

TEACHING INDUCTIVELY: GAMES IN THE TERTIARY CLASSROOM

David Low (d.low@adfa.edu.au)

School of Physical, Environmental and Mathematical Sciences, The University of New South Wales at the Australian Defence Force Academy, Canberra, ACT 2600, Australia

KEYWORDS: Games, curriculum, inductive teaching, learning styles

ABSTRACT

Inductive teaching methods, where students construct models rather than being told facts, are aids to deeper learning, but are notoriously difficult to incorporate into mainstream tertiary teaching. Games present a relatively painless path to engage and motivate students to actively participate in the learning process. This paper presents a brief reflection on the background of, and motivation for, using games as tools for inductive teaching. The intent here is to provide examples of how games can be incorporated into a curriculum, along with some commentary on the challenges which may be encountered during development and implementation, based on the experiences of the author.

Proceedings of the 16th UniServe Science Annual Conference, University of Sydney, Sept 29th to Oct 1st, 2010, 72-78, ISBN Number 978-0-9808597-1-3

INTRODUCTION

MOTIVATION

Tertiary educators are faced by a multitude of conflicting requirements. Curricula demand both breadth and depth: the more material you elect to cover, the less you can explore each topic. Small classes are generally regarded as better learning environments, but institutions often see large lecture classes as a more efficient use of their staff. Most students would appreciate an “easy course”, while academics have a professional duty to rigorous testing of competency. No single solution has been presented to this multivariate problem: it is unlikely that one exists! However, it is undeniable that interested, motivated students are more likely to get something out of a course than disinterested, unmotivated students. Thus, a significant amount of educational research effort is spent on motivational issues, in addition to attempts to understand cognitive learning.

Games have been played since time immemorial, for a variety of purposes. Martin Gardner (b.1914-d.2010) wrote 311 instalments of “Mathematical Games”, arguably the best-known section of *Scientific American*, over 25 years from the mid-1950’s through to the early-1980’s. The long-standing appeal of this column is reflected in the extensive set of books into which it was later collated and republished. Games have been discussed in the teaching and learning literature for at least forty years (see, e.g., Avendon & Sutton-Smith (1971), or Ellington, Addinall & Percival (1981)). Nevertheless, the use of games in formal teaching activities has been concentrated at the primary school level (see, e.g., Ellington, Fowle & Gordon (1998), or Cruickshank & Telfer (1980)). Furthermore, as discussed by Selkirk (1986), games have been seen as primarily supporting the mathematics curriculum. A notable exception to both points would be the exploratory roleplaying activities implemented by Francis and Byrne (1999), which involve students taking on the part of scientists of varying specialities, working collectively to understand the universe (and gain professional kudos at the same time!).

Classroom games at the tertiary level are likely better suited to developing science-based graduate attributes, rather than assisting students learning the specifics of any discipline (barring, perhaps, algorithmic games used as computer science/programming exercises). It is the aim of this work to demonstrate some examples of both types, where games can be used in the tertiary classroom to motivate students, encourage their active involvement, and develop understanding. While “general science” courses have been out of favour in Australian universities for many years, there are some signs (such as Australia actively engaging with the Bologna Process as of April 2009) that the wheel may be turning, in which case one may expect a greater emphasis on generalist critical-thinking in tertiary education.

INDUCTIVE AND DEDUCTIVE APPROACHES TO TEACHING AND LEARNING

As children, we learn how the world works by an inductive process: we try something, observe the result, and draw inferences. If you don't know how something works, this is a natural approach – and, of course, it strongly resembles the “testing” part of the conventional scientific method (which includes preceding steps of “observe” and “hypothesise”, and a subsequent “reform” step). Given that a teacher already understands the material, however, conventional teaching approaches – especially at the tertiary level – tend more towards a deductive process: starting from a general principle, derive implications. Induction is messy, but promotes deeper learning; deduction allows for control and pacing of material, but has a tendency towards learning by mimicry (Felder & Silverman, 1988). It is interesting – and perhaps a little disappointing – that teachers often prefer to use a deductive style because it allows control over presentation; and that students often prefer deductive teaching because it is neat and compartmentalised, and conforms to their expectations and experiences from prior classroom teaching.

It takes effort (and, perhaps, courage) for both teachers and students to engage in an inductive style of learning. In reality, given constraints such as the need to cover a syllabus, the inductive style of teaching is probably best suited to cases where the underlying “rule of nature” can be relatively easily determined. As practising scientists are well aware, a great deal of time, and a large amount of frustration, is usually involved in attempts to understand natural processes!

Inductive teaching can be implemented in a number of ways, under a number of names. Prince and Felder (2006, 2007) present an extensive comparison of inductive methods in common use, such as inquiry-based learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching. The common aim is to start from specifics (a set of observations, or a particular problem), and encourage and guide students to discover the underlying principles for themselves: “learning by doing”, rather than “teaching by telling”. Games, we propose, can be used in a similar way: encouraging students to become actively involved in the classroom, by temporarily removing them from it (in an intellectual sense!).

EXAMPLES

In this section, we consider two quite distinct types of games which have been used by the author in different classroom settings. The aim here is to summarise the rules of each game, and then to discuss the implications for teaching and learning. For further details on the specifics of each game, the reader should consult the primary references directly.

THE SCIENTIFIC METHOD: ELEUSIS AND ZENDO

Robert Abbott invented the game *Eleusis* in 1956, and it was publicised by Gardner (1959, 1977). *Zendo* (Heath, 1997) is a modern development, with the most significant difference being that *Eleusis* uses a standard deck of playing cards and focuses on mathematical and colour/suit sequences, while *Zendo* uses abstract shapes and arrangements. A similar activity, based on the game *Patterns* (Sackson, 1969), has been developed into a classroom activity by McCoy (1999). The games vary in details such as scoring, yet have a common theme:

1. the moderator (“Nature”) decides on a hidden law, which the players must try to determine. For example, “always change suits on subsequent plays”, or “no more than two pieces of the same shape”. The moderator then displays two sequences or arrangements, one that obeys the law and one that does not;
2. players (“scientists”) take turns (“perform experiments”) by constructing their own sequences/arrangements for the moderator to evaluate. The moderator declares each attempt as being either consistent with the hidden law, or contrary to it;
3. if a player thinks they have determined the hidden law, they elucidate it (“make a hypothesis”). If it is correct, the game ends; if it is incorrect, the moderator shows a counter-example which is consistent with the hidden law, yet contrary to the stated hypothesis, and the game continues.

With a skilled moderator, adept at misdirection in the examples and counter-examples, even simple laws – the only ones which are recommended in a teaching environment – can be a challenge to determine. With repeated play, students learn a few things about science:

1. the results of simple experiments are easier to interpret than those of complicated ones (Occam's Razor);
2. a control experiment, followed by a series of small variations to a minimal number of parameters, can help identify the key aspects of a problem; and
3. counter-examples are something to be embraced, rather than feared! Preconceptions based on spurious correlations often require a counter-example to force a change of thinking.

When used as a teaching tool rather than simply as entertainment, it is important to include a reflection stage once the game has concluded: students should be encouraged to discuss their personal choices, how the "experiments" of other students affected their own play, and whether there were any "Eureka!" moments; or, as is perhaps more often the case in real science, if there were any, "That's not what I expected..." moments.

It is equally important to point out the challenges that face scientists in reality, which the game does not model: philosophically speaking, nature does not always throw up counter-examples on demand; prosaically, experiments cost money and take time; and critically, the "real" game doesn't end with a declaration of truth! Educators may wish to avoid issues such as the kudos of publishing positive results introducing a bias against spending a scientific career obtaining negative results, although it may lead to a discussion of ethics which is often missing from science degrees!

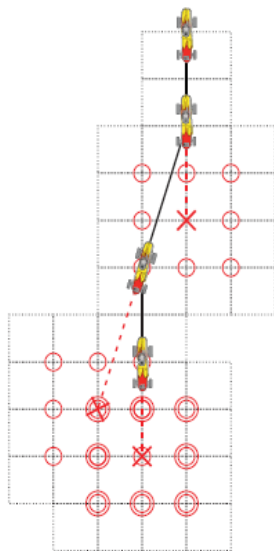
At UNSW@ADFA, this game has been used with small numbers (1-4) of first-year science students in the Chief of Defence Force Scholars Program (CDFSP), who undertake a "research oriented" Bachelor of Science degree where 1/6th of their coursework program is replaced by research training and project work. While small groups are important for the game to avoid significant downtime (even simultaneous turns by players require evaluation time from the moderator), any science course, at any level, could benefit from the activity.

NEWTON-I, VECTORS, FRICTION AND GRAVITATION: RACETRACK AND TRIPLANETARY

The origins of the pencil-and-paper game *Racetrack* are unclear, but it was first drawn to public attention by Gardner (1973), with further details given in a republished collection (Gardner, 1986). Commercial versions include the boardgames *Tacara* (pub. Eggert-Spiele, 2000) and *Bolide* (pub. Rio Grande Games, 2005). Fundamentally, it is a simulation game, modeling cars racing around a circuit, using simple Newtonian kinematics. The game is played on a sheet of square-gridded graph paper, using the intersections of the lines. To prepare for play, a closed track should be drawn on the gridded paper: the track width can vary from a few to a dozen or more squares; and better games result on tracks with varying degrees of curvature. Mark a start/finish line, upon which each player marks their car's starting location. Turns consist of players moving their car as follows:

1. firstly, as an intermediate step, duplicate the player's move of the previous turn (for the first turn, treat this as a null move);
2. then, if desired, alter the final destination for this turn by one grid point in any direction;
3. draw a line connecting the previous and new destination points.

See Figure 1 for an example of how turns are constructed. In effect, from turn to turn, a car can either maintain its velocity, or change it by one unit in any direction. The aim of the game is to complete the circuit in the least number of moves, without the car's path leaving the track, or being in the same place as another car at the same time. The game is well-suited to attempted solution by algorithmic means, and presents a programming challenge to students of computer science (see, for example, Holzer & McKenzie, (2010)). Figure 2 shows an example of a completed game.



- ← Car starts here, with a velocity of “two squares down”
- ← First move to here, with no change in velocity.
- ← Default for the next move is to position X (at end of dashed line), but there are options, as marked with small circles.
- ← The driver chooses to move here (front-right option).
- ← Again, the dashed line terminating at X shows the default next move (duplicating the previous move). The driver chooses the back-left option.
- ← The new default path is once again “two squares down”, as that duplicates the previous move; options for the next move are shown with larger circles.

Figure 1: An example of how turns are constructed in *Racetrack*. Image sourced from http://www.boardgamegeek.com/file/download/4qzlxve9vs/Drifter_Race.pdf

There are some obvious ways that *Racetrack* can be used to illustrate vectors: for example, ideas such as $\mathbf{v}_2 = \mathbf{v}_1 + \Delta\mathbf{v}$ are clear, but the often confusing equivalence $\Delta\mathbf{v} = \mathbf{v}_2 - \mathbf{v}_1$ is also simple to demonstrate graphically. This can be tied to the concept and mathematics of acceleration, if each turn is given a fixed time duration. It is equally obvious that the movement system is based on Newton’s First Law (N1); but rather than stating this and showing how the game implements it (a deductive approach), the game can be introduced *before* Newton’s Laws are discussed, and thus used as an inductive learning tool.

This can work well in a large first-year physics class, and has been conducted with $n \approx 200$ students in a tiered theatre at UNSW@ADFA. If students are provided with a pre-printed track, and instructed in the rules of the game, it is usually not difficult to persuade them to participate in groups of two or three. After a few minutes of play, regain the attention of the class (often the most difficult part of the exercise...) and explain that the lead driver has encountered an oil slick (or ice) on the road, extending from the current location of the lead car to a line some distance ahead. Then, by asking the students to discuss how the rules should be modified to deal with this situation, ideas such as N1 can be introduced by the students, rather than by the teacher. With guidance, the discussion can be extended to other concepts, including acceleration as the rate of change of velocity, the role of friction between tyres and road during acceleration (both in magnitude and direction). The game can be reintroduced in later classes when, for example, one wishes to discuss forces, acceleration and centripetal motion (addressing questions such as, “what is happening as a car goes around a corner?”). If students discover clues for themselves via the game, they are far more likely to recall and accept them, as part of their internal world-view, than if they are simply told how things “are”.

Variations of this game, featuring spacecraft navigating through the solar system (albeit in two dimensions), have been described by Vinson (1998) and Lowry (2008). The former is a direct translation of *Racetrack* to a spacecraft theme; the latter is notable for including a mathematical implementation of inverse-square gravitation, allowing for direct comparison of the effect of gravity on objects due to different mass stellar objects. Intermediate in complexity, and with some advantages for classroom use, is the 2D-astrogation aspect of the game *Triplanetary* (Miller & Harshman, 1973).

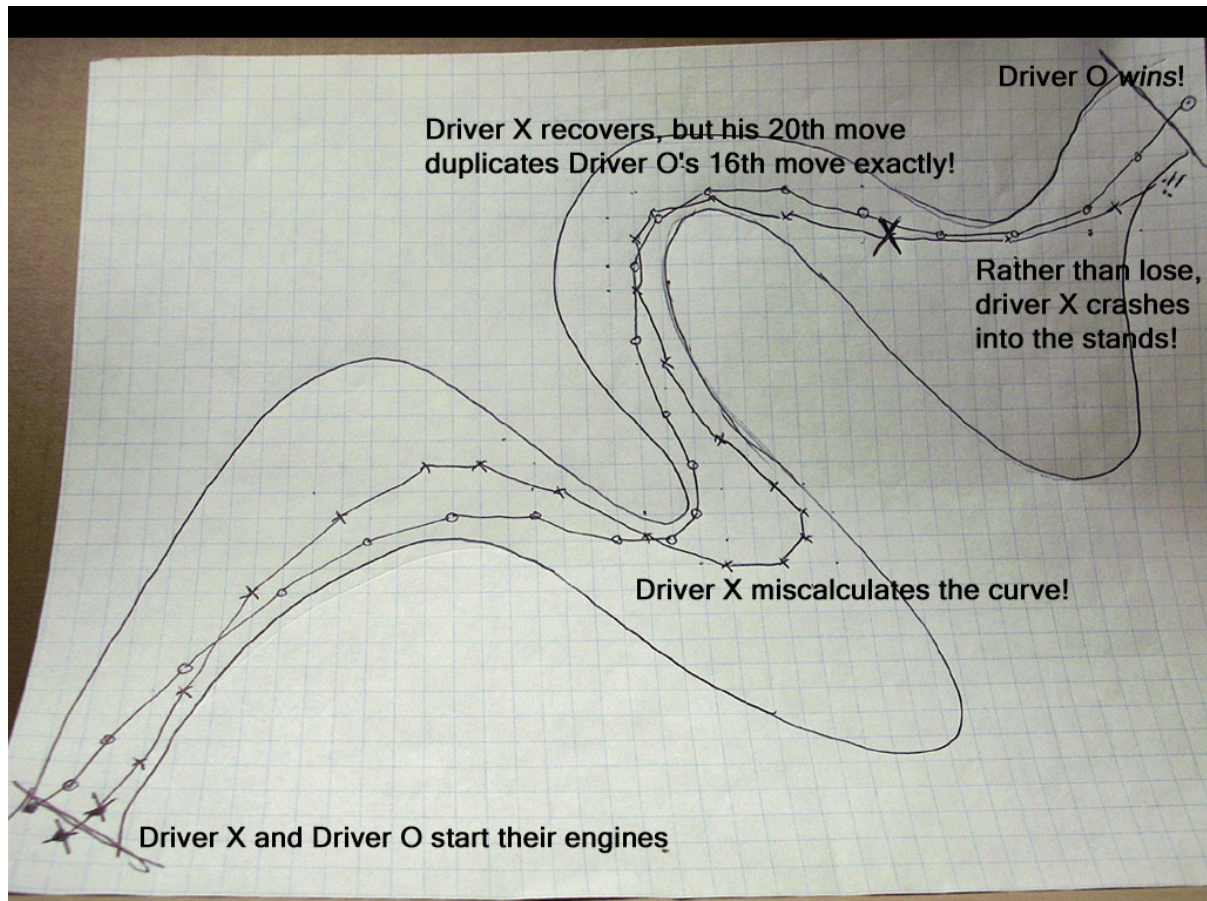


Figure 2: An example of a completed game of *Racetrack*, including commentary. Image source <http://www.boardgamegeek.com/image/114849/racetrack>.

Rather than playing on the intersections of a square grid, *Triplanetary* uses the spaces on a hexagonal grid. Hexagons are the regular polygon which, when tessellated, allows the greatest degree of directional flexibility, permitting equiscaled motion in six directions, and avoiding the $\sqrt{2}$ scaling issue which is tacitly ignored during diagonal movement in *Racetrack*. As well as providing a “friction free” environment, and thus perhaps a cleaner picture of how velocity is changed by expending fuel, *Triplanetary* provides an excellent forum for the discussion of relative velocity (“From your point of view, what does it look like that other spaceship is doing?”).

A multi-part exercise can also serve as an introduction to gravitation, by asking students to navigate (“astrogate”?) around a stylised solar system. The first time the exercise is offered, it can be with the (unrealistic) situation of unlimited fuel for velocity changes, and ask students to minimise their fuel usage. This can be followed by discussion of how the simple movement model could be changed to account for the gravity of large bodies such as planets: in effect, asking students to come up with a rule for gravity! One interesting way to introduce this idea is by considering the Earth-Moon system and asking what forces/accelerations must be acting to keep the Moon in orbit. This process, of attempting to determine (how to modify) the “rules of the game” are yet another example of the inductive learning process in action. Once the students have a (reasonable!) gravity model/rule in place, the astrogation exercise can be re-run (usually as a take-home activity), with the students attempting to minimize their fuel usage by taking advantage of gravity-assisted “slingshot” maneuvers. Followup discussion can mention the variety of methods used to guide space probes in real-life exploration of the solar system. Figure 3 shows how *Triplanetary* deals with gravitation in 2D: it is interesting to note that under this rule-set, planetary orbits can be entered naturally, with no need for additional rules!

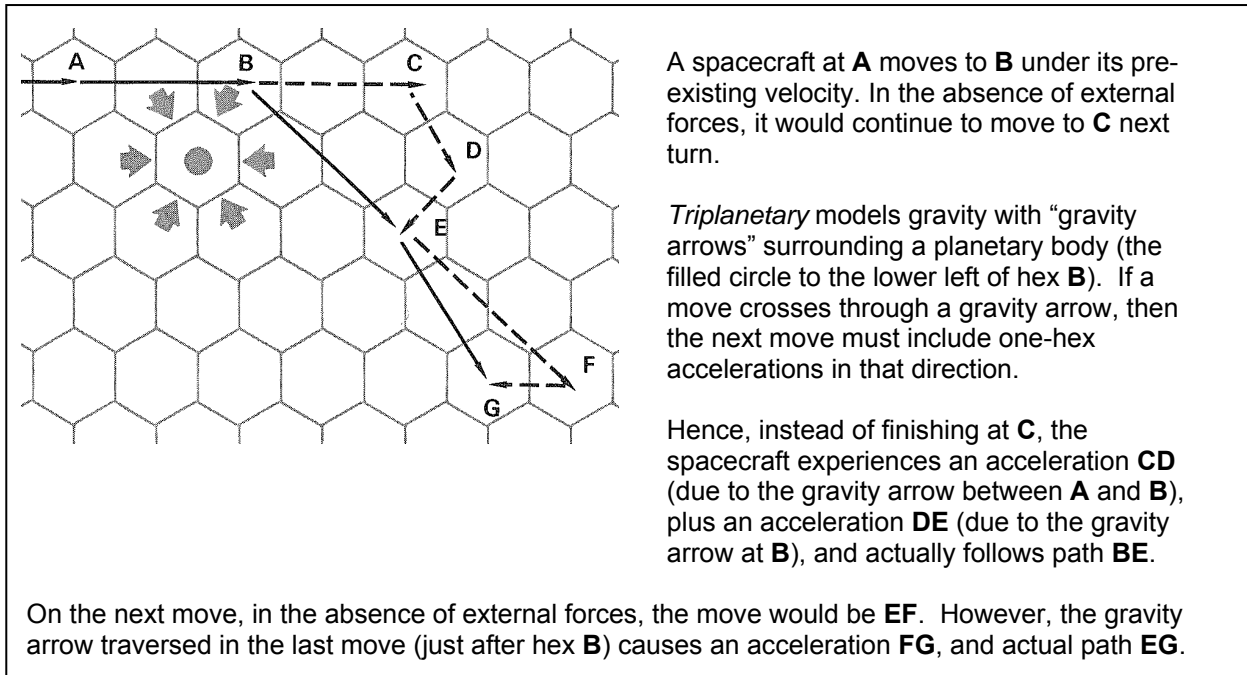


Figure 3: The implementation of gravitation in *Triplanetary*, sourced from the *Triplanetary* rulebook, <http://www.boardgamegeek.com/file/download/ymglb856x/Triplanetary.pdf>

While three-dimensional Newtonian vector movement games exist (e.g. Ad Astra Games publishes *Attack Vector Tactical* (2004), a full 3D space game, and *Birds of Prey* (2008), simulating jet-fighter air-to-air combat), they are arguably too complicated (in that they become too realistic!) to include in a classroom setting. Indeed, a reasonable guideline to the use of games in the classroom is that the game engine should not be more complicated than the process it is trying to model, to avoid the possibility that the details of the implementation overwhelm the message. The purpose of using games as an inductive learning tool is primarily to motivate and engage the students, and highlight the processes involved by allowing the students to discover them for themselves. Moving along the path from “game” to “simulation” is similar to moving from an inductive to a deductive process.

DISCUSSION

Objective evaluation of the efficacy of these methods is difficult, as there is no control sample against which to compare. In addition, for any particular course, these approaches were used as a small part of a larger course, rather than as the dominant technique. However, students were regularly asked to comment on the variety of teaching methods used in these courses. Responses of a positive nature strongly featured keywords such as “interactive”, “active” and “conceptual” when referring to the classroom activities and the development of their understanding. For example:

- “Interactive lessons and demonstrations that explained and entertained”
- “Involved the class via quirky examples”
- “Very interactive teaching encouraged discussion”
- “Engaging: only lectures where I could stay awake – and focus”
- “Conceptual understanding as the basis of the course”

On the negative side, as early as halfway through their first semester of tertiary study, students in a large first-year class ($n \approx 200$) were well aware that the time spent with these activities took time away from other things, such as numerical worked examples, theoretical derivations, and depth of coverage. A selection of comments relating to the “ways in which the teaching could be improved” from this class included:

- “Difficult to relate teaching to practical problem solving”
- “Would prefer a factual rather than conceptual approach”
- “Teach us! Too much work to do by self-study”

- “Focus on the specific content...to allow the class time to understand the concept before presenting thought-provoking material to further enhance learning”

While this dichotomy could be explained by students being accustomed to classwork being a mix of theory plus numerical problems, it is also clear that, in a large first-year class for example, there will be a wide mix of preferred learning styles (Low, 2009), as well as an understandable reticence for students to embrace being taken out of their comfort zone. It is clearly important for inductive teaching methods to be used carefully, for students to be briefed on why certain approaches are being used, and – perhaps most importantly to students – how they will tie in with assessment. These cautions are, naturally enough, common to any formal educational activity.

Nevertheless, if one accepts that active students are more likely to learn than passive students, and if the development of “active minds” is our goal, then the use of games as teaching tools in the tertiary environment certainly presents a pathway to that end. Tertiary education has not yet reached the stage where every activity requires a predetermined outcome, with a measurable result, and an associated evaluation metric: thankfully, in the author’s opinion, we still have the freedom to give students the opportunity to play.

REFERENCES

- Avendon, E. & Sutton-Smith, B. (Eds) (1971) *The study of games*. New York: John Wiley & Sons.
- Cruickshank, D. R. & Telfer, R. (1980) Classroom games and simulations. *Theory into Practice*, 19(1), 75-80.
- Ellington, H., Addinall, E. & Percival, F. (1981) *Games and simulations in science education*. London: Kogan Page Ltd.
- Ellington, H., Fowlie, J. & Gordon, M. (1998) *Using games and simulations in the classroom: a practical guide for teachers*. Routledge.
- Felder, R. M. & Silverman, L. K. (1988) Learning and teaching styles in engineering education. *J. Engr. Educ.*, 78(7), 674-681. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.92.774&rep=rep1&type=pdf>
- Francis, P. J. & Byrne, A. P. (1999) Use of role-playing exercises in teaching undergraduate astronomy and physics. *Publ. Astron. Soc. Aust.*, 16(2), 206-211. http://www.atnf.csiro.au/pasa/16_2/francis/paper.pdf
- Gardner, M. (1959) *Mathematical Games*. *Scientific American*, 200(6), 160-168.
- Gardner, M. (1973) *Mathematical Games*. *Scientific American*, 228(1), 108-115.
- Gardner, M. (1977) *Mathematical Games*. *Scientific American*, 237(4), 18-25.
- Gardner, M. (1986) *Knotted doughnuts and other mathematical entertainments*. New York: W. H. Freeman and Company.
- Heath, K. (1997) *Zendo*. College Park, MD: Looney Labs.
- Holzer, M. & McKenzie, P. (2010) The computational complexity of RACETRACK. *Proceedings of 5th International Conference, Fun with Algorithms (FUN 2010)*, 2nd-4th June 2010, Ischia, Italy.
- Low, D. (2009) Student perceptions of lecture approaches in first-year Engineering Physics. *Proceedings of the 2009 UniServe Science Conference*, 1st-2nd October, Sydney, Australia. http://sydney.edu.au/science/uniserve_science/images/content/2009_papers/low.pdf
- Lowry, M. (2008) Teaching universal gravitation with vector games. *The Physics Teacher*, 46(9), 519-521.
- McCoy, R. (1999) *Inductive reasoning: the game of patterns*. Project PHYSNET. East Lansing, MI: Michigan State University. http://physnet2.pa.msu.edu/home/modules/pdf_modules/m70.pdf
- Miller, M. W. & Harshman, J. (1973) *Triplanetary*. Normal, IL: Game Designers' Workshop.
- Prince, M. & Felder, R. (2006) Inductive teaching and learning methods: definitions, comparisons, and research bases. *J. Engr. Education*, 95(2), 123-138. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.62.8102&rep=rep1&type=pdf>
- Prince, M. & Felder, R. (2007) The many faces of inductive teaching and learning. *J. College Sci. Teaching*, 36(5), 14-20. [http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Inductive\(JCST\).pdf](http://www4.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Inductive(JCST).pdf)
- Sackson, S. (1969) *A gamut of games*. Random House.
- Selkirk, K. (1986) Simulation games: a mathematical activity. *Mathematics in Schools*, 15(1), 40-43. <http://www.jstor.org/stable/30216311>
- Vinson, M. (1998) Space Race: a game of physics adventure. *The Physics Teacher*, 36(1), 20-21.