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Teaching the Repeated Prisoner's Dilemma With a Computerized Tournament

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Abstract: The authors present a constructivist approach for teaching game theory, on the basis, in part, of Axelrod's research approach. Using the Axelrod tournament multi-user system (ATMUS) software, students create strategies for a repeated prisoner's dilemma (RPD). Later, these strategies are matched with those of their classmates' in a classroom tournament while the instructor interactively and graphically demonstrates the behavior of the strategies. A two- to three-week instructional implementation strategy is provided to highlight effective use of the ATMUS software, according to constructivist learning principles, to ensure that students are engaged in critical thinking regarding RPD.

Keywords: computer-assisted instruction (CAI), constructivism, game theory, repeated prisoners' dilemma
JEL codes: A20, A22, C70, C72, C73

The dominant method in economics instruction is traditional in approach, focusing on the classroom lecture, with other media support and classroom discussion (Benzing and Christ 1997; Becker and Watts 1996). This traditional approach focuses on the transmission of information from the teacher to the student, with the underlying assumption that knowledge can and should be transferred from teacher to student. This approach works best for verbally oriented information that is hierarchically structured and can be conveyed (by instructor or textbook) through sequential explanation of the necessary knowledge (Roblyer, Edwards, and Havriluk 1997). For example, information regarding how the national accounting system is designed can be conveyed in this manner, where students learn by absorbing the information in a traditional lecture format.

An alternative instructional approach, rarely employed in economics instruction, is a constructivist approach to instruction, where the teacher's role shifts from dispenser of knowledge to facilitator of learning (Grabe and Grabe 2001). Users of the constructivist approach to learning and instruction maintain that for knowledge to be acquired in a meaningful way, it must be personally and actively constructed

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by each individual learner (Moreno and Mayer 1999). Several key attributes of constructivist instruction, according to Driscoll (2000), include the following: (a) providing for social negotiation, (b) supporting multiple perspectives and use of multiple modes of representation, (c) encouraging ownership in learning, and (d) nurturing self-awareness of the knowledge-construction process (382–383). A constructivist approach is particularly appropriate for facilitating the acquisition of higher-order thinking skills. For example, students in macroeconomics need to decide which policy instruments should be used in which intensity to solve an unemployment problem, thus requiring them to consider the side effects of the instruments. Another topic in economics that lends itself particularly well to a constructivist approach is game theory, given the need for students to think strategically.

We present the Axelrod tournament multi-user system (ATMUS), which provides an example of implementing constructivist methods to teaching game theory. ATMUS focuses on the repeated prisoner's dilemma (RPD), which is a commonly taught topic in introductory game theory. Similar to other educational simulations for game theory (Bodo 2002), ATMUS is based on the Axelrod (1984) research approach. Axelrod asked peers to submit RPD strategies for a tournament. Later, he matched these strategies in a tournament to determine properties of successful strategies.

Building on Axelrod's approach, Bodo (2002) created RPD simulations in a Mathematica software environment with student-designed strategies. Bodo's system is moving in the direction toward more student cognitive activity during the learning process, as supported by constructivism. Because students can use his system independently (outside of class), and it does not require advanced programming skills, the students can focus better on the strategic thinking aspects of the RPD. However, there are some limitations to Bodo's system.

From a constructivist point of view, Bodo's (2002) system could have more focus on students' personal thinking processes by allowing them to analyze the behavior of their strategies in an interactive way. Although he has a tool to generate strategies, does not allow students to interactively analyze their strategies. Furthermore, no graphical feedback during an actual game is provided, making it difficult for students to discern the results of their choices. Providing some graphical displays during the tournament would also allow for the system to be more reinforcing and engaging so that students could figuratively see their progress and reflect on their learning.

In addition, Bodo's (2002) system requires a Mathematica license (which is expensive) and basic prerequisite Mathematica skills. Given that Mathematica is complex, students may focus more on the technical details of using Mathematica rather than on their strategic thinking regarding the RPD. Bodo also does not provide a systematic instructional strategy for integrating the system within classroom activities, which is important for other instructors so they can integrate the approach in their classrooms.

The ATMUS system addresses many of these weaknesses. In terms of a constructivist approach, ATMUS allows the students to focus on their strategic thinking rather than the technical issues because it is more intuitive to use (with a graphical user interface that does not require software or prerequisite software knowledge), and it is a stand-alone system. ATMUS also allows for student engagement in the learning process because it provides visual feedback while the tournament progresses. Selected games can be analyzed graphically during the tournament. These visual displays facilitate student reflection on their thinking. Furthermore, ATMUS provides predesigned portfolios consisting of a mix of certain friendly or unfriendly strategies (e.g., Dove, Hawk, Tit-for-Tat). In this environment, students can test and analyze their self-designed strategies.

Overall, the ATMUS system is simpler to implement than Bodo's (2002) system, and it is very flexible, allowing students to design every two-node finite automata strategy. Even mixed strategies can be played. In terms of learning, the ATMUS approach also includes an instructional plan for integrating the tool within a classroom setting. The instructional plan and the ATMUS system are available free of charge.[1] The approach has been successfully used at Florida State University, Tallahassee; California State University, Pomona; and California State University, Northridge; as well as in Germany at the University of Hannover. Instructors were asked to provide a short report about the usefulness of the ATMUS approach, and feedback from instructors was positive in all cases. At the California State University, Pomona, we performed a small-scale empirical evaluation, which also suggested that students' understanding and comprehension of game theory improved.[2] Feedback from the students as well as the small-scale empirical evaluation indicate that students increased not only their confidence in solving game theory problems but also their strategic skills, and they valued game theory as a strategic tool more than they did before using the ATMUS approach.

THE DESIGN OF ATMUS

ATMUS was designed on the basis of a set of instructional goals for learning RPD. It is desirable to define the instructional goals to systematically design and evaluate instruction (Dick and Carey 1996). In this case, the desirable instructional goals for RPD were determined to be as follows:

Goal 1. Interpret a payoff matrix, especially regarding dominant strategies and Nash equilibria.

Goal 2. Understand how individual rational behavior alone can lead to a Pareto suboptimal solution in an unrepeated prisoner's dilemma situation and understand the incentives that could lead to the same result occurring when the game will be played repeatedly for a known number of rounds.

Goal 3. Describe the advantages and disadvantages of standard strategies (e.g., Tit for Tat, Grim/Trigger, Dove, Hawk) and discriminate among them for RPD with an unknown number of rounds.

Goal 4. Select standard strategies given assumptions about the opponent's strategies (e.g., if the opponent plays Dove, then playing Hawk is good).

Goal 5. Define strategies that respond flexibly to the moves of the opponent.

Goal 6. Evaluate advantages and disadvantages of self-designed strategies.

Goal 7. Construct or invent useful strategies given assumptions about the behavior of a portfolio of opponents.

Although the first and second goals can be taught by more traditional teaching methods, the computer-based ATMUS program was specifically designed to meet the third through seventh goals (which require higher-order thinking skills) from a constructivist perspective.

THE AXELROD TOURNAMENT

ATMUS is an educational approach based upon a similar research approach by Axelrod (1984). Axelrod designed a two-player game payoff matrix with two possible moves for each player, which represented a prisoner's dilemma situation similar to the one shown in Figure 1. If Player 1 would be confronted with the payoff matrix of Figure 1 in a one-round-only game, the player would have an incentive to choose defection D, no matter if Player 2 would cooperate (C) or if Player 2 would defect too, because Player 1 would get a payoff of 4 vs. 3 in the first case and a payoff of 2 vs. 1 in the second case. The same is applicable for Player 2. Hence, defection/defection (D/D) is a dominant strategy equilibrium. The interesting fact in a prisoner's dilemma situation is that there is a possible outcome, which is Pareto-superior to D/D. If both players would play cooperation/cooperation (C/C), they would both be better off. Hence, playing D/D is rational from an individual standpoint but not from a social standpoint (Dutta 1999; Fudenberg and Tirole 1991).

However, in an RPD with an unknown number of rounds, the situation changes: Playing D/D is not necessarily rational anymore. For example, a player can make

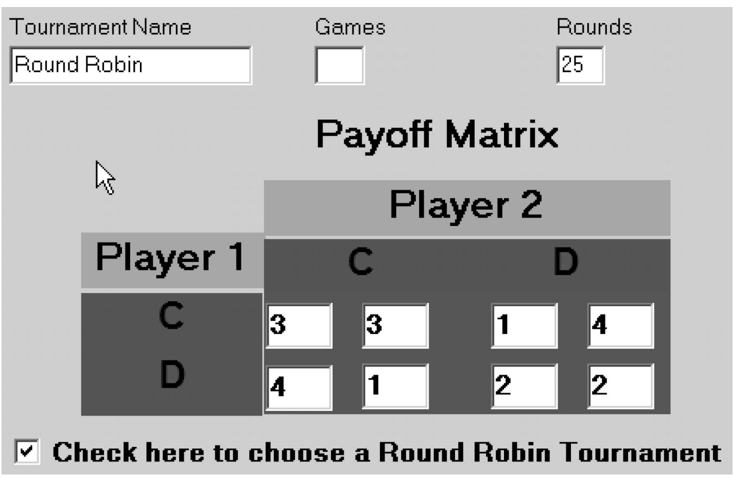

FIGURE 1. Payoff matrix and settings for an ATMUS tournament.

a peace offering to the other player (playing C) to invite him to do the same in later rounds. If this is successful (both players are playing C), the Pareto-optimal solution C/C would result. However, if the second player answers a peace offering by taking advantage of the first player by playing D, this later can be punished by the first player by playing D. These opportunities make the RPD an interesting strategic problem for game theory, because peace offerings, revenge, earning reputation, and threatening the opponent become strategic options (Binmore 1992).

In his research, Axelrod asked individuals to submit computer programs modeling a strategy for a two-player RPD problem, which responds to the unknown strategy (program) of an unknown opponent. After the strategies (programs) were submitted, Axelrod matched them against each other in pairs in a tournament not only to find the most successful strategy but also to evaluate properties of successful and poorly performing strategies (see Axelrod [1984] for details).

A literal application of the Axelrod approach in a classroom setting would mean that the students would have to program strategies in a program language, and later these strategies (computer programs) would compete against each other in a computer-simulated tournament. This approach is not practical because only a small portion of the students have sufficient programming skills to program a strategy. Even those students who are sufficiently experienced in programming might not program a strategy if they believe it might be too time consuming. The idea behind ATMUS is to apply the original Axelrod approach in a classroom setting in a way that is not too difficult and time consuming. We describe how students can generate strategies easily and how these strategies can be set up for later competition in a classroom tournament.

THE AXELROD TOURNAMENT MULTI-USER SYSTEM (ATMUS)

ATMUS is a computer-based, Axelrod-like tournament, but in contrast to the original approach, students are not required to program their strategies using programming language. They can define their strategies using the ATMUS *Strategy Generator* module without any programming skills. These strategies are saved on the students' computer or e-mailed to the instructor to be used later in a tournament. The tournament can be run and presented in the classroom with the help of the ATMUS *Tournament Presenter.*

The ATMUS *Strategy Generator*

The ATMUS *Strategy Generator* allows students to create their own strategies, which meets an essential criterion of the constructivist approach: that knowledge should be personally constructed by each individual learner. The *Strategy Generator* offers an intuitively easy way to define a strategy. The students are only required to fill out an on-screen, computer-based form and submit it via e-mail to the instructor (for the classroom tournament) or save it on their own PC (to run their own private tournament). Filling out the computer form takes the students only a few minutes. The *Strategy Generator* is designed so that a wide range of strategies (even mixed strategies) can be defined. Specifically, every two-node finite automata strategy[3] can be defined. This includes, but is not limited to, common textbook strategies such as Hawk, Dove, Tit-for-Tat, or Grim/Trigger (see Figure 2 for one example of how a Grim/Trigger strategy can be designed with the *Strategy Generator*).

In particular, an ATMUS strategy consists of eight predefined moves for eight consecutive rounds of a game, in which two strategies at a time are matched up. For all rounds greater than eight, those moves that were defined for rounds five to eight are repeated sequentially. For each round, the students can define one of four types of actions. A specific move (C or D) can be (1) independent of the opponent's move (unconditional type of action, UA), (2) dependent on what the opponent did *n* rounds ago (recursive type of action, RA), (3) dependent on what the opponent did on average during the last *n* rounds[4] (duration average type of action, DA), or (4) dependent on both the last move of the opponent and the person's last move (extensive form type of action, XF); see Figure 2 for examples. By changing the probability for any of the eight moves to a value smaller than 100 percent, a strategy can be played as a mixed strategy rather than a pure strategy. After a strategy has been defined, the students can choose a name for their strategy and save it, together with the student's e-mail address, as an ASCII file.

Although it is not possible for the student to design every possible strategy within the *Strategy Generator*, most students were satisfied with the options. Given the tradeoff between providing more flexibility and increased user-interface complexity, we limited the *Strategy Generator* to include just four types of actions. However, to accommodate more advanced students who mentioned wanting more flexibility, the future *Strategy Generator* will introduce an expert level that will provide extra types of actions (e.g., a two-round extensive form).

The ATMUS Tournament Presenter

The ATMUS *Tournament Presenter* is a tool that matches predefined strategies pairwise in a tournament. It is mainly designed to present the tournament in a

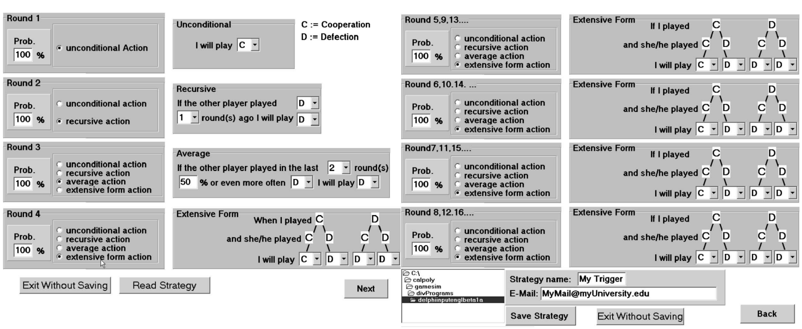

FIGURE 2. Creating a Grim/Trigger strategy with the ATMUS strategy generator.

classroom. It also can be used on the student's computer to test different strategies in different portfolios, which we discuss later.

To prepare the tournament, the instructor must set up the payoff matrix, choose how many games every strategy will play, and determine for how many rounds each game will continue (see Figure 1 for an example). According to these settings, the students' strategies will be matched up pairwise and the payoffs (what each strategy earns in each consecutive round and in each consecutive game) will be added to rank the students' strategies. It is important that the instructor emphasizes that the strategy with the most overall points rather than the strategy with the most won matches wins the tournament. Otherwise, students may focus too much on winning over their opponents in a head-to-head game rather than accumulating payoffs.

To guarantee a fair tournament, one needs to ensure that every strategy plays the same amount of games. One option to ensure a fair tournament is to choose to play a round-robin tournament within ATMUS. In case the evaluation and presentation of a round-robin tournament with a large number of strategies would be too time consuming to complete in a classroom setting, ATMUS provides an additional option for larger tournaments (50+ strategies). Here, every strategy plays only a limited number of games, as predefined by the instructor. The opponents for each of these games will be determined by a random process, which is based on a drawing without replacement.

Experimental software such as ATMUS in itself does not constitute an instructional approach. However, ATMUS is particularly conducive for being implemented in a constructivist manner. We describe the specifics of a constructivist instructional strategy to employ ATMUS.

INSTRUCTIONAL STRATEGY USING ATMUS

The instructional strategy is organized into three consecutive phases. Each phase will cover approximately 1 or 2 weeks. We show how the instructional goal mentioned, as well as constructivist learning goals, can be reached during different phases of the instructional strategy. Depending on how intensively the topics are covered, an instructor should reserve between 2 weeks (as an addition in a principles of economics class) and 3 weeks (with intensive discussion in an undergraduate game theory class) for the ATMUS approach.

Phase 1 focuses on understanding. Approximately two weeks should be made available for this phase. In the first week, the instructor serves mainly as a dispenser of knowledge, teaching the basics of game theory and the main properties of an RPD situation, according to instructional goals 1 and 2. These goals can be reached with traditional teaching methods, and no special equipment is needed. In the second week of phase 1, the students should also learn about standard RPD strategies. Again, the instructor serves mainly as a dispenser of knowledge, now teaching the properties of common RPD strategies according to the third instructional goal. In addition to the traditional (more textbook-like) presentation, the knowledge is presented in a more conceptual way by using the ATMUS *Tournament Presenter*.

To demonstrate the properties of given textbook strategies, the instructor can use the ATMUS *Strategy Generator* prior to class to generate the strategies and later, in the classroom, use the ATMUS *Tournament Presenter* to match two strategies and explain their strategic properties. A helpful tool for this purpose is the graphical interface of the *Tournament Presenter*. A game can be graphically presented step-by-step for every consecutive round. Figure 3 shows an example of a game after seven rounds according to the payoff matrix of Figure 1: An *original* Tit-for-Tat strategy (circles) is playing against an *imperfect* Tit-for-Tat strategy (rectangles). The latter is created as imperfect because it plays D (marked in dark gray) instead of C (marked in light gray) in the fourth round. Later, it proceeds to play as an original Tit-for-Tat strategy. The ATMUS graph in Figure 3 shows problems that could be involved with playing original and imperfect Tit-for-Tat strategies against each other: They never return to C/C. In the same way, the strategic properties of other standard strategies can be presented to students.

Phase 2 takes place in the computer lab or a classroom equipped with a classroom computer and LCD projector. It focuses on instructional goals 3–5. Phase 2 is much more constructivist-oriented than phase 1. The instructor must install the ATMUS *Strategy Generator* and the *Tournament Presenter* on each computer in the lab and also provide different strategy portfolios, each consisting of a certain mix of textbook strategies. The instructor provides a self-organized learning environment for the students and helps the students if requested. The students are divided into groups of two or three. It is their objective, according to a given payoff matrix, to generate a set of three or four strategies[5] that they believe will be successful in a tournament when competing against strategies generated by other students (see phase 3). Although the students are provided with information about the relevant payoff matrix, they do not know how many rounds are in each game.

The students can use the ATMUS *Tournament Presenter* together with the provided strategy portfolios to discover in a hands-on approach what they learned

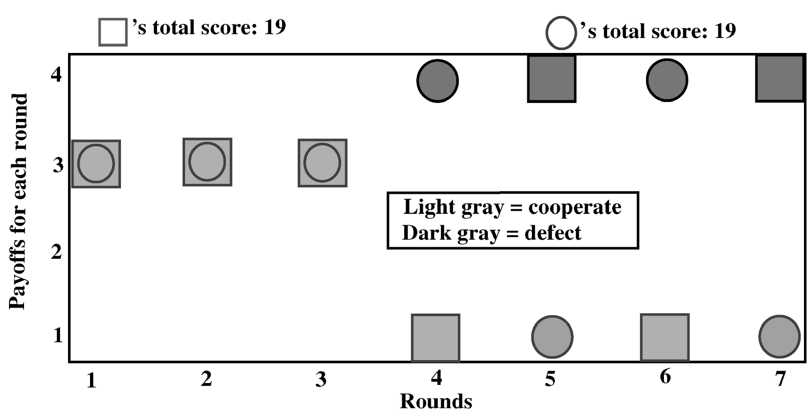

FIGURE 3. Scores for a Tit-for-Tat vs. an imperfect Tit-for-Tat strategy.

in phase 1 about the properties of the textbook strategies selected earlier. They also can test their own strategies through different portfolios provided by the instructor, or they can generate their own portfolio to evaluate how their strategy performs. For example, if the instructor provides a portfolio consisting of only Tit-for-Tat strategies, the students will experience that no strategy performs better in this environment than a Tit-for-Tat strategy. In this way, they will learn by their own experience (rather than from a textbook) that Tit-for-Tat represents a Nash equilibrium (e.g., Binmore 1992, 366). Evaluating the performance of a strategy is supported by the *Watch List* option of ATMUS. Students can define conditions to interrupt the tournament (e.g., always when their own strategy plays) to analyze specific games step by step.

Last, the students will intentionally construct a set of strategies to use to compete in the tournament. Because the students of each group have discussed their strategies, tested them extensively, and adjusted them accordingly, the students gain self-awareness of the knowledge-construction process. Because it is their own set of strategies competing in the tournament and because they name the strategies, this also facilitates ownership in the learning process. Both the self-awareness and ownership are important for constructivist goals.

In Phase 3 the strategies submitted by the different groups in phase 2 will be matched in a tournament, which is presented in real time in the classroom. The ATMUS *Tournament Presenter* matches the strategies against each other, according to the instructor's predefined settings (see Figure 1 for a screen shot). A key purpose of the tournament is to increase motivation toward the topic; thus, it is important that presentation of the tournament is engaging. For example, the instructor should avoid discussing the properties of the strategies but rather comment on the progress of the tournament (e.g., "Strategy Mr. Nice is in the lead, followed by Wolf"). Along this line, the instructor can refer to another feature of the ATMUS *Tournament Presenter* the Top-Ten graphic (Figure 4), which shows the ranking of the top-10 strategies. The Top-Ten graphic is dynamically updated during the tournament after every game and shows the sum of all payoffs a strategy earned to provide immediate feedback to the students.

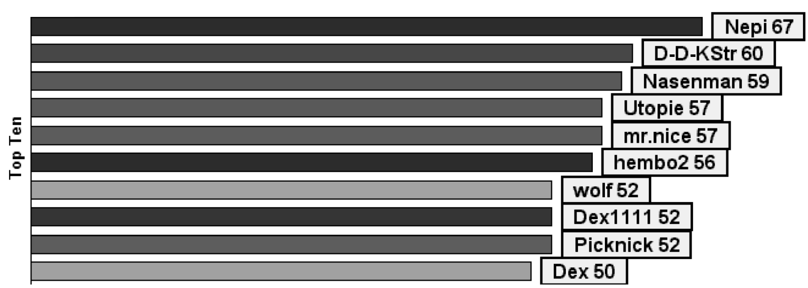

FIGURE 4. ATMUS tournament presenter, Top-Ten graphic.

After the tournament is finished, the instructor could rerun the same tournament and, together with the students, could analyze the strengths and weaknesses of the strategies (according to instructional goal 6). In this context, it must be emphasized (to the students) that a poorly performing strategy does not indicate that the strategy's creators lack understanding about game theory. Because the performance of a strategy is highly dependent on how the other strategies in the tournament are designed (cooperative, nasty, or flexible), a poorly performing strategy could result from incorrect assumptions about the other strategies in the tournament. For example, in some of the authors' game theory classes students programmed aggressive, Hawk-like strategies. In this environment, Trigger-like strategies performed better than more forgiving strategies. Although this did not coincide with Axelrod's results, it gave the instructor a good chance to explain the results. To highlight this phenomenon (with respect to instructional goal 7), the instructor could choose a subsample from all of the students' strategies (e.g., the 20 percent most aggressive strategies) and demonstrate how different strategies perform in this portfolio. This instructional activity engages the students in becoming again (now in retrospective) more cognitively aware of their thinking processes and also supports multiple perspectives (the students will learn how much the performance of their strategy depends on the environment in which it has to compete against other strategies): two constructivist attributes of instruction.

CONCLUSIONS AND FUTURE RESEARCH

We described how the RPD can be taught with a constructivist approach and in a cognitively active and motivating manner through use of ATMUS. The ATMUS *Strategy Generator* provides students and instructors with an easy-to-use tool to create RPD strategies within a few minutes. The ATMUS *Tournament Generator* helps instructors and students to easily set up Axelrod-like tournaments to match previously created RPD strategies. These tournaments enable the instructor and students to analyze and explain specific properties of RPD strategies, according to their success in the tournament.

ATMUS employs a constructivist approach for teaching game theory and meets Driscoll's (2002) characteristics of constructivist instruction. First, ATMUS facilitates students' critical evaluation of their strategies among themselves and, thus, provides for social negotiation. Discussion among the students and instructor regarding which strategies to submit for the tournament requires extensive negotiation. Second, ATMUS supports multiple perspectives and use of multiple modes of representation by its premise that there is no right strategy. Students learn that the same strategy can work differently in different strategy portfolios and thus learn to take different positions in evaluating effectiveness of the strategy. For example, a student could program an aggressive strategy, assuming the others are peaceful, whereas another student could use a Tit-for-Tat strategy, assuming the others are also using a Tit-for-Tat strategy, and both could be right, given their assumptions about what the others are doing. Overall, this helps students to understand game theory conceptually rather than only mathematically. Third, ATMUS encourages ownership in learning because the students personalize their strategies, and game theory becomes more authentic and personally meaningful. Plus, they are reinforced by the program both visually and semantically (their name is listed on the screen with the other competitors; they create a unique name for their strategies), which leads the overall experience to be engaging and confidence building. Fourth, ATMUS fosters self-awareness of the knowledge construction process by requiring students to reflect continually on the success of their strategies. For example, if they use a trial-and-error method, they still must regularly reflect on what strategy works and, through an evolutionary process, learn which strategy is most effective. By evaluating tournament results post hoc, with the assistance of the instructor and peers, they could also reflect on how or why certain strategies were more successful than others.

Our future research will focus on instructionally related issues. ATMUS will be directly accessible via the Internet so that students can compete in a multiplayer environment from different locations. On a regular basis (e.g., every quarter), these strategies will be matched in a tournament to determine the most successful submitted strategies. Also, we will be testing different uses of ATMUS, such as (1) benefits of using it for individual students versus in small group settings; (2) advantages of using it prior to formal instruction versus as part of the instruction (in a whole-group setting); and (3) more constructivist features, such as structured online discussion boards, where students can reflect on the outcomes of tournaments.

NOTES

1. The authors provide ATMUS at http://www.csupomona.edu/~clange/atmus.html. From this location, ATMUS can be downloaded and is ready to use.
2. Results are available from the authors on request.
3. A two-node finite automata strategy is based on a graph. It considers two different kinds of moves (here, C and D) and defines the initial move (presented as node). On the basis of opponents' moves, the graph defines when in general to change to a different move and when to proceed with the same move. The players' possible moves are presented as nodes, whereas the opponents' possible moves are presented as arrows in the graph (see Binmore 1992, 361–363, for more details).
4. *n,* the number of rounds ATMUS can evaluate from an already-played game, is limited to a maximum of five rounds.
5. Although it is also possible to require each team to submit only one strategy, allowing teams to submit more than one strategy makes it easier to find a compromise if a team cannot agree on which strategy to submit.

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