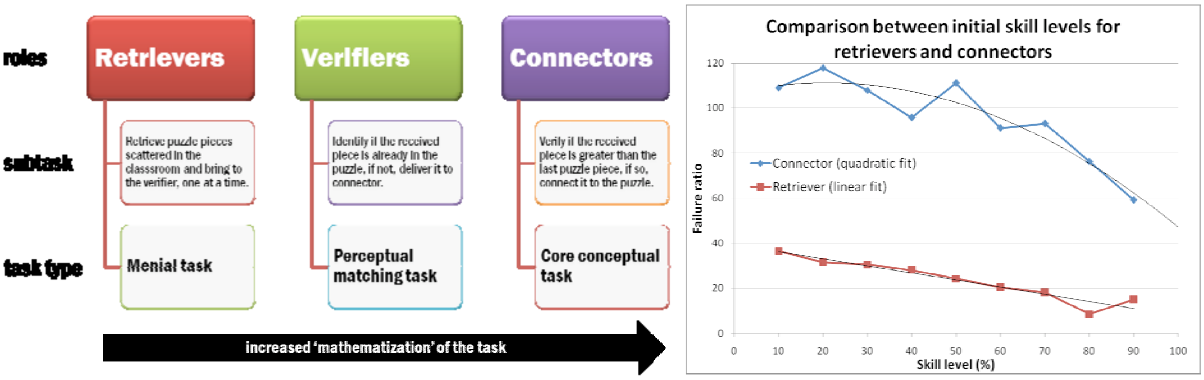
Agent-Based Modeling and Team Work in Classrooms

Agent-based modeling (ABM) has been increasingly used by scientists to study a wide range of phenomena such as species in an ecosystem or molecules in a chemical reaction (Bonabeau, 1999; Wilensky & Reisman, 2006). Such phenomena, in which the elements within the system (molecules, or animals) have multiple behaviors and a large number of interaction patterns, have been termed complex and are collectively studied in the interdisciplinary field called complex systems. In recent decades there has been a surge in social-science studies employing ABM (Epstein & Axtell, 1996). Recently, ABM has been used to illustrate aspects of cognitive development in social context (Abrahamson & Wilensky, 2005; Blikstein, Abrahamson & Wilensky, 2006). We argue that ABM has potential to contribute to the advancement of theory on group work and collaboration in classrooms, particularly, the computational power of ABM enables researchers to mobilize an otherwise static list of conjectured behaviors and witness emergent group-level patterns.

A classroom engaged in collaborative group work can be seen as a complex adaptive system (Hurford, 2004) in which optimal as well as suboptimal behavioral patterns may emerge. Despite individual students' initially explorative behaviors, once a functioning coordination scheme evolves in a group and is evaluated as well adapted to performing the mandated task, an implicit quietus is set on any further exploration or task rotation, and the group achieves dynamic stability. Such arrangement would be fitting for workplaces, but its instantiation in classrooms may present teachers with the dilemma of maximizing group production at the expense of individual learning, especially of struggling students who are benignly assigned by the group to mathematically lesser tasks. ABM methodology may provide education researchers and practitioners tools for understanding such classroom dynamics, so that they can identify points of leverage for working *with* students' natural behavioral inclinations to achieve equitable participation.

Implementation of a Model in the Form of Agent-Based Procedures

We set out to build a computational model that would simulate phenomena we had observed in a middle-school mathematics classroom engaged in group-based problem-solving activity (Abrahamson & Wilensky, 2005). In that classroom, roles were spontaneously assigned by students within groups so that the pedagogical value of individual students' tasks could be indexed by each student's prior mathematical achievement. Such inequitable labor division is injurious, because it perpetuates and even exacerbates the classroom achievement stratification. For our model, we chose a simpler numeric puzzle task (see Figure 1a). This linear puzzle consists of set of numbered pieces to be concatenated in ascending order (1, 2, 3, 4…). Necessary activities within this task are *retrieving* pieces (simplest task), *verifying* if pieces are already present in the puzzle (intermediate demand), and *connecting* pieces (most demanding task). Initially, puzzle pieces are scattered all over the classroom. Piece-retrievers wander around and, when they find a piece, grab it and go back to their group's table, delivering it to the piece-verifier. The piece-verifier evaluates whether a copy of the piece is already present (the puzzle cannot have repeated pieces). If so, the piece-verifier orders the piece-retriever to discard the piece and bring a new one. If the piece is suitable, the piece-verifier delivers it to the piece-connector, who will check if the piece fits the puzzle in its current state, and connect it to the puzzle. For each successful micro-task, students receive positive feedback in the form of an increment in their skill (speed and/or accuracy). Overall group performance is evaluated by the time-to-completion divided by the number of correct pieces. Our independent variables are: (a) pedagogical style (with or without mandated role rotation); (b) students' initial skill level for each task and distribution of skill levels within students; (c) task difficulty.



a. *b.*

Figure 1. Design rationale for the Stratified Learning Zone model, and results from multiple runs of the model.

Initial Findings

In analyzing the model's output, one must adopt a skeptical stance, because in any act of modeling lies the inherent possibility that some critical aspect of a situation has been overlooked. Yet, this challenge of modeling is certainly not unique to agent-based modeling but is typical of any scientific endeavor. That said, after many sets of experiments over a large initial parameters set, we were able to plausibly demonstrate relations between pedagogical practice and student learning, as follows: (i) The overall performance of groups with mandated role-rotation decreased by approximately 40%; (ii) When student–agents were reinforced for group performance rather than individual learning, students became entrenched within skills reflecting their initial skill-level distribution; (iii) However, when role rotation was mandated, even though production slowed down, more learning occurred, per student. A careful analysis of the impact of each task on group performance is necessary to build a causal explanation of our numerical results. Increasing a low-level task skill (i.e., increasing the number of puzzle pieces a retriever–student can bring to the group per time tick) appears to decrease the correct/incorrect puzzle-pieces ratio (failure ratio) linearly (see red line in Figure 1b, bottom), whereas increasing the high-level task skill effects a non-linear trend (see blue line in Figure 1b, top).

Conclusions

We have presented a computer-based methodology for conducting research into collaborative learning. To demonstrate the methodology, we described the design and implementation of an agent-based model that simulates the emergence of inequitable participation patterns in a collaborative-inquiry activity. In future publications we will explain in details results from experiments with the model, the validation of the model using real world data, and limitations of this approach. Hopefully, by harnessing the perspectives and methodologies of complexity science, such as through building and experimenting with agent-based simulations of classroom interaction dynamics, we can create useful tools that inform theory building and equip practice.

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