Packing for Another Planet: Learning Scientific Methodology Through Alternative Reality Gaming

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Abstract: We use an alternative reality game (ARG) to teach a wide variety of STEM topics as a planetary exploration activity. The program is organized as a professional development workshop for middle and high school science educators and has included teachers from many fields: life sciences, physical sciences, and technology. Teachers are grouped into teams of scientists and charged with designing a scientific mission of discovery to another planet. The game culminates in a competition for funding. The ARG relies on the combined expertise of all participants and illustrates the highly interdisciplinary nature of science. The game combines fieldwork, laboratory experiments, and directed readings, as well as independent research. User reviews from before and after the use of the teaching ARG indicate that participants were more engaged and found it easier to apply large amounts of data and concepts when presented through a cohesive storyline with a defined goal.

Epistemic Training in the Scientific Method

Traditional secondary curricula generally separate the science and mathematic disciplines into discrete courses with little to no connection between them. The major topics – biology, chemistry, physics, and Earth sciences – are taught in isolation from on another. Mathematics are generally a complete aside from science or, at best, incorporated as a mechanism for manipulating numerical data in laboratory assignments (Frykholm & Glasson, 2005). When offered, laboratory experiments are rarely truly experimental but rather designed to be illustrative (AAAS, 2009). With time and funding always limited it is difficult to include long-term, hypothesis-driven experiments into the standard curricula.

The typical arrangement of topics gives students a completely inaccurate idea of scientific training and practice. In actuality, scientists must be able to evaluate data and practices from outside their specialty and are required to understand many technological applications in order to collect or utilize data. Scientists generally work closely with engineers and are required to accurately communicate needs and understand the limitations of any technology employed. The increased reliance on computational methods requires scientists to have a good working knowledge of computer science and mathematics and to likewise be able to work in conjunction with specialists in these fields. Outside of secondary classrooms the basic scientific disciplines are highly dependent on one another and the boundaries between STEM fields are not practical. The interdisciplinary nature of astrobiology emphasizes learning from all disciplines and offers many areas of interest to students. Natural connections are made between fields as disparate as biology and astronomy when a student must contemplate, for example, the metabolisms that would be supported by a particular star system.

The educational requirements and certification process for secondary science teachers places great emphasis on mastering content and pedagogical practice. Few post-graduate science teaching programs require an independent experimental project. Instead, teachers are schooled in the mechanics and philosophy of the scientific method without ever being able to fully employ the scientific method or design an experiment (Hammrich, 2001; Schwartz *et al.,* 2004). In this way scientific data and the scientific method are treated as declarative knowledge, without practice (Dreyfuss & Dreyfuss, 1986). This ARG emphasizes learning within the appropriate epistemic frame (Shaffer, 2006). The game creates procedural knowledge by immersing participants in the business of hypothesis building and experimental design in a self-directed approach.

This ARG emphasizes project-based learning. Hypothesis building and experimental design are essential to the activities and final project. Student groups are supplied with a body of data from an exoplanet and then directed through fieldwork and experiments that can help them interpret the data. Participants are given instruction in effective literature search to guide their thinking. The end goal of the ARG is for the student groups to design a mission to the exoplanet, complete with hypothesis-driven scientific goals. The student groups are encouraged to explore questions of their choosing and the mission can be specific to the strengths and interests of their group. The final project is a presentation of the proposed mission and a request for funding for this work from a panel of reviewers. Student groups use information gained from lectures, experiments, and literature research to guide their decisions. Final missions must include not only a hypothesis but define the impetus for the hypothesis, it's importance to NASA science goals, and expected outcomes.

Astrobiology: the Interdisciplinary Search for Life in the Cosmos

While unfamiliar to many, astrobiology is the field of science concerned with the origin, evolution, and distribution of life in the Universe. Workers in this field include biologists, ecologists, chemists, planetary scientists, geologists, astronomers, and physicists. Astrobiology is a highly technological field and data collection and interpretation requires the expertise of mathematicians, computer scientists, and engineers as well. Astrobiology provides an ideal context for presenting principles and data from all basic sciences and STEM fields and illustrates the connections between the sciences. Most importantly for teaching science to a younger audience, astrobiology provides a creative, exciting scientific application. Recent high profile missions like the Mars Science Laboratory aboard Curiosity, the Cassini Orbiter, and the Mercury Messenger are making the discoveries in this field more widely known to a general audience and have captured the imagination of the public.

Learning goals for the astrobiology workshop are taken from the NASA Astrobiology Roadmap and emphasize NAI science objectives. Some of the topics covered in the workshop include:

- The Drake Equation and the Scale of the Universe
- Understanding Evolution and Geologic Time
- Defining Life: The Chemical Nature of Biology
- Planetary Formation and Atmospheres
- Interstellar Real Estate: Defining the Habitable Zone
- How to Find a Habitable Planet
- Life Detection – will we know it when we find it?

An astrobiology workshop has been offered as part of the Pennsylvania Space Grant Consortium Summer Professional Development Series for five years however, only in the last two years has the curriculum been taught as an ARG. Workshops can last from 5 to 10 days and are taken for credit, fulfilling the continuing education requirements for licensed teachers in Pennsylvania, Maryland, and New Jersey. Content for the workshop is aligned with standards so that teachers can use specific activities from the workshop to meet mandated curriculum goals and address specific test topics. The workshops are held at the Pennsylvania State University and facilitated by faculty and researchers from the Pennsylvania State Astrobiology Research Center, an associate facility of the NASA Astrobiology Institute.

Team Selection, Planet Assignment and Initial Datasets: Setting Up the Game

The ARG is played by teams of teachers. Teams are selected by the workshop facilitators in order to increase the diversity of scientific discourse. The workshop is open to teachers in all STEM fields and it is our goal to create teams with one representative from each of the basic sciences as well as some scientific generalists. Each team has five people with at least one biology teacher and at least one physical science (chemistry or physics) teacher.

Prior to their arrival the teachers are asked to read *How to Find a Habitable Planet* by James Kasting (2010). This text includes a thorough outline of the scientific background behind astrobiology and planetary habitability and is directed towards a general audience. On the first day of the workshop participants have a book club style Q&A with the author. This requirement ensures that all teachers, regardless of their scientific specialty, have the same requisite basic knowledge and ensures meaningful conversation with facilitating scientists.

Each group is given a body of data from an imaginary exoplanet. This dataset includes the mass, radius, density, surface temperature, distance from star or parent planet as well as orbital parameters of the planet. The data set also describes the method used to detect the planet. Additionally, each group receives a set of three spectra for their planet that we imagine has been retrieved through space telescopy. Each planet has a surface as well as atmospheric spectra and a third piece of information unique to their world. A wide variety of spectroscopic techniques are included in the initial data packets - absorption and reflectance - and include many types of electromagnetic radiation, as well as different quantitative systems. This type of information will likely be unfamiliar with the team but interpretation of the spectra are also given with the initial data. Emphasizing the highly collaborative nature of scientific research, participants are encouraged to discuss their datasets with the facilitators as well as one another.

What the participants do not know is that the data are collected from four very real target planets of astrobiological interest: Mars, Io, Europa, and the Archean Earth. Using real planets allows the facilitators to supplement the data given to the groups throughout the term of the workshop depending on the interests of the group. For example, if a group becomes interested in atmospheric characteristics “new data” can be “downloaded” from the imaginary orbiter to help the group better define their mission. Conversely, groups will often want data that simply does not exist yet for a planet. This, in and of itself, is an important lesson about the realities of scientific research. By realizing the paucity of some kinds of data the teams begin to develop targets for their mission plans.

The final piece of data that teams are given at the onset is an actual geologic “sample” from the surface of their exoplanet. Each group receives a substrate that we can imagine came from some sort of “sample return mission”. Teams will use the surface samples from the exoplanets in actual experiments to help them understand the nature of their planet. The “samples” are different varieties of ground sand that are spiked with various minerals, salts, and organics. In fact, one “sample” (the sample from Archean Earth) even contains DNA. These mixtures are designed to be representative of the spectroscopic data and give each planet unique chemical characteristics that support different hypotheses for life on that planet.

Playing the Game: Lab, Field, and Library

The epistemic format of the ARG is meant to mimic the working habits of a research scientist. Essentially, this is a game about collecting and analyzing data and building new research directions based on those data. To that end, instruction is given primarily through data collection as part of laboratory experiments, fieldwork and independent research of primary literature. These activities each offer teams new data that will inform the direction of their mission proposal.

Learning by Doing

Groups conduct a variety of experiments with the “sample return mission” substrates that direct their mission planning. We use a re-enactment of the Viking Lander gas exchange experiments to prepare groups for experimentation and to give training in hypothesis building. We review the procedures used and discuss the assumptions behind the protocol used in the Viking mission. The facilitator demonstrates possible false positives as well as false negatives and participants design experiments that can test these scenarios.

Having learned how to examine an analytical protocol and the basics of experimental design participants are led through a series of experiments to help them learn more about their exoplanet of interest. Participants are encouraged to develop follow up experiments for every activity and facilitators work with groups to make these possible. One experiment requires groups to attempt to extract DNA from these substrates. Of course only one sample contains DNA but there are often false positive results due to contamination. Lecture and reading material emphasize the longevity of the DNA molecule and groups must consider other data from their exoplanet to decide if their positive result indicates extant or fossil life.

Another laboratory experiment teaches participants how electromagnetic spectroscopy is collected and how to interpret it. This is especially useful for understanding the exoplanet data sets they are given and also to help them understand the literature. The vast majority of data we have on other planets comes from remote sensing of the surfaces of these bodies. In order to illustrate spectroscopy we have participants build their own spectrometers from cardboard boxes and diffraction grating. We then perform flame tests on their “sample return mission” substrates in order to identify major elements from the surface of their planet. We use this test to confirm or complement surface spectra that were given in the initial data set. This activity covers a variety of core subjects including optics, wave physics, and chemistry and helps participants understand the different spectroscopic methods,

Learning in the Field

As part of the workshop we go out into the field and sample from sites that could be considered analogs of their exoplanets. Our sites include an acid mine drainage site, a highly organic runoff pond from a golf course, a very cold mountain spring, and an iron-rich slag pit. We collect environmental data at these sites and evaluate the habitability of these locations. We then collect samples so that we can observe the native organisms of these sites, many of which are distinctive extremophiles. Participants receive training in collecting sterile samples and culturing from environmental samples and are giving information on how to integrate a field component into their own curriculum. Participants are free to design experiments that can inform them about the range of their viability and requirements for life that may inform their mission planning for their exoplanet of interest.

Going to the Literature

Interpretation and analysis of this data is conducted primarily as an independent research activity. Facilitators try to offer interpretive information as little as possible and instead coax the participants towards resources that will help them learn the contextual meaning of the collected data. The ARG relies heavily on independent research. Participants are given instruction in library search techniques and offered assistance in finding reliable primary sources that are available to the public. While selected readings are required prior to lectures and lectures are offered daily, each class is designed to accompany a specific post-lecture experiment or activity.

How to Win at Science: Mission Proposals and Panel Review

The final project of the astrobiology ARG is a presentation of the proposed exoplanet mission to the class at large and a panel of peer reviewers made up of the workshop guest lecturers and invited faculty. Participating groups can choose a level of funding for their mission - Flagship, New Frontiers, or Discovery – with Flagship being most expensive and Discovery being the least expensive. According to the rules of the ARG panelists have only enough “money” to “fund” one Flagship mission or up to three less expensive missions. Projects are evaluated on three criteria: the validity of the scientific question, the utility of proposed methods, and the cost-effectiveness of their approach

In preparation for the final project participants are given information on the science goals of the NASA Astrobiology nstitute and the funding classes of NASA Solar System Programs. While this may seem like bureaucratic minutiae we include this in the final stage of the ARG to create an incentive for participants to learn about existing technologies in planetary exploration. Existing technology can be used at minimal costs for the proposed missions in the ARG. Groups do extensive research on the instruments already developed and become very familiar with the capabilities of currently deployed orbiters, rovers, and rocketry in a way that is informative and engaging. Using existing technology allows groups to expand their own data collection goals for their missions while requesting only funds only for new, novel tools specific to their world.

While stressful, we endeavor to make the panel reviews a very fun activity as well. To keep things interesting we include a winning category that is “people’s choice” that just considers the “cool” factor for a given mission. Panel reviews lead to very enjoyable, frank discussions about the practicalities of planetary exploration and are a vital part of the learning activity. Groups often become very invested in the peculiarities of their exoplanets and their mission proposals. By the time of the final project they are experts on their worlds. After panel review the facilitators reveal the true identity of their exoplanets and emphasize that the participants are now experts on four distinct planets of great astrobiological interest.

Outcomes and Intent

While we have embedded enormous amounts of scientific knowledge in the ARG our major goals are quite simple. We hope participants gain an appreciation for the goals of the NASA space program and realize the enriching potential of this research. We want participants to realize that project-based learning like an ARG can be a fun, creative way of teaching large amounts of material from multiple scientific disciplines if you can make the goal engaging and the experiments exciting. Most importantly, we want participants to leave with an appreciation for scientific methodology, to feel as if they have collaborated in a scientific effort, and to feel confident in their ability to design an experimental program.

In order to assess the success of a workshop all participants are asked to complete a detailed questionnaire about the content and their experience and to write a brief review. Prior to teaching through the ARG workshop reviews complained that we included too many lectures which were obtuse or impractical, with little consideration for the goals of secondary science instruction. Through the ARG we have given the lectures new meaning, as a data collection opportunity that informs the greater goal and teaches scientific methodology. 71% of ARG participants said that they found the collaborative approach to be more informative within the context of the class whereas only 40% of the participants found the material to be useful in the more traditional lecture-based curriculum.

In previous years participants had complained that the hands-on activities were merely descriptive and relied too heavily on expensive equipment or supplies that would never be accessible to secondary schools. By making experimentation and data collection part of the ARG our activities were given new utility within the game. We were also very sensitive to include only supplies and apparatus that are inexpensive and easily available and even included part numbers and ordering information from Carolina Biological and Ward’s Scientific to participants. 82%

of the participants in the ARG enjoyed the interactive, embedded design of the experiments within the context of the final project. In previous years only 45% of the participants had found the hands-on activities to be useful. ARG participants expressed a newfound appreciation for the how data is collected and how scientific knowledge is built incrementally through reflection upon previous work. By teaching the workshop as an ARG we hoped to give teachers the tools to use this same style of teaching in their own classrooms.

Our final activity is a roundtable discussion and “debriefing” where teachers are encouraged to speak openly about what portions of the workshop they found the most useful how they might implement the material introduced in the workshop. While most teachers found the format very enjoyable many expressed reservation about using the same style of instruction in their own classroom. Most participants recognized that teaching in an ARG format requires a great deal of participation on the part of the teacher as DM/GM to keep the project moving in a positive direction. Teachers recognize that this format requires a great deal of general preparation compared to the usual lecture-based system. We have tried to emphasize to the participants that using real - rather than imaginary - data sets will make the task of directing the ARG much easier and only requires good literature search skills. In addition to the roundtable discussion a small, randomly selected focus group is lead through a review by a third-party evaluator. These focus group discussions also indicated that participants were reluctant to use an ARG or really any project-based learning because it is difficult to evaluate and assign grades for this type of open-ended work. Participants were unsure if they could evaluate projects as precisely and as easily as they could exams.

While we were not able to support a longitudinal study of outcomes we have found, through casual communication, that despite the reservations expressed a minimum of 10% of participating teachers have used the ARG method for at least a portion of their curriculum. If the opportunity to continue the workshop with a follow-up study were to arise it would be useful to form two participants into two groups – one provided information on the pedagogical foundation of gameful learning and the second, like the groups discussed in this paper, unaware that they are actually participating in a role-playing game and learning through a gaming framework. As presented, we never explicitly called the workshop format an ARG but rather, referred to the format as extended inquiry-based learning. It would be interesting to see if teachers are more or less likely to use the ARG technique if they are aware that this is a game process that has been used in other curricula.

Our Success as an Epistemic Learning Environment

Shaffer (2006) identifies three key components of an epistemic learning and gaming system that teaches not just content but equips new ways of thinking;

- An epistemic game uses knowledge and/or skills from the field or environment in question
- An epistemic game teaches the player the values of the community
- An epistemic game establishes the identity of the player as a member of the community

Clearly the astrobiology ARG offers students enormous amounts of background. By formatting this large amount of information as objectives in game play knowledge acquisition becomes less onerous and takes on significance as part of a strategy. Even the very vital library and literature search skills that scientists rely on can be more interesting when the goal is a self-directed objective rather than an arbitrary assignment or report.

This ARG explicitly communicates the specific goals and contributions of the NASA Astrobiology Institute in a way that engages students in the mission of the space program by asking them to be fellow contributors. In sharing our vision of scientific research we hope we have inducted the participating teachers in the scientific values of the astrobiology community. More generally, by sharing the complexities of scientific methodology we invite them to participate as more informed consumers of science and hope they become engaged in the values of scientific research as a whole.

One of the most important goals of the workshop was to be sure that teachers understand that they are valuable members of the scientific community given that they are actively preparing future researchers. We emphasize the funding structure of NASA missions so that teachers understand that greater than 90% of the budget of any major mission goes towards scientists and engineers. Human capital is the greatest strength in science and our success relies on inspired, well-prepared students that are ready to meet future research challenges.

Our epistemic gaming ARG approach offers sound science training and emphasizes collaboration and recognition of interdisciplinary work. Our design is able to engage students in learning large amounts of data that would otherwise be rather boring rote memorization and also makes mundane tasks such as literature search into a goal-oriented activity. By requiring students to employ the scientific method not as an arcane five-step process but as an organized way of asking questions and producing data the ARG is able to demonstrate scientific methodology in an exciting context of self-determination and discovery.

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