Learning the Rules of the Game

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Games have often been used in the classroom to teach physics ideas and concepts,[1] but there has been less published on games that can be used to teach scientific thinking. D. Maloney and M. Masters describe an activity in which students attempt to infer rules to a game from a history of moves,[2] but the students don't actually play the game. Giving the list of moves allows the instructor to emphasize the important fact that nature usually gives us incomplete data sets, but it does make the activity less immersive. E. Kimmel[3] suggested letting students attempt to figure out the rules to Reversi by playing it,[4] but this game only has two players, which makes it difficult to apply in a classroom setting. Kimmel himself admits the choice of Reversi is somewhat arbitrary. There are games, however, that are designed to make the process of figuring out the rules an integral aspect of play. These games involve more people and require only a deck or two of cards. I present here an activity constructed around the card game Mao, which can be used to help students recognize aspects of scientific thinking. The game is particularly good at illustrating the importance of falsification tests (questions designed to elicit a negative answer) over verification tests (examples that confirm what is already suspected) for illuminating the underlying rules.

Richard Feynman famously said that if you think of all the bits of knowledge that physics has discovered as dots, then our job as teachers is to help students see how the dots are connected. If you know how to draw lines between the dots, you can not only reconstruct dots you have forgotten, but you can even extend the lines beyond the current realm of knowledge to find new dots.[5] This process of figuring out the patterns in the connection between the dots has often been compared to figuring out the rules of a game—some connections are allowed, and others are against the rules. Lederman and Teresi, for example, ask their readers to imagine aliens watching a soccer match.[6] Through a quirk of biology, these aliens cannot perceive checkered spheres, so they must infer the presence of a ball from the actions of the players and the occasional deflection of the net (followed by mysterious celebration and weeping). Using scientific thinking, the aliens figure out the rules of the game. Feynman himself used the metaphor of a "great chess game being played by the gods, and we are observers of the game."[7] By experiment, we attempt to control the context of the game, so that we can infer the nature of the rules.

P. Wason designed a classic psychology experiment (recently creatively staged as a YouTube video on D. Mueller's "Veritasium" channel[8]) that challenged the participant to discern the rule that governed a sequence of three numbers

BOX ONE: *Start of a typical game*

Maria, Richard, Vera, Annie, and Edwin sit in clockwise order around a table for a game of Mao. Since Richard and Annie have played before, and the others have not, they agree that Annie should be the final authority on rules disputes. Richard shuffles and deals five cards to each player. He places the rest of the cards in a stack in the center of the table, then turns the top card over. It's a six of clubs. Silence falls. Maria and Vera glance at each other nervously. Finally, Edwin asks, "Are we supposed to do something?" Richard sternly says, "Talking" and slides Edwin a card off the top of the deck.

After another moment, Annie slides a card to Vera, saying, "Taking too long." Vera jumps and decides to try something. She places a three of diamonds on top of the six of clubs. Annie returns the card to Vera, plus another card from the top of the deck, saying, "Playing a card that does not fit." Annie then plays a nine of clubs on top of the six of clubs. Edwin thinks now maybe they are supposed to play cards of the same suit, so he tries playing a two of clubs. Annie says nothing.

Maria guesses that it's her turn next and tries putting down a four of clubs. Annie says nothing. Edwin and Vera glance at Richard, who calmly looks at his cards. After a moment, Annie slides a card off the deck to Maria, saying, "Taking too long." [Four reverses direction of play.] Maria, rattled, throws down a three of clubs.

Tentatively, Edwin tries playing a three of diamonds. No response. Annie plays a jack of diamonds. Vera confidently plays a queen of diamonds, but Annie returns the card, plus a penalty card, saying, "Playing out of sequence" Richard plays an ace of diamonds. [Jack skips the next player.] Maria plays a seven of diamonds. Annie gives Maria a penalty card and says, "Failure to say 'have a nice day.'"

Maria says, hesitantly, "Have a nice day?" Annie does not respond to Maria, but after a moment, gives Edwin a penalty card and says, "Failure to take a penalty card." [On playing a seven, the active player says "Have a nice day," and the next player must take a penalty card, unless they can immediately play another seven, in which case they do, and say "Have a very nice day," and the third player must take two penalty cards, unless that player has a seven, and so forth, until a player cannot play a seven.

Obviously, this has to come up when a player who knows this can take advantage of it, or the player who could get out of the penalty by playing a seven will not know to do so. Again, the knowledge of the rules is provisional until you move into a different region of applicability.] Play continues with Annie….

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by posing alternate sequences of numbers to the interlocutor, who would confirm or deny whether the proposed sequence was consistent with the rule.[9] Most participants latched onto an idea early, like that the numbers "2, 4, 8" reflected doubling or that "2, 4, 6" represented even integers, and then posed sequence after sequence to verify that rule, rather than trying to devise a falsification test that would disprove their hypothesis. I have observed this pattern myself, as my students try to learn Mao.

Mao is a very unusual card game in that the purpose of Mao is for the players to discern the rules as they play. It is not possible to "win" a game of Mao, so the focus of play is not on winning. A full description of the rules is beyond the scope of this article, but an internet search will turn up several websites that describe variants.[10] Box 1 gives an example of how a typical game session might begin.

To use Mao in the classroom, I have developed a structure around it. I have five or six students join me to play the game at a central table in the classroom. With a larger class, I have solicited help to lead multiple groups in the activity simultaneously. If a few students know the game already, it helps to place them among the initial active players. The other students watch from the periphery. To avoid the problem of multiple conflicting rules variants, the typical Mao game requires one player to be the final arbiter, and I play that role for my class. After 10 minutes, I allow the watchers to "tag in" and replace students at the table. Ten minutes after that, the watchers are allowed to interfere in the game: if a watcher calls "freeze," the players stop moving, at which point the watcher may move the cards around to change the conditions about to be played. This enables the watchers to design controlled experiments to test their hypotheses. Box 2 gives an example of how this activity could play out for a few rounds. After a final 10 minutes, I call the game to a close and the class discusses their observations of what happened. Within these 30 minutes of play, students can usually figure out the four basic rules as well as some aspects of the conditional rules.

One facet that makes Mao suited for teaching scientific thinking skills is that a player who breaks the rules is penalized, but players are never rewarded for performing an action that is not explicitly forbidden. Thus, verification tests can lead to players constructing elaborate rules that do not exist. For example, one unusual rule in some variants is that when a nine of diamonds is played, the player must say a phrase with the word "badger" in it. The exact phrase does not matter, but the word "badger" must be present. My students were playing with a card deck that had the faces of famous physicists on them, and they thought the rule was that you had to call the physicist on the card a badger ("Richard Feynman is a badger!"). Many verification tests later, they had no new information to distinguish that the word badger was the key feature of the rule, not the name of the face on the card. This example helps illustrate that scientific rules are always provisional—they seem to work perfectly well … until you move beyond their regime of applicability, and then they don't.[11]

BOX TWO: *Introducing experiments to the game*

Maria, Richard, Vera, Annie, and Edwin are playing as before (see Box 1), but now George and Jocelyn are watching from the periphery. A two of diamonds is the top card of the discard pile. The turn order is clockwise. Maria plays a five of diamonds. Jocelyn thinks she has figured out that each card played must have one higher number than what is showing on top of the discard pile, so she decides to test this hypothesis: she calls "freeze!"

Richard is about to play a 10 of diamonds, but Jocelyn changes his card to a six of diamonds. When she allows play to continue, no penalty is called. Jocelyn momentarily thinks she's got it, but then realizes she doesn't know whether the number or the suit (or both) are the key features.

Meanwhile, George has a theory that you can change suits if you play your card on top of a queen, so a few turns later, when Vera is about to play a three of hearts on a queen of hearts, he calls "freeze" and changes the queen of hearts to a queen of clubs.

When play continues, Vera is penalized for "playing a card that does not fit." This lets George know that he was wrong about the queen being the key factor.

The closing discussion allows the teacher to emphasize the difference between verification and falsification testing. The students themselves are often startled to realize how often they performed verification tests, even when they just watched the "Veritasium" video before beginning the game! Another aspect that often emerges in discussion is the way trial and error are initially used to gather information, but the players naturally transition to more systematic ways of thinking. Students also realize the importance of maintaining controlled variables—if they change more than one card around at a time, they do not know which change produced the result (see Box 2). The teacher can also emphasize the Duhem-Quine thesis[12]—if a student's test fails, she doesn't immediately know which aspect of the reasoning undergirding her hypothesis was incorrect.

The teacher must watch the game closely to ensure that penalties are applied correctly and consistently. If the teacher is inconsistent or overlooks a situation where a test should have failed, the students can get very frustrated. Second, the teacher must keep an overview (and mental notes for the debrief) of what techniques and tests the students are performing. Finally, it is useful to observe how the students react to this activity. Some students get very excited about the process, and others get very frustrated to the point of even "checking out" or sabotaging the game. These behavior patterns translate well into how the students will be in the lab—the former students tend to be skills-focused and build knowledge, while the latter students are often answer-focused and want everything spelled out clearly. There are exceptions, but when I do this activity early in the semester, I have found it gives me indications toward how my students will behave for the rest of the term.

If Mao seems too complicated, there is a simpler game called Eleusis that could serve the same purpose[13]. In principle, as Kimmel suggests, any game could be used in this manner, if the teacher invents some mechanism by which students can determine whether a play is valid or invalid, but Mao and Eleusis have the benefit that figuring out the rules is built into the game—they are designed to do exactly this.

I have carried out this activity in the first week of class many times since I first implemented it in 2007, and every time students have found it a memorable experience. Some enjoyed it, some hated it, but they all remembered it.[14] It provided a framework in which we could discuss experiment design and hypothesis testing for the rest of the semester. For example, since introductory labs are so often experiments that have been done many, many times, students easily fall into the trap of thinking their job is to verify that a light ray will bend according to Snell's law, or springs will stretch in compliance with Hooke's Law, or that current will vary linearly with potential difference. Their experience with Mao gives me the vocabulary to remind them that they are trying to falsify these laws, not verify them.[15] As another example, if a student studying the period of a pendulum changed mass and length together, I could talk about the time in Mao when they changed too many cards at once and confused the issue. If students become frustrated that their experimental procedure did not yield "the right answer," their experience with the game provides a way for me to emphasize the process rather than the result.

Games provide a vivid and effective way to engage students in the process of science. In particular, games in which the goal is to figure out the rules as the game is being played can put the students in the position of Lederman's soccer-blind aliens. A structured in-class activity allows the students to literally play with and engage in scientific thinking. Discussion can then provide an opportunity for students to reflect on their own learning behavior and cognitive patterns. Finally, the activity provides a framework within which scientific ideas can be reinforced throughout the semester.

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References

1. Too many to list, especially if you include video games, but see e.g. M. Vinson, "Space Race: A game of physics adventure," *Phys. Teach.* **36,** 20–21 (Jan. 1998), E. Forringer, R. Forringer, and D. Forringer, "The Plus or Minus Game – Teaching estimation, precision, and accuracy," *Phys. Teach*. **54**, 172 (March 2016), J. McGahan, "A game for facilitating the learning of units in physics," *Phys. Teach***. 15**, 233 (April 1977), P. Black, P. Davies, and J. Ogborn, "A quantum shuffling game for teaching statistical mechanics," *Am. J. Phys.* **39**, 1154 (Oct. 1971), or P. Nelson, "Teaching introductory STEM with the marble game," *Biophys. J.* **104** (2), 532 (2013).
2. D. Maloney and M. Masters, "Learning the game of formulating and testing hypotheses and theories," *Phys. Teach.* **48,** 22 (Jan. 2010).
3. E. Kimmel, "The game of physics," *Am. J. Phys*. **41**, 1199 (Oct. 1973).
4. Nineteenth-century European two-player game, with some similarities to Go, in which black and white tiles are alternately placed on a grid. Runs of tiles capped at either end by the opponent's color are captured and flipped to the other color. Currently marketed by Mattel under the name Othello. See, e.g. http://www.othelloonline.org/. 5. R. Feynman, M. Gottlieb, and R. Leighton, *Tips on Physics* (Pearson, 2006).
6. L. Lederman and D. Teresi, *The God Particle (*Houghton-Mifflin, NewYork, 1993).
7. R. Feynman, R. Leighton, and M. Sands, *The Feynman Lectures on Physics* (Addison-Wesley, Reading, MA, 1963), Vol. 1, p. 2-1.
8. "Can You Solve This?" YouTube, https://www.youtube.com/watch?v=vKA4w2O61Xo.
9. P. Wason, "On the failure to eliminate hypotheses in a conceptual task," *Q. J. Psychol.* **12** (3), 129–140 (1960).
10. The basic rules are very similar to Uno, which most U.S. students will have played. See, e.g., http://gameofmao.com/ or https://en.wikipedia.org/wiki/Mao_(card_game) for rule variants.
11. It's also an example of reinforced conditioning. Skinner describes how a pigeon repeats behavior it associates with reward, even when the reward is not causally linked to the behavior. B. F. Skinner, "'Superstition' in the pigeon," *J. Exp. Psychol.* **121** (3), 273–274 (1992). Neither the pigeon nor the student has engaged in the scientific thinking required to tease out accurate causality, but the behavior "works" in that the desired result is achieved.
12. W. Quine, "Main trends in recent philosophy: Two dogmas of empiricism," *Philos. Rev*. **60** (1), 20-43 (1951).
13. Invented by R. Abbott in 1956 and popularized in M. Gardner, "Mathematical games," *Sci. Am.* **200,** 160 (June 1959). In Eleusis, there is only one rule that needs to be guessed, and the players take turns being the "God" who establishes the rule. The other players are "scientists" who are trying to discern the rule by playing cards in a sequence, and when they think they know the rule they can declare themselves "prophets" and start trying to apply it on God's behalf. I have not tried this game in the classroom, but I could imagine it working well, particularly with a smaller group or with students who find Mao too bewildering. In 2006 J. Golden developed a simpler variant specifically to teach students about scientific thinking, as Abbott describes here: "Eleusis and Eleusis Express," http://www.logicmazes.com/games/eleusis/ .
14. An alumnus wrote me recently, and the one example he chose, unprompted, to share of what he remembered from the 2009 class was the Mao exercise.
15. To help reinforce this, I try to give them plausible but false models, so their experiments can actually disprove incorrect models, rather than verify standard hypotheses. See, e.g., T. Erickson and E. Ayars, "Fake papers as investigation prompts," *Phys. Educ.* **40**, 6 (2005).

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